MASSACHUSETTS
Department of Elementary
and Secondary Education

Release of Spring 2024 MCAS Test Items

from the

High School Introductory Physics Paper-Based Test

July 2024
Massachusetts Department of Elementary and Secondary Education

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and Secondary Education

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Overview of High School Introductory Physics Test

The spring 2024 high school Introductory Physics test was administered in two formats: a computer-based version and a paper-based version. Most students took the computer-based test. The paper-based test was offered as an accommodation for eligible students who were unable to use a computer. More information can be found on the MCAS Test Administration Resources page at www.doe.mass.edu/mcas/admin.html.

Most of the operational items on the high school Introductory Physics test were the same, regardless of whether a student took the computer-based version or the paper-based version. In places where a technology-enhanced item was used on the computer-based test, an adapted version of the item was created for use on the paper test. These adapted paper items were multiple-choice or multiple-select items that tested the same Science content and assessed the same standard as the technology-enhanced item.

This document displays released items from the paper-based test. Released items from the computer-based test are available on the MCAS Resource Center website at mcas.pearsonsupport.com/released-items.

Test Sessions and Content Overview

The high school Introductory Physics test was made up of two separate test sessions. Each session included selected-response questions and constructed-response questions. On the paper-based test, the selected-response questions were multiple-choice items and multiple-select items, in which students select the correct answer(s) from among several answer options.

Standards and Reporting Categories

The high school Introductory Physics test was based on learning standards in the 2016 *Massachusetts Science and Technology/ Engineering Curriculum Framework*. The Framework is available on the Department website at www.doe.mass.edu/frameworks/current.html.

The introductory physics standards are grouped under the three content reporting categories listed below. Note that standard HS.PHY.1.8 is included in the Energy reporting category.

- Motion, Forces, and Interactions
- Energy
- Waves

Most items on the high school Introductory Physics test are also reported as aligning to one of three MCAS Science Practice Categories. The three practice categories are listed below.

- Practice Category A: Investigations and Questioning
- Practice Category B: Mathematics and Data
- Practice Category C: Evidence, Reasoning, and Modeling

More information about the practice categories is available on the Department website at www.doe.mass.edu/mcas/tdd/practice-categories.html.

The table at the conclusion of this document provides the following information about each released operational item: reporting category, standard covered, science practice category covered (if any), item type, and item description. The correct answers for released selected-response questions are also displayed in the table.

Reference Materials

Each student taking the paper-based version of the high school Introductory Physics test was provided with an Introductory Physics Reference Sheet. A copy of the reference sheet follows the final question in this document. Each student also had sole access to a calculator.

During both high school Introductory Physics test sessions, the use of authorized bilingual word-to-word dictionaries and glossaries was allowed for students who are currently or were ever reported as English learners.

High School Introductory Physics

SESSION 1

This session contains 21 questions.

You may use your reference sheet in this session.

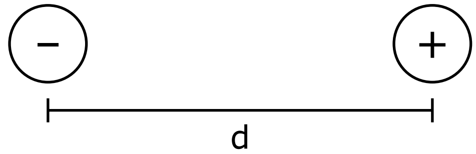
Directions

Read each question carefully and then answer it as well as you can. You must record all answers in this Test & Answer Booklet.

For some questions, you will mark your answers by filling in the circles in your Test & Answer Booklet. Make sure you darken the circles completely. Do not make any marks outside of the circles. If you need to change an answer, be sure to erase your first answer completely.

If a question asks you to show or explain your work, you must do so to receive full credit. Write your response in the space provided. Only responses written within the provided space will be scored.

1 The diagram shows two charged particles separated by a distance, d.



Which of the following describes how the forces between the two charged particles change as the distance between the particles changes?

Ⓐ As the particles move farther apart, the attractive forces increase.

Ⓑ As the particles move farther apart, the repulsive forces decrease.

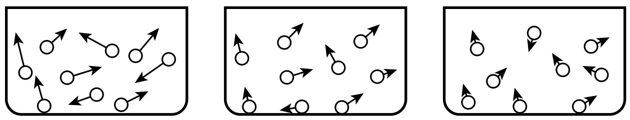
Ⓒ As the particles move closer together, the attractive forces increase.

Ⓓ As the particles move closer together, the repulsive forces decrease.

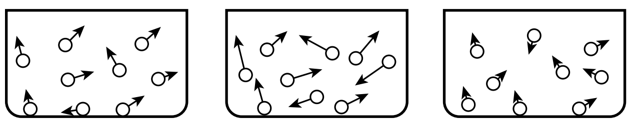
2 A student heated water in a container.

Which of the following models best shows how the molecular motion of the water changed as it was heated?

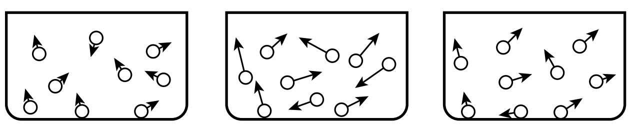
Ⓐ Less heat added → More heat added



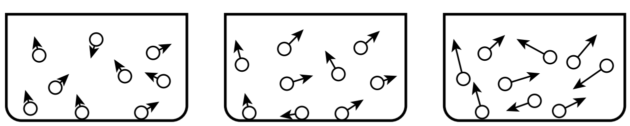
Ⓑ Less heat added → More heat added



Ⓒ Less heat added → More heat added



Ⓓ Less heat added → More heat added



3 A sound has a frequency of 110 Hz both in air and in water. The velocity of sound is 340 m/s in air and 1500 m/s in water.

How does the wavelength of the sound in water compare to its wavelength in air?

Ⓐ The wavelength in water is about 0.07 times shorter.

Ⓑ The wavelength in water is about 0.32 times shorter.

Ⓒ The wavelength in water is about 3.09 times longer.

Ⓓ The wavelength in water is about 4.40 times longer.

4 A 6.0 V battery, a 2.0 Ω resistor, and a 4.0 Ω light bulb are connected in series. How much current will flow through the circuit?

Ⓐ 1.0 A

Ⓑ 1.5 A

Ⓒ 3.0 A

Ⓓ 4.5 A

5 Which of the following has the greatest momentum?

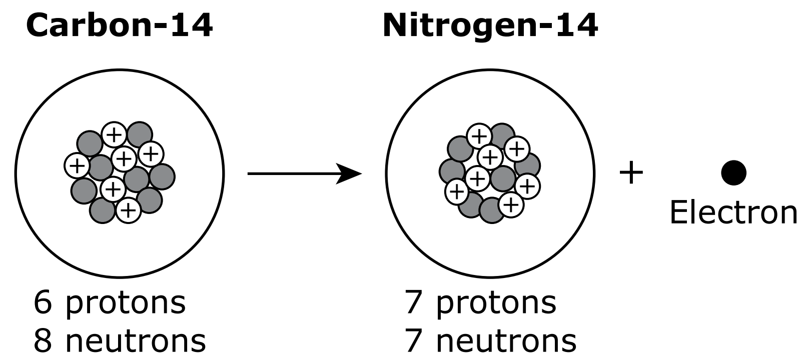
Ⓐ a 1600 kg car at rest

Ⓑ a 0.05 kg ball moving at 50 m/s

Ⓒ a 50 kg athlete running at 8 m/s

Ⓓ a 100 kg crate being lifted at 1 m/s

6 Carbon-14 is produced in Earth's atmosphere. The nucleus of carbon-14 is not stable and changes to nitrogen-14 to become more stable, as shown.



Carbon-14 changes to nitrogen-14 through

Ⓐ alpha decay.

Ⓑ beta decay.

Ⓒ gamma decay.

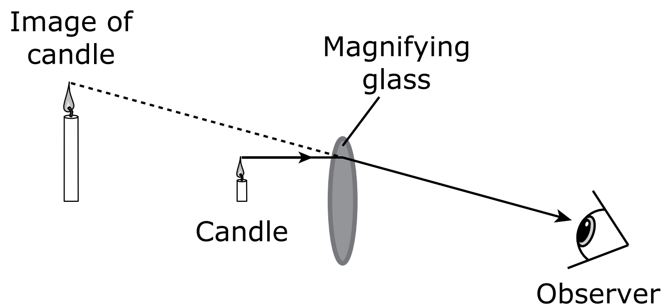
Which of the following describes this type of decay?

Ⓐ A neutron changes into a proton and an electron.

Ⓑ A proton changes into a neutron and an electron.

This question has two parts.

7 A magnifying glass was used to create an enlarged image of a candle. The diagram shows the candle and the image of the candle that an observer saw. The solid lines represent the actual path of light.



Part A

Which of the following explains why the light traveled from the candle to the observer in the path shown?

Ⓐ The light refracted as it entered and exited the magnifying glass.

Ⓑ The light diffracted as it entered and exited the magnifying glass.

Ⓒ The light reflected off the surface of the magnifying glass instead of passing through the magnifying glass.

Ⓓ The light traveled as a particle through the magnifying glass instead of traveling as a wave through the magnifying glass.

Part B

The path of the light from the candle appeared to bend as it traveled to the observer.

As the light from the candle entered the magnifying glass, the light

Ⓐ sped up.

Ⓑ slowed down.

Because the frequency of the light did not change, the wavelength of the light

Ⓐ increased.

Ⓑ decreased.

8 Which of the following is an example of light behaving like a particle?

Ⓐ When violet light shines on a metal plate, electrons are ejected from the metal plate.

Ⓑ When light passes through slits and interferes, it forms a pattern of bright and dark regions on a wall.

Ⓒ When a light source is directed onto a soap bubble, reflections from the surface of the bubble produce colors.

Ⓓ When a laser beam shines on a round object, a circle with a bright spot in the center appears on a screen behind the object.

9 A 10 kg object accelerates at 5 m/s^2 over a distance of 4 m. What is the net force on the object?

Ⓐ 0 N

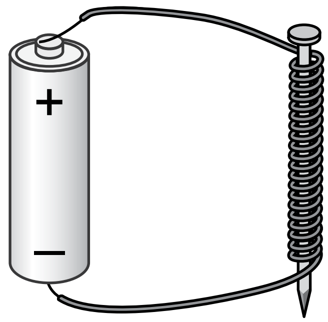
Ⓑ 20 N

Ⓒ 40 N

Ⓓ 50 N

This question has two parts.

10 In an investigation, students wrapped an insulated copper wire around an iron nail so that the nail had 20 loops around it. They connected the ends of the wire to a 1.5 V battery. The setup is shown.



A student held the nail with the wire above several metal paper clips. Some of the paper clips accelerated upward toward the nail.

Part A

The upward force that acted on the paper clips was from

Ⓐ an electric field.

Ⓑ a magnetic field.

Ⓒ a gravitational field.

The field was generated by the

Ⓐ heat generated in the wire.

Ⓑ stationary particles in the wire.

Ⓒ current flowing through the wire.

Part B

The students next investigated the number of paper clips that could be picked up when there were different numbers of loops of wire around the nail. The students made the table shown to record their data.

Number of Loops of Wire	Number of Paper Clips Picked Up
10	
20	
30	
40	

Which of the following questions were the students most likely trying to answer in their investigation?

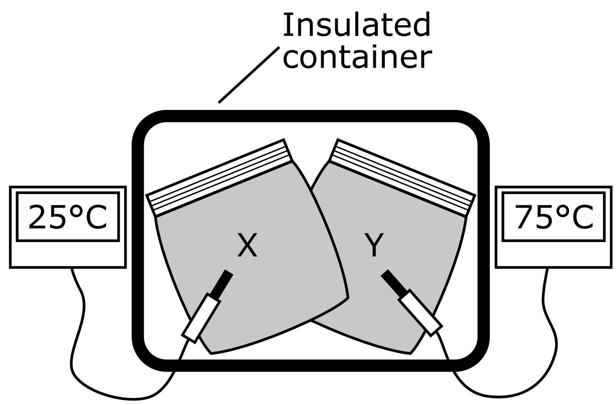
Ⓐ How does the number of paper clips picked up affect the electric field around the battery?

Ⓑ How does the number of paper clips picked up affect the gravitational field on the battery?

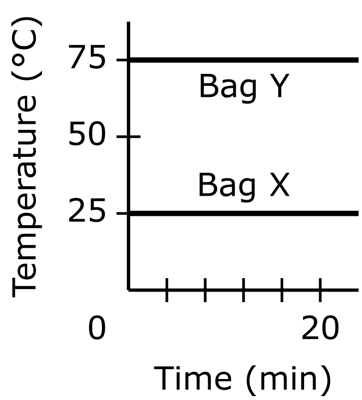
Ⓒ How does the number of loops of wire affect the strength of the magnetic field around the wire?

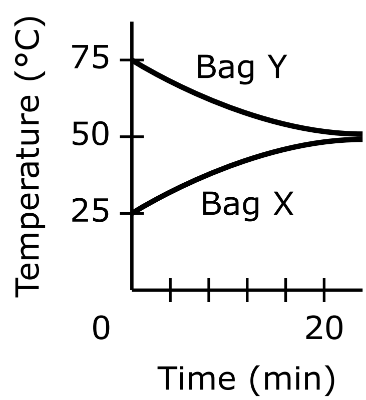
Ⓓ How does the number of loops of wire affect the electric field that moves through the paper clips?

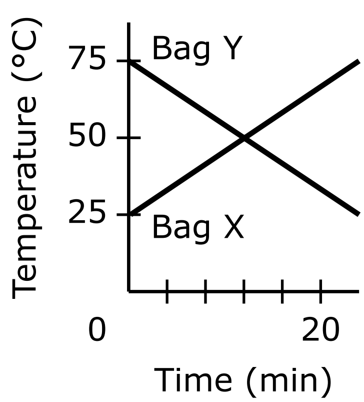
11 The diagram shows an experimental setup to measure heat transfer between two sealed bags of cooking oil. The bags are in an insulated container. Bag X contains 200 mL of cooking oil at 25°C. Bag Y contains 200 mL of cooking oil at 75°C. The temperature of the oil in each bag is recorded over 20 minutes.

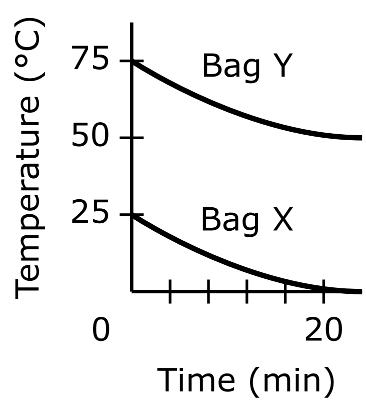


Which graph shows the temperature of the oil in each bag over the 20-minute period?

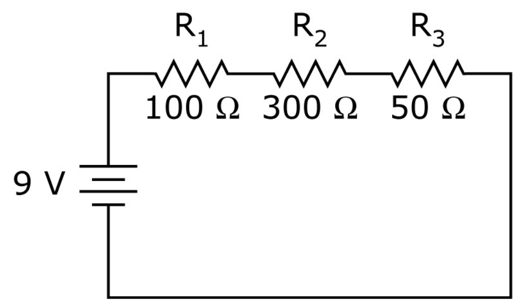
Ⓐ


Ⓑ


Ⓒ


Ⓓ


12 The diagram shows a circuit.



The current in the circuit is 0.02 A. Which table shows the correct values for the voltage drop across each resistor and the total voltage drop across the circuit?

Ⓐ

R_1	R_2	R_3	Total
1 V	3 V	0.5 V	4.5 V

Ⓑ

R_1	R_2	R_3	Total
2 V	6 V	1 V	9 V

Ⓒ

R_1	R_2	R_3	Total
3 V	3 V	3 V	9 V

Ⓓ

R_1	R_2	R_3	Total
4 V	12 V	2 V	18 V

13 In a vacuum, radio waves have a lower frequency than infrared radiation. Which of the following best compares radio waves and infrared radiation in a vacuum?

Ⓐ In a vacuum, radio waves and infrared radiation have the same speed. Therefore, radio waves have a longer wavelength than infrared radiation.

Ⓑ In a vacuum, radio waves and infrared radiation have the same speed. Therefore, radio waves have a shorter wavelength than infrared radiation.

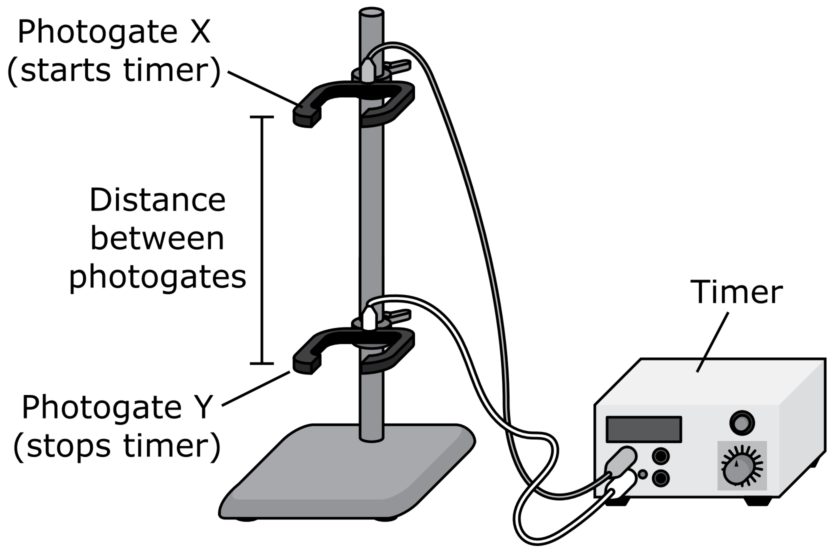
Ⓒ In a vacuum, radio waves and infrared radiation have the same wavelength. Therefore, radio waves have a faster speed than infrared radiation.

Ⓓ In a vacuum, radio waves and infrared radiation have the same wavelength. Therefore, radio waves have a slower speed than infrared radiation.

The following section focuses on the motion of falling objects.

Read the information below and use it to answer the three selected-response questions and one constructed-response question that follow.

Students in a physics class investigated the amount of time it took a metal marble to fall different distances. The students used two photogates, X and Y, to measure the times. Photogates are devices that start or stop a timer when an object passes through them. The setup for the investigation is shown.



The marble had a mass of 0.07 kg. In each trial, the marble was dropped from photogate X with an initial velocity of 0 m/s. The distance between the photogates was decreased after each trial. The table shows the distance the marble fell and the time the marble took to fall in each trial. Air resistance was negligible.

Data for 0.07 kg Marble

Trial	Distance between Photogates (m)	Time to Fall between Photogates (s)
1	0.8	0.40
2	0.6	0.34
3	0.4	0.29
4	0.2	0.20

14 Based on the data from trial 1, what was the average speed of the marble as it traveled the 0.8 m distance?

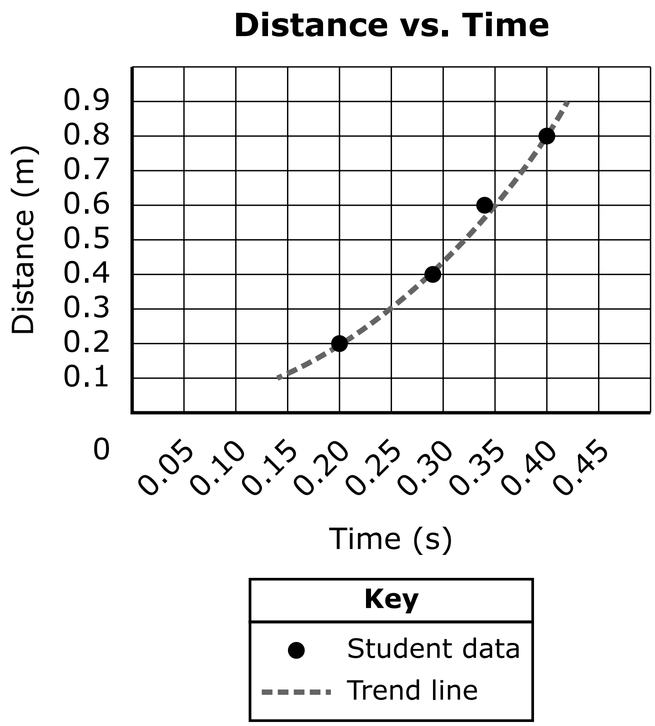
Ⓐ 0.3 m/s

Ⓑ 0.5 m/s

Ⓒ 2 m/s

Ⓓ 4 m/s

15 The students created the graph to show the distance the marble traveled between the photogates over time.



The graph indicates that the marble was

Ⓐ accelerating.

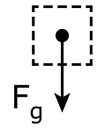
Ⓑ traveling at a constant velocity.

The graph also indicates that the magnitude of the net force acting on the marble was

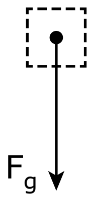
Ⓐ equal to zero.

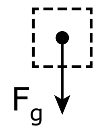
Ⓑ greater than zero.

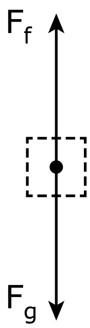
16 The students drew a free-body force diagram to represent the force acting on the marble after it had fallen 0.2 m in trial 1, as shown. Assume air resistance was negligible.

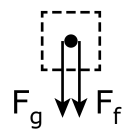


Which of the following free-body force diagrams represents the force or forces acting on the marble after it had fallen 0.4 m?

Ⓐ 

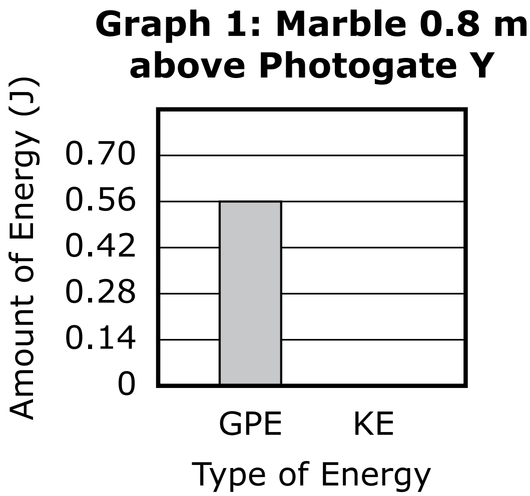
Ⓑ 

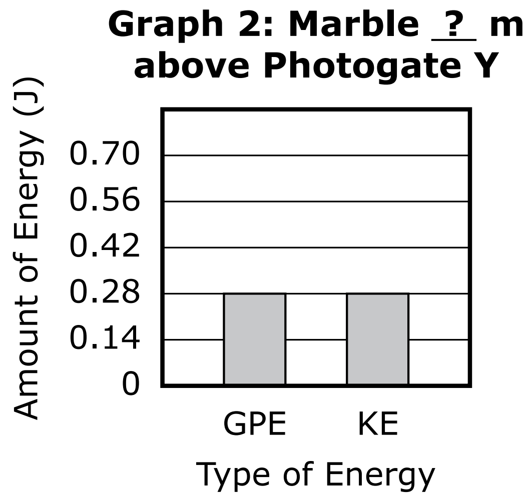
Ⓒ 

Ⓓ 

This question has three parts. Write your response on the next page. Be sure to label each part of your response.

17 The students made bar graphs to represent the marble's gravitational potential energy (GPE) and kinetic energy (KE) at different positions as it fell during trial 1, as shown. The students forgot to identify the position of the marble in the title of Graph 2.





A. Identify the position of the marble above photogate Y in Graph 2. Explain your reasoning.

B. Draw two bars on Graph 3 on the next page to show the amount of GPE **and** the amount of KE the marble had when it was 0.2 m above photogate Y in trial 1.

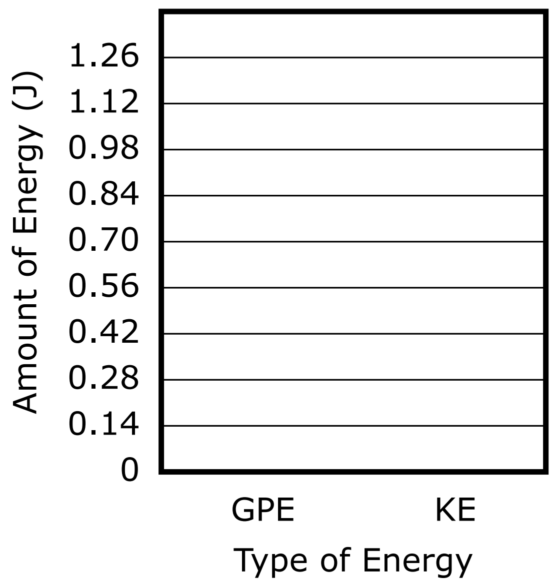
C. In Graph 2, the students ignored the effect of air resistance.

Describe how the marble's GPE **and** the marble's KE would have been affected if there had been a large amount of air resistance acting on the marble.

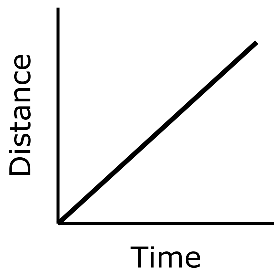
17

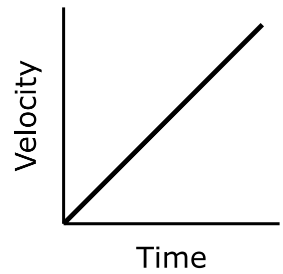
B.

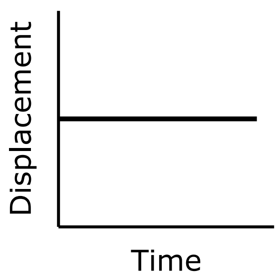
Graph 3: Marble 0.2 m above Photogate Y

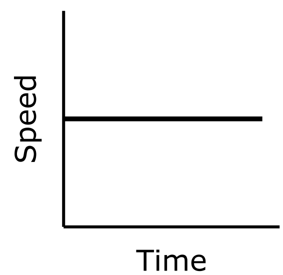


18 Which of the following graphs must represent constant, positive acceleration?

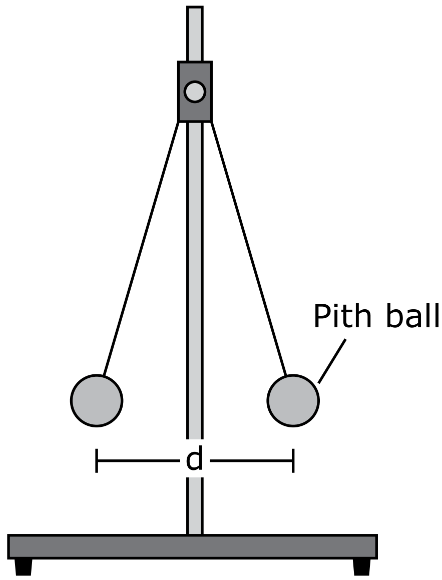
Ⓐ 

Ⓑ 

Ⓒ 

Ⓓ 

19 A student is investigating electrostatic forces using two pith balls. Pith balls have a very small mass and can be easily charged. The student charges each pith ball, which results in the balls being separated by a distance, d, as shown in the diagram.



The pith balls have

Ⓐ opposite charges.

Ⓑ the same charge.

If the student increases the magnitude of the charge on each pith ball, the distance between the pith balls will

Ⓐ increase.

Ⓑ decrease.

Ⓒ remain the same.

This question has four parts. Write your response on the next page. Be sure to label each part of your response.

20 Mechanical and electromagnetic waves are used in different forms of communication.

A. Identify the mechanical wave commonly used for communication between people near each other.

B. Identify one electromagnetic wave used for communication on Earth and describe how it is used.

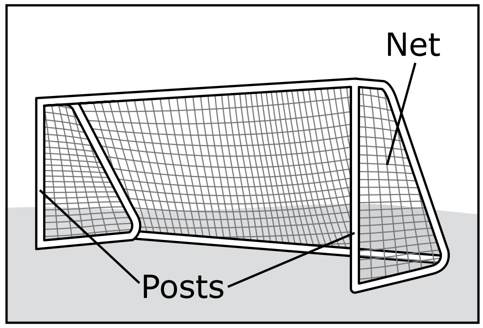
C. Identify which type of wave, mechanical or electromagnetic, should be used to send a signal from Earth to a rover on the surface of Mars. Explain your answer.

D. Describe one difference between mechanical and electromagnetic waves **not** identified in your explanation for Part C.

20

This question has four parts. Write your response on page 25. Be sure to label each part of your response.

21 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.

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

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.

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.

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.

The students create a list of six factors in the investigation, as shown.

1. the ball's mass
2. the ball's velocity after being kicked
3. how hard the ball is kicked
4. the amount of light on the field
5. how inflated the ball is
6. the time of day the data are collected

From the students' list, identify each of the following:

- **two** factors that will change during the investigation
- **two** factors that must be kept constant (controlled)
- **two** factors that will not affect the outcome of the investigation

In your response, you may use the numbers 1–6 to identify the factors instead of writing out the words.

21

D.

Factors That Will Change:
Factors That Must Be Kept Constant (Controlled):
Factors That Do Not Affect The Outcome:

High School
Introductory Physics
SESSION 2

This session contains 22 questions.

You may use your reference sheet in this session.

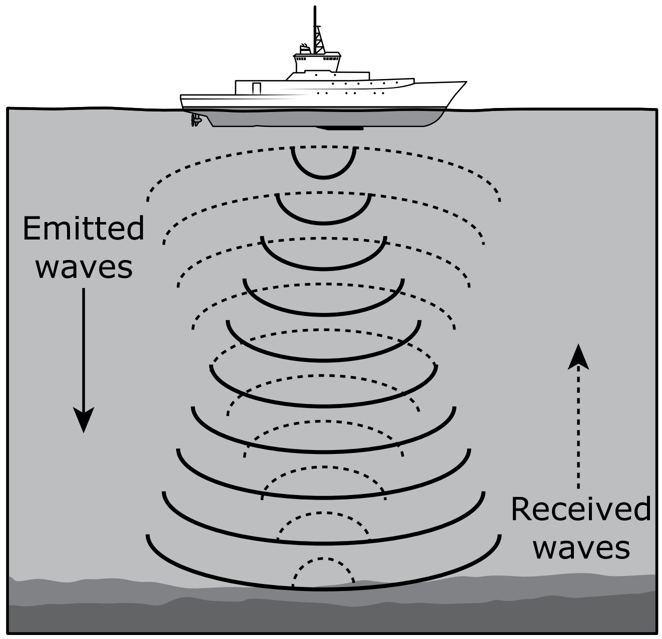
Directions

Read each question carefully and then answer it as well as you can. You must record all answers in this Test & Answer Booklet.

For some questions, you will mark your answers by filling in the circles in your Test & Answer Booklet. Make sure you darken the circles completely. Do not make any marks outside of the circles. If you need to change an answer, be sure to erase your first answer completely.

If a question asks you to show or explain your work, you must do so to receive full credit. Write your response in the space provided. Only responses written within the provided space will be scored.

22 Sonar is a technology that uses sound waves to measure distances underwater. Sonar can be used by a ship to produce a detailed image of the bottom of an ocean. The diagram shows a ship using sonar.



What must happen to a sound wave emitted by the ship to produce the detailed image?

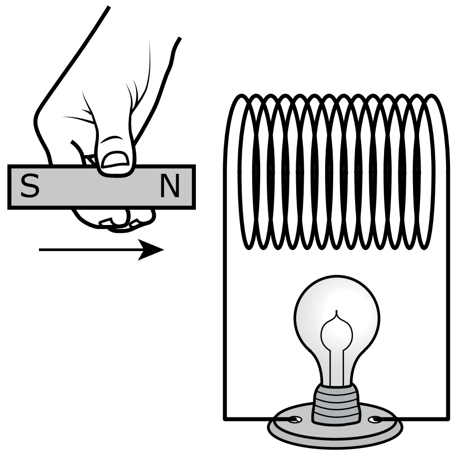
Ⓐ The sound wave must be absorbed by the bottom of the ocean.

Ⓑ The sound wave must be diffracted by the bottom of the ocean.

Ⓒ The sound wave must be reflected by the bottom of the ocean.

Ⓓ The sound wave must be refracted by the bottom of the ocean.

23 In an investigation, a strong magnet is passed through a coil of wire that is connected to a light bulb, as shown in the diagram.



What does this investigation **best** demonstrate?

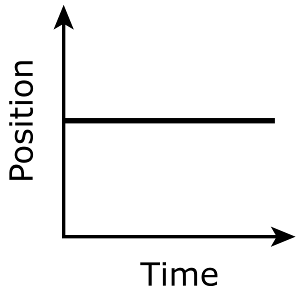
Ⓐ A moving electric field can create a magnetic field.

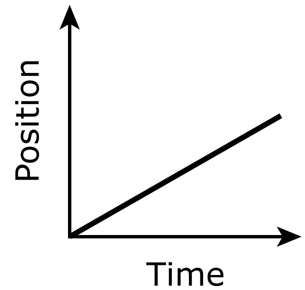
Ⓑ A changing magnetic field can produce a current.

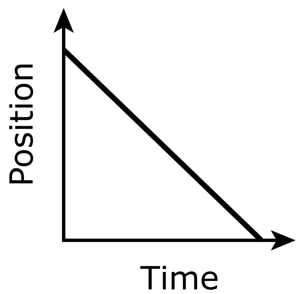
Ⓒ A moving magnet can cause a wire to become a magnet.

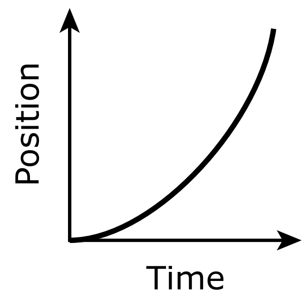
Ⓓ A changing electric current can create charges in a magnet.

24 A net force is acting on an object. Which of the following graphs shows the object's position over time?

Ⓐ


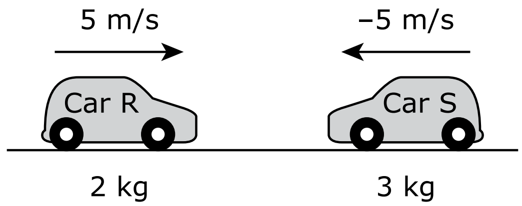
Ⓑ


Ⓒ


Ⓓ


This question has two parts.

25 Two toy cars, car R and car S, moved toward each other at a constant speed. Car R had a mass of 2 kg, and car S had a mass of 3 kg, as shown.



Part A

What was the total momentum of the system as the cars moved toward each other?

Ⓐ −15 kg • m/s
Ⓑ −5 kg • m/s
Ⓒ 10 kg • m/s
Ⓓ 25 kg • m/s

Part B

The incomplete table shows the velocity of each car at different times. At 2.5 s, the cars collided and bounced off each other. Assume no energy was lost to the environment.

Time (s)	Car R Velocity (m/s)	Car S Velocity (m/s)
1	5	−5
2		−5
3	−7	

What was the velocity of car R at 2 s?

Ⓐ −5 m/s
Ⓑ −3 m/s
Ⓒ 3 m/s
Ⓓ 5 m/s

What was the velocity of car S at 3 s?

Ⓐ −5 m/s
Ⓑ −3 m/s
Ⓒ 3 m/s
Ⓓ 5 m/s

26 In which of the following water samples do the water molecules have the **least** average kinetic energy?

Ⓐ 100 mL of water at 40°C

Ⓑ 200 mL of water at 35°C

Ⓒ 300 mL of water at 15°C

Ⓓ 400 mL of water at 20°C

27 Two objects are separated by a certain distance. Which of the following would **most** increase the force of gravitational attraction between the objects?

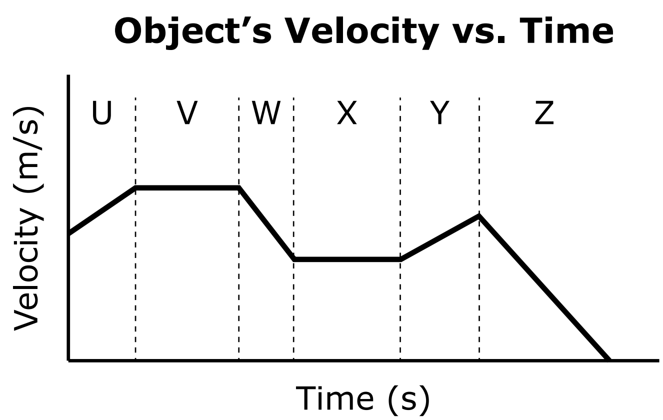
Ⓐ doubling the mass of one of the objects

Ⓑ doubling the distance between the objects

Ⓒ reducing the mass of one of the objects by one-half

Ⓓ reducing the distance between the objects by one-half

28 The graph shows the velocity of an object over time, with intervals labeled U–Z.



During which two intervals is the direction of the net force acting on the object opposite to the direction of the object’s motion?

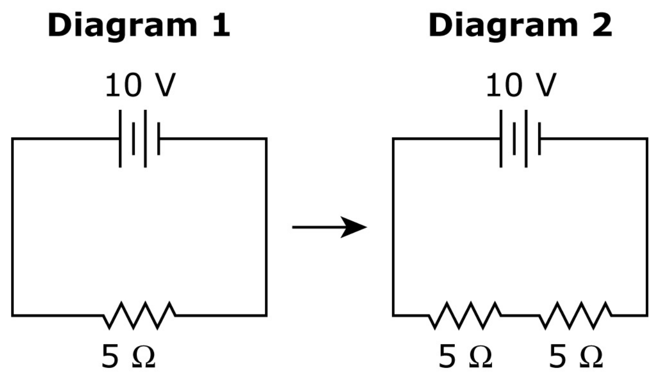
Ⓐ U and V

Ⓑ W and Z

Ⓒ V and X

Ⓓ Y and Z

29 A student builds a circuit with a battery and a resistor, as shown in diagram 1. The student then adds another resistor to the circuit, as shown in diagram 2.



Which of the following describes how the current in the circuit changes when the student adds the second resistor?

Ⓐ The current decreases from 2 A to 1 A.

Ⓑ The current decreases from 50 A to 25 A.

Ⓒ The current increases from 0.5 A to 1 A.

Ⓓ The current increases from 2 A to 4 A.

30 The temperature of a metal rod increases by 5°C. What additional information is required to calculate the energy that was absorbed by the metal rod?

Ⓐ the length and the mass of the rod

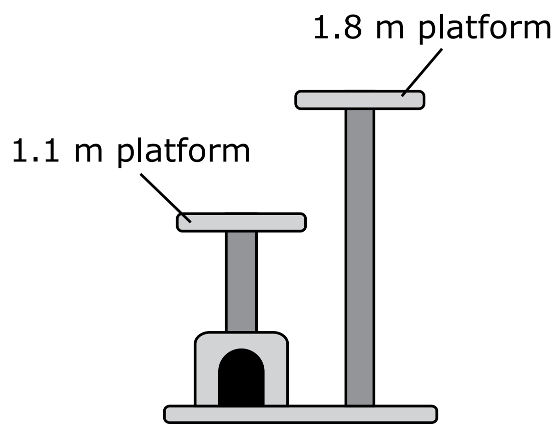
Ⓑ the specific heat and the density of the metal

Ⓒ the density of the metal and the length of the rod

Ⓓ the mass of the rod and the specific heat of the metal

This question has two parts.

31 Cats play and sleep on cat towers. A cat tower with two platforms is shown. One platform is 1.8 m above the ground, and the second platform is 1.1 m above the ground.



Part A

A 1.5 kg cat sat on the 1.8 m platform. What was the gravitational potential energy of the cat relative to the ground?

Ⓐ 2.4 J

Ⓑ 10.5 J

Ⓒ 18 J

Ⓓ 27 J

Part B

The cat jumped from the 1.8 m platform to the 1.1 m platform. Which of the following best describes the gravitational potential energy (GPE) and the kinetic energy (KE) of the cat as it was moving to the 1.1 m platform?

Ⓐ The cat's GPE and KE increased.

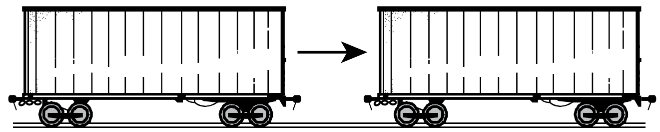
Ⓑ The cat's GPE and KE decreased.

Ⓒ The cat's GPE decreased and its KE increased.

Ⓓ The cat's GPE increased and its KE decreased.

32 A railroad car with a mass of 400,000 kg is moving at a speed of 8.0 m/s toward a stationary railroad car with a mass of 1,200,000 kg, as shown in the diagram.

400,000 kg 1,200,000 kg



8.0 m/s

The moving car connects to the stationary car. Both cars then move in the same direction the first car was moving.

What is the speed of both railroad cars after they connect?

Ⓐ 1.0 m/s

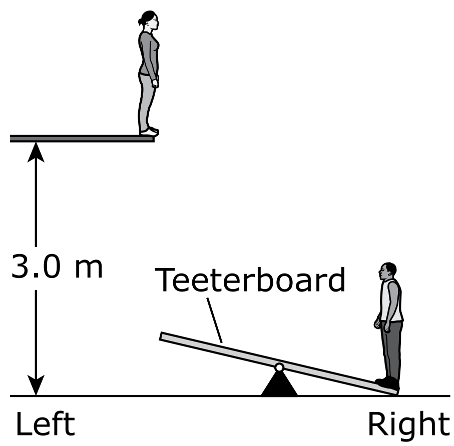
Ⓑ 2.0 m/s

Ⓒ 4.0 m/s

Ⓓ 8.0 m/s

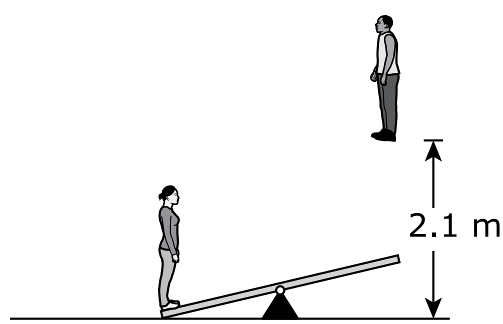
33 Two 65 kg performers are using a teeterboard to perform a routine. One of the performers is at rest on the right side of the teeterboard while the other performer steps off a 3.0 m platform and lands on the left side of the teeterboard. The teeterboard and performers are shown.

Before



After the performer on the left comes to rest on the left side of the teeterboard, the performer on the right moves upward and reaches a maximum height of 2.1 m, as shown.

After



What is the percent efficiency of the teeterboard for this routine?

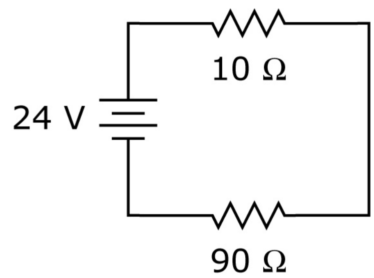
Ⓐ 30%

Ⓑ 41%

Ⓒ 70%

Ⓓ 143%

34 A circuit with two resistors is shown.



The voltage drop across the 10 Ω resistor is

Ⓐ less than the voltage drop across the 90 Ω resistor.

Ⓑ equal to the voltage drop across the 90 Ω resistor.

The current through the 10 Ω resistor is

Ⓐ less than the current through the 90 Ω resistor.

Ⓑ equal to the current through the 90 Ω resistor.

The following section focuses on the motion of athletes.

Read the information below and use it to answer the three selected-response questions and one constructed-response question that follow.

Track and field is a sport that consists of many different events, including the 100 m sprint and the high jump.

100 m Sprint

The 100 m sprint is a short running race. Athlete K completed a 100 m sprint in 10.9 s. The table shows athlete K's average velocity for each 10 m segment of the running race.

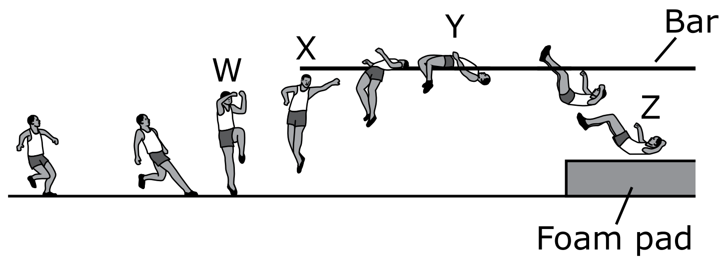
Average Velocity of Athlete K

Running Race Segment (m)	Average Velocity (m/s)
0 – 10	4.8
10 – 20	8.7
20 – 30	9.8
30 – 40	10.6
40 – 50	10.8
50 – 60	10.8
60 – 70	10.6
70 – 80	10.4
80 – 90	10.4
90 – 100	10.4

High Jump

The high jump is an event in which an athlete runs toward a bar and then jumps over it. Athlete M completed a high jump and then safely collided with a foam pad. Athlete M's mass was 80 kg. The diagram shows several positions of athlete M during the high jump, with four positions labeled W, X, Y, and Z.

Athlete M
Completing a High Jump



35 Which of the following shows athlete M's high jump positions X, Y, and Z from least to greatest gravitational potential energy (GPE)?

Ⓐ **Y** **X** **Z**

Least GPE ⟶ Greatest GPE

Ⓑ **X** **Z** **Y**

Least GPE ⟶ Greatest GPE

Ⓒ **Z** **X** **Y**

Least GPE ⟶ Greatest GPE

Ⓓ **Z** **Y** **X**

Least GPE ⟶ Greatest GPE

36 Athlete M landed on the foam pad after completing the high jump. Which of the following best compares landing on the foam pad with landing on the ground?

Ⓐ Landing on the foam pad increased the time of the collision, which caused the force on the athlete to be reduced.

Ⓑ Landing on the foam pad increased the force on the athlete, which caused the velocity of the athlete to be reduced.

Ⓒ Landing on the foam pad increased the velocity of the athlete, which caused the time of the collision to be reduced.

Ⓓ Landing on the foam pad increased the velocity of the athlete, which caused the force on the athlete to be reduced.

37 During which of the following race segments was the average net force on athlete K most likely zero?

Ⓐ 0 – 20 m

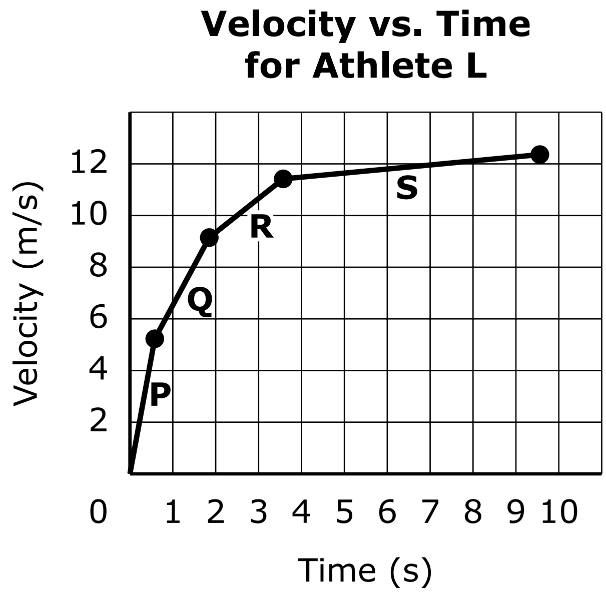
Ⓑ 20 – 40 m

Ⓒ 60 – 80 m

Ⓓ 80 – 100 m

This question has three parts. Write your response on the next page. Be sure to label each part of your response.

38 Another athlete, athlete L, completed a 100 m sprint in 9.6 s. The graph shows athlete L's velocity over time. Four time intervals are labeled P, Q, R, and S.



A. Identify the interval of the race when athlete L had the greatest acceleration. Explain your reasoning.

B. Calculate athlete L's average acceleration for the entire race. Show your calculations and include units in your answer.

C. Compare the net force on athlete L during interval Q with the net force on athlete L during interval S. Explain your reasoning.

38

39 A car safety engineer is conducting an investigation to analyze the performance of three types of airbags. The engineer installs a different type of airbag in each of three identical cars. Each car will be crashed into a wall. At the time of the collision, sensors inside the cars will measure the collision forces applied by each airbag. The airbag that applies the lowest forces on its car's sensors will be considered the most successful.

Which of the following should be controlled in the investigation?

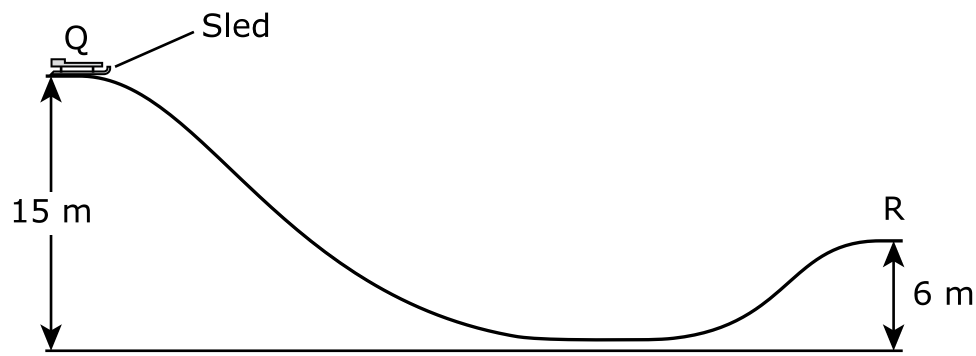
Ⓐ the speed of each car just before its collision

Ⓑ the efficiency of each car just before its collision

Ⓒ the time it takes each car to stop during its collision

Ⓓ the average acceleration of each car during its collision

40 A sled with a mass of 5 kg begins at rest on top of a hill at position Q. The sled moves down the hill and comes to rest on top of the next hill at position R, as shown.



As the sled moves from position Q to position R, how does the mechanical energy of the sled change?

Ⓐ It increases by 300 J.

Ⓑ It increases by 1250 J.

Ⓒ It decreases by 450 J.

Ⓓ It decreases by 750 J.

41 When a light wave passes from air into clear syrup, its direction is shifted toward the normal. Which of the following **best** explains why this occurs?

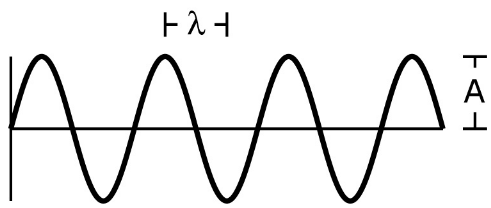
Ⓐ The speed of the light wave is slower in the syrup.

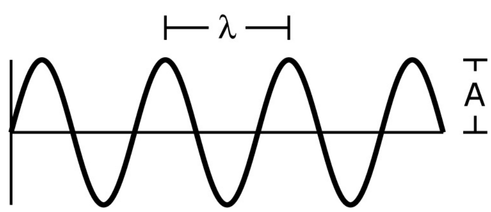
Ⓑ The speed of the light wave is faster in the syrup.

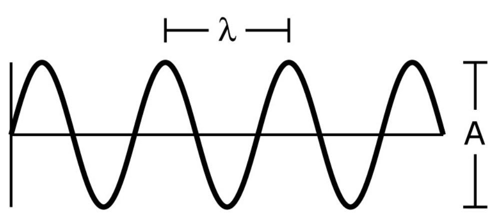
Ⓒ The frequency of the light wave is lower in the syrup.

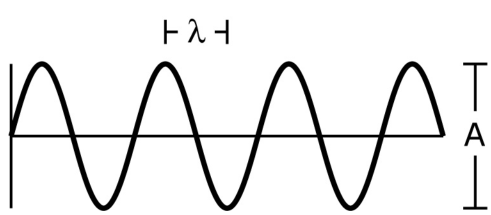
Ⓓ The frequency of the light wave is higher in the syrup.

42 Which of the following diagrams correctly labels the wavelength (λ) and amplitude (A) of a wave?

Ⓐ


Ⓑ


Ⓒ


Ⓓ


This question has four parts. Write your response on the next page. Be sure to label each part of your response.

43 Two charged objects, Y and Z, are held a distance, d, from each other. Both objects are positively charged, as shown.

A. Compare the magnitude of the electrostatic force acting on object Y with the magnitude of the electrostatic force acting on object Z.

B. Determine the direction (left or right) of the electrostatic force acting on object Y **and** the direction (left or right) of the electrostatic force acting on object Z. Explain your reasoning.

C. The objects are released and start to move.

Identify whether the magnitude of the electrostatic force acting on object Z increases, decreases, or remains the same after the objects are released. Explain your reasoning.

D. Describe how the kinetic energies of object Y and object Z change as a result of the objects being released. Explain your reasoning.

43

Massachusetts Comprehensive Assessment System
Introductory Physics Reference Sheet

Formulas

$s_{average} = \frac{d}{\Delta t}$	$p = mv$	$F_e = k\frac{q_1 q_2}{d^2}$	$Q = mc\Delta T$
$v_{average} = \frac{\Delta x}{\Delta t}$	$F\Delta t = \Delta p$	$KE = \frac{1}{2}mv^2$	$v = \lambda f$
$a_{average} = \frac{\Delta v}{\Delta t}$	$F_{net} = ma$	$\Delta PE = mg\Delta h$	$T = \frac{1}{f}$
$v_f = v_i + a\Delta t$	$F_g = mg$	$W = \Delta E = Fd$	$V = IR$
$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$	$F_g = G\frac{m_1 m_2}{d^2}$	$eff = \frac{E_{out}}{E_{in}}$	

Variables

a = acceleration
c = specific heat
d = distance
E = energy
eff = efficiency
f = frequency
F = force
g = acceleration due to gravity
Δh = change in height
I = current

KE = kinetic energy
λ = wavelength
m = mass
p = momentum
ΔPE = change in gravitational potential energy
q = charge of particle
Q = heat added or removed
R = resistance

s = speed
Δt = change in time
T = period
ΔT = change in temperature
v = velocity
V = potential difference (voltage)
W = work
Δx = change in position (displacement)

Unit Symbols

ampere, A	hertz, Hz	meter, m	second, s
coulomb, C	joule, J	newton, N	volt, V
degree Celsius, °C	kilogram, kg	ohm, Ω	

Definitions

speed of electromagnetic waves in a vacuum = 3×10^8 m/s

G = Universal gravitational constant = $6.7 \times 10^{-11} \frac{N \bullet m^2}{kg^2}$

k = Coulomb's constant = $9 \times 10^9 \frac{N \bullet m^2}{C^2}$

$g \approx 10$ m/s² at Earth's surface

$1\ N = 1\frac{kg \bullet m}{s^2}$

$1\ J = 1\ N \bullet m$

High School Introductory Physics
Spring 2024 Released Operational Items

PBT Item No.	Page No.	Reporting Category	Standard	Science Practice Category	Item Type*	Item Description	Correct Answer (SR)**
1	3	*Energy*	HS.PHY.3.5	None	SR	Describe how changing the distance between two charged particles affects the forces between the particles.	C
2	4	*Energy*	HS.PHY.3.2	C. Evidence, Reasoning, and Modeling	SR	Determine which model shows how the molecular motion of a substance changes as it is heated.	D
3	5	*Waves*	HS.PHY.4.1	B. Mathematics and Data	SR	Compare the wavelength of a sound wave in air and water.	D
4	5	*Motion, Forces, and Interactions*	HS.PHY.2.9	B. Mathematics and Data	SR	Calculate the current flowing through a series circuit.	A
5	5	*Motion, Forces, and Interactions*	HS.PHY.2.2	B. Mathematics and Data	SR	Determine the object with the greatest momentum.	C
6	6	*Energy*	HS.PHY.1.8	C. Evidence, Reasoning, and Modeling	SR	Interpret a model to describe a nuclear process.	B;A
7	7	*Waves*	HS.PHY.4.5	C. Evidence, Reasoning, and Modeling	SR	Interpret a diagram to determine the wave behavior shown, and describe how the speed and wavelength of light changes as it passes from air into another medium.	A;B;B
8	8	*Waves*	HS.PHY.4.3	None	SR	Identify an example of light behaving like a particle.	A
9	8	*Motion, Forces, and Interactions*	HS.PHY.2.1	B. Mathematics and Data	SR	Calculate the net force on an object.	D
10	9	*Motion, Forces, and Interactions*	HS.PHY.2.5	A. Investigations and Questioning	SR	Explain that current flowing through a wire produces a magnetic field that can apply a force, and determine the question that was being answered by an investigation.	B;C;C
11	11	*Energy*	HS.PHY.3.4	C. Evidence, Reasoning, and Modeling	SR	Determine which temperature vs. time graph represents two objects in thermal contact.	B
12	12	*Motion, Forces, and Interactions*	HS.PHY.2.9	B. Mathematics and Data	SR	Analyze a series circuit to determine the voltage drop across each resistor and the total voltage drop across the circuit.	B
13	12	*Waves*	HS.PHY.4.1	C. Evidence, Reasoning, and Modeling	SR	Compare the speed and wavelength of radio waves and infrared radiation in a vacuum, given that radio waves have a lower frequency than infrared radiation.	A
14	14	*Motion, Forces, and Interactions*	HS.PHY.2.10	B. Mathematics and Data	SR	Calculate the average speed of an object.	C
15	15	*Motion, Forces, and Interactions*	HS.PHY.2.10	B. Mathematics and Data	SR	Interpret a distance vs. time graph to describe the motion of an object and the magnitude of the net force on the object.	A;B

PBT Item No.	Page No.	Reporting Category	Standard	Science Practice Category	Item Type*	Item Description	Correct Answer (SR)**
16	16	*Motion, Forces, and Interactions*	HS.PHY.2.10	C. Evidence, Reasoning, and Modeling	SR	Identify the free-body force diagram for an object falling with negligible air resistance.	B
17	17	*Energy*	HS.PHY.3.2	C. Evidence, Reasoning, and Modeling	CR	Interpret a graph of the gravitational potential energy (GPE) and kinetic energy (KE) of a falling object to identify the object's height and explain the reasoning, create a graph of the object's GPE and KE, and describe how the object's GPE and KE would have been affected by air resistance acting on the object.	
18	19	*Motion, Forces, and Interactions*	HS.PHY.2.10	C. Evidence, Reasoning, and Modeling	SR	Interpret motion graphs to determine which graph represents constant, positive acceleration.	B
19	20	*Motion, Forces, and Interactions*	HS.PHY.2.4	C. Evidence, Reasoning, and Modeling	SR	Interpret a diagram to compare the charges on two objects and to describe how changing the magnitudes of the charges would affect the system.	B;A
20	21	*Waves*	HS.PHY.4.1	None	CR	Identify sound waves as a type of mechanical wave, describe how one type of electromagnetic wave can be used, explain why electromagnetic waves must be used in space, and describe a difference between mechanical and electromagnetic waves.	
21	23	*Motion, Forces, and Interactions*	HS.PHY.2.3	A. Investigations and Questioning	CR	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.	
22	27	*Waves*	HS.PHY.4.5	C. Evidence, Reasoning, and Modeling	SR	Interpret a diagram to determine the wave behavior used by a device.	C
23	28	*Motion, Forces, and Interactions*	HS.PHY.2.5	C. Evidence, Reasoning, and Modeling	SR	Describe what an investigation demonstrates when a magnet is passed through a coil of wire.	B
24	29	*Motion, Forces, and Interactions*	HS.PHY.2.1	B. Mathematics and Data	SR	Interpret position vs. time graphs to determine which graph represents an object with a net force acting on it.	D
25	30	*Motion, Forces, and Interactions*	HS.PHY.2.2	B. Mathematics and Data	SR	Calculate the total momentum of a system and the velocity of an object just after a collision.	B;D;C

PBT Item No.	Page No.	Reporting Category	Standard	Science Practice Category	Item Type*	Item Description	Correct Answer (SR)**
26	31	*Energy*	HS.PHY.3.4	None	SR	Determine which water sample has the least average kinetic energy based on the temperatures of the samples.	C
27	31	*Motion, Forces, and Interactions*	HS.PHY.2.4	B. Mathematics and Data	SR	Determine which change would cause the greatest increase in gravitational attraction between two objects.	D
28	32	*Motion, Forces, and Interactions*	HS.PHY.2.10	C. Evidence, Reasoning, and Modeling	SR	Analyze a velocity vs. time graph to determine when the direction of the net force on an object is opposite the object's motion.	B
29	33	*Motion, Forces, and Interactions*	HS.PHY.2.9	B. Mathematics and Data	SR	Describe how adding another resistor in series affects the current in a circuit.	A
30	33	*Energy*	HS.PHY.3.4	B. Mathematics and Data	SR	Identify the information required to calculate the energy absorbed by an object.	D
31	34	*Energy*	HS.PHY.3.1	C. Evidence, Reasoning, and Modeling	SR	Calculate the initial gravitational potential energy of an object, and describe how the object's gravitational potential energy and kinetic energy changed as the object's height decreased.	D;C
32	35	*Motion, Forces, and Interactions*	HS.PHY.2.2	B. Mathematics and Data	SR	Calculate the speed of two railroad cars after the cars collide, connect, and move together.	B
33	36	*Energy*	HS.PHY.3.3	C. Evidence, Reasoning, and Modeling	SR	Calculate the percent efficiency of a device that converts kinetic energy to gravitational potential energy.	C
34	37	*Motion, Forces, and Interactions*	HS.PHY.2.9	C. Evidence, Reasoning, and Modeling	SR	Compare the voltage drop across and current through two resistors in a circuit.	A;B
35	40	*Energy*	HS.PHY.3.1	C. Evidence, Reasoning, and Modeling	SR	Order the gravitational potential energy of an object at three heights from least to greatest.	C
36	40	*Motion, Forces, and Interactions*	HS.PHY.2.3	C. Evidence, Reasoning, and Modeling	SR	Compare the collision time and the force on an object for two collisions with different surfaces.	A
37	41	*Motion, Forces, and Interactions*	HS.PHY.2.1	B. Mathematics and Data	SR	Interpret data to determine when there was zero net force on a moving object.	D

PBT Item No.	Page No.	Reporting Category	Standard	Science Practice Category	Item Type*	Item Description	Correct Answer (SR)**
38	42	*Motion, Forces, and Interactions*	HS.PHY.2.10	B. Mathematics and Data	CR	Analyze a velocity vs. time graph to explain when an object has the greatest acceleration during a time interval, calculate the average acceleration of the object over a given amount of time, and compare the net forces on the object for two different time intervals and explain the reasoning.	
39	44	*Motion, Forces, and Interactions*	HS.PHY.2.3	A. Investigations and Questioning	SR	Determine a variable that should be controlled in an investigation about reducing the forces from a collision.	A
40	44	*Energy*	HS.PHY.3.1	B. Mathematics and Data	SR	Calculate an object's change in mechanical energy.	C
41	45	*Waves*	HS.PHY.4.5	None	SR	Explain why light bends when traveling from one medium to another.	A
42	45	*Waves*	HS.PHY.4.1	C. Evidence, Reasoning, and Modeling	SR	Identify the diagram that has the wavelength and amplitude of a wave correctly labeled.	B
43	46	*Energy*	HS.PHY.3.5	C. Evidence, Reasoning, and Modeling	CR	Analyze a diagram to compare the magnitude of the electrostatic forces acting on two objects, explain why the electrostatic forces have certain directions, and explain how releasing the objects changes the magnitude of the force acting on one of the objects and the kinetic energies of the objects.	

* Science item types are: selected-response (SR) and constructed-response (CR).

** Answers are provided here for selected-response items only. Sample responses and scoring guidelines for constructed-response items will be posted to the Department's website later this year.