MASSACHUSETTS
Department of Elementary
and Secondary Education

Release of Spring 2023 MCAS Test Items

from the

High School Introductory Physics Paper-Based Test

July 2023
Massachusetts Department of Elementary and Secondary Education

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and Secondary Education

This document was prepared by the
Massachusetts Department of Elementary and Secondary Education
Jeffrey C. Riley
Commissioner

Massachusetts Department of Elementary and Secondary Education
75 Pleasant Street, Malden, MA 02148-4906
Phone 781-338-3000 TTY: N.E.T. Relay 800-439-2370
www.doe.mass.edu

Overview of High School Introductory Physics Test

The spring 2023 high school Introductory Physics test was a next-generation assessment that 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 STE 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 chapter. Each student also had sole access to a calculator.

During both high school Introductory Physics test sessions, the use of bilingual word-to-word dictionaries was allowed for current and former English learner students.

High School Introductory Physics

SESSION 1

This session contains 21 questions.

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 velocities and masses of four objects are listed in the table.

Object	Velocity (m/s)	Mass (kg)
W	9	14
X	10	14
Y	11	12
Z	12	12

Which object has the greatest momentum?

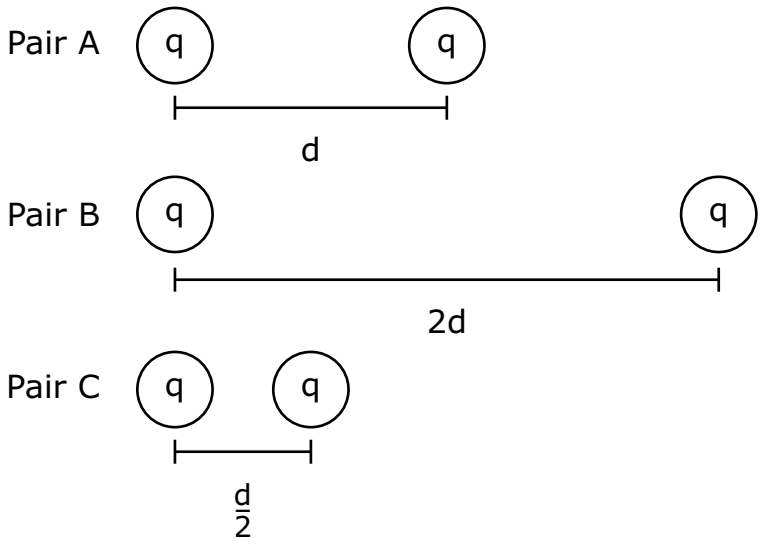
Ⓐ object W

Ⓑ object X

Ⓒ object Y

Ⓓ object Z

2 The diagram shows three pairs of positively charged particles, A, B, and C.



Which of the following best describes two of the pairs of charged particles?

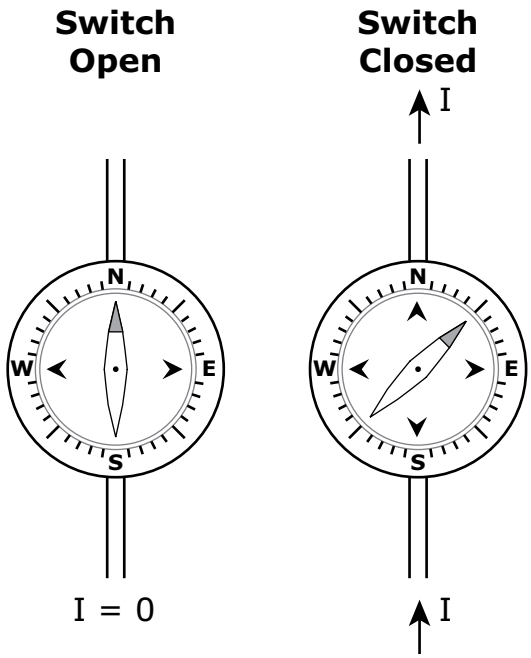
Ⓐ Pair A has the least electrical force, and pair B has the greatest electrical force.

Ⓑ Pair B has the least electrical force, and pair A has the greatest electrical force.

Ⓒ Pair B has the least electrical force, and pair C has the greatest electrical force.

Ⓓ Pair C has the least electrical force, and pair B has the greatest electrical force.

3 A student performs an investigation using a compass and a circuit with a switch. The switch is initially open, and the compass is placed over part of the wire so that the compass needle and wire are aligned. When the switch is closed, the compass needle moves. The diagrams represent the compass placed over the wire.



Which of the following **best** explains why the compass needle moves when the switch is closed?

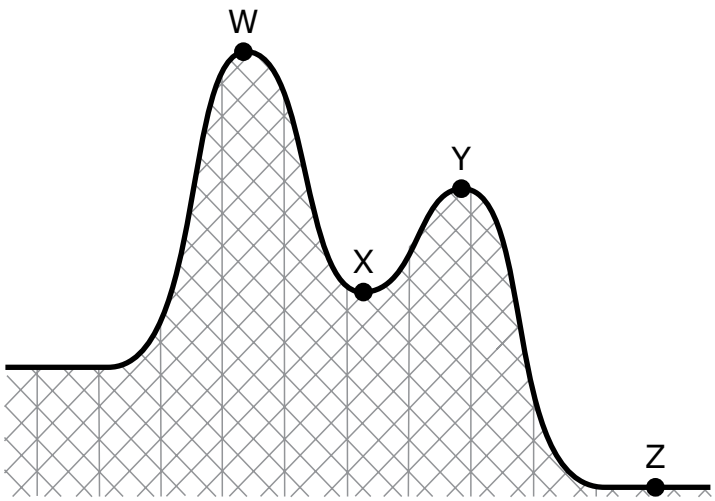
Ⓐ Potential energy causes kinetic energy to be produced.

Ⓑ Electrical power causes a gravitational pull to be produced.

Ⓒ Moving electric charges cause a magnetic force to be produced.

Ⓓ Moving magnetic poles cause electromagnetic waves to be produced.

4 A part of a roller coaster's track is shown. Assume friction is negligible. Four points on the track are labeled W, X, Y, and Z.



Where on the track would a car have the **most** gravitational potential energy?

Ⓐ point W

Ⓑ point X

Ⓒ point Y

Ⓓ point Z

Where on the track would a car have the **most** kinetic energy?

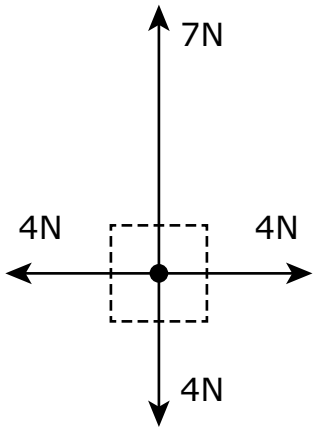
Ⓐ point W

Ⓑ point X

Ⓒ point Y

Ⓓ point Z

5 The free-body force diagram for an object is shown.



Based on the free-body force diagram, which of the following describes the motion of the object?

Ⓐ The object is accelerating upward.

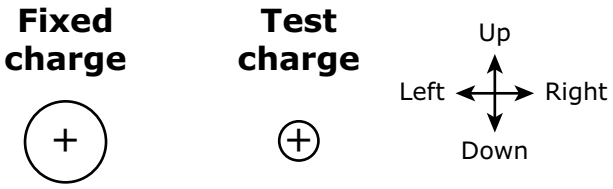
Ⓑ The object is accelerating to the right.

Ⓒ The object is moving upward with a constant speed.

Ⓓ The object is moving to the left at an increasing speed.

This question has two parts.

6 A positive test charge is placed in the field of a positive charge that is fixed in position. The test charge is first held in place and then allowed to move. The diagram shows the two charges.



Part A

The field of the fixed charge will cause the test charge to move

Ⓐ upward.

Ⓑ to the right.

Ⓒ downward.

Ⓓ to the left.

Part B

Which of the following describes how the distance and the forces between the two charges will change as the test charge moves?

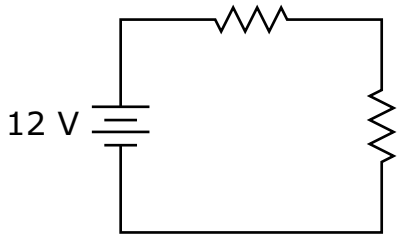
Ⓐ The distance will increase, making the forces increase.

Ⓑ The distance will increase, making the forces decrease.

Ⓒ The distance will decrease, making the forces increase.

Ⓓ The distance will decrease, making the forces decrease.

7 A circuit with a 12 V battery and two resistors is shown.



The total current in the circuit is 2 A. Which of the following must be the values of the resistors?

Ⓐ 2 Ω and 4 Ω

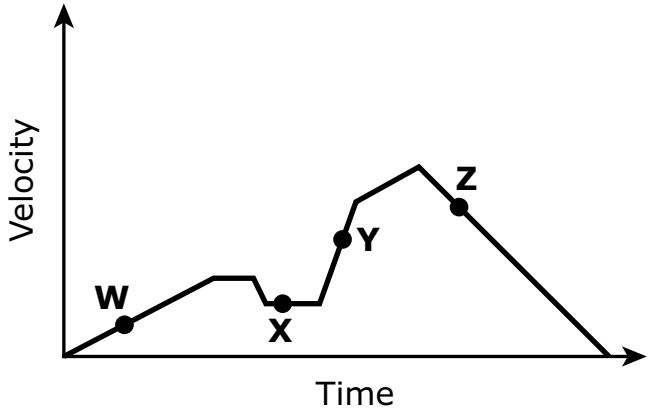
Ⓑ 8 Ω and 16 Ω

Ⓒ 8 Ω and 24 Ω

Ⓓ 10 Ω and 16 Ω

8 A truck is traveling along a highway. The graph shows the truck's velocity with respect to time.

Motion of a Truck



At which labeled point on the graph does the truck have the greatest acceleration?

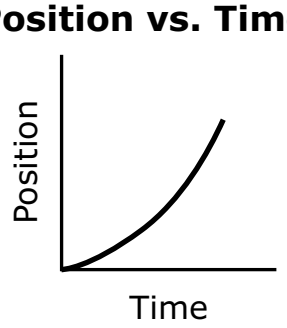
Ⓐ point W

Ⓑ point X

Ⓒ point Y

Ⓓ point Z

9 The graph shows the position of an object over time.



The velocity of the object is

Ⓐ increasing.

Ⓑ decreasing.

Ⓒ constant.

The forces acting on the object are

Ⓐ balanced.

Ⓑ unbalanced.

10 The table shows the net force that acted on an object and the distance it moved during each of four time intervals.

Time Interval	Net Force (N)	Distance Moved (m)
1	10	4
2	7	2
3	5	6
4	12	2

During which time interval was the **most** work performed on the object?

Ⓐ time interval 1

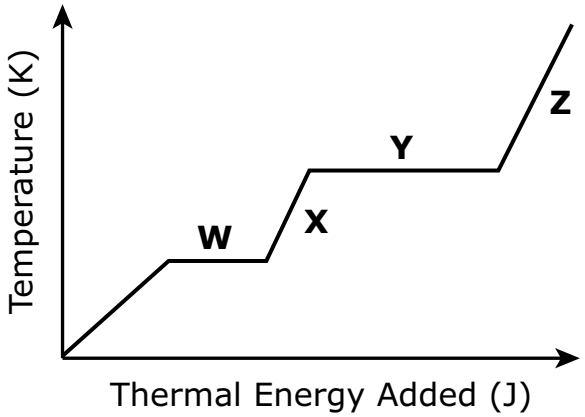
Ⓑ time interval 2

Ⓒ time interval 3

Ⓓ time interval 4

11 The graph shows the change in temperature of a substance as thermal energy is added. Four sections of the graph are labeled.

Heating Curve for a Substance



In which section of the graph is the substance changing phase from a liquid to a gas?

Ⓐ section W

Ⓑ section X

Ⓒ section Y

Ⓓ section Z

The following section focuses on two classroom demonstrations of wave behaviors.

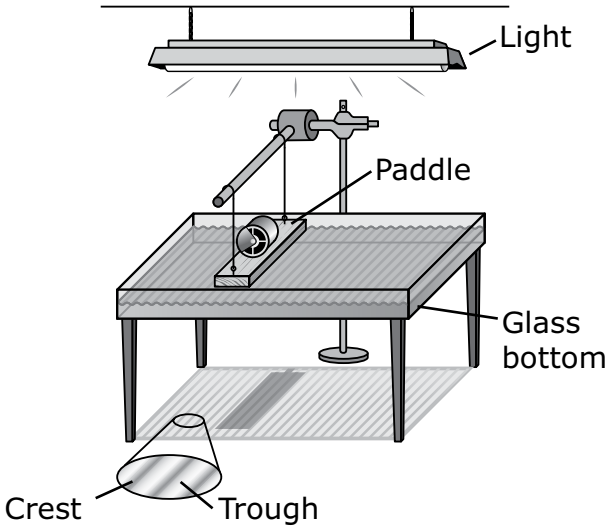
Read the information below and use it to answer the selected-response questions and constructed-response question that follow.

Students in a physics class studied wave behaviors by observing different types of waves in two demonstrations.

Demonstration 1

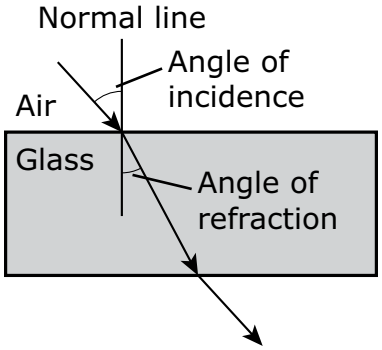
For demonstration 1, the students observed waves in a ripple tank, which is a container with a glass bottom. The ripple tank was filled with a couple inches of water. The waves were generated by a paddle that moved up and down in the water. The students could adjust the frequency of the paddle's movement.

A light above the tank created shadows of the waves on the floor. Each wave crest made a dark shadow, while each wave trough made a light shadow. The setup for demonstration 1 is shown.



Demonstration 2

For demonstration 2, the students directed red light from a laser pointer at a block of glass. The red light had a frequency of 4×10^{14} Hz. The path of the light as it traveled through the block is represented in the diagram.



12 Which of the following describes the waves in both demonstrations 1 and 2?

Ⓐ They carry energy.

Ⓑ They are longitudinal.

Ⓒ They are electromagnetic.

Ⓓ They move at the same speed.

13 In demonstration 1, the students set the frequency of the paddle's motion in the ripple tank to 12 Hz. Based on this information, what can be determined about the waves created?

Ⓐ the speed at which a wave moves across the ripple tank

Ⓑ the amount of time it takes a wave to complete one cycle

Ⓒ the speed with which a wave loses energy to its surroundings

Ⓓ the amount of time it takes a wave to reach the far end of the ripple tank

14 What is the wavelength of the laser light used in demonstration 2?

Ⓐ 2.5×10^{-15} m

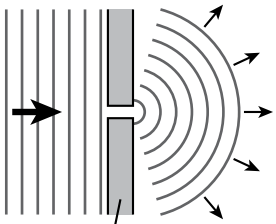
Ⓑ 7.5×10^{-7} m

Ⓒ 1.3×10^{6} m

Ⓓ 1.2×10^{23} m

This question has two parts.

15 The students modified demonstration 1 by placing two barriers in the middle of the ripple tank. The waves passed through a small gap between the barriers. The diagram shows the wave pattern that was produced as the waves passed through the small gap.



Part A

As the waves pass through the gap, they

Ⓐ bent around it.

Ⓑ increased in frequency.

Ⓒ gained energy and spread out.

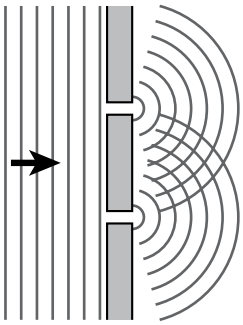
This wave phenomenon is called

Ⓐ diffraction.

Ⓑ refraction.

Part B

The students added a third barrier to the ripple tank so that there were two gaps. As the waves passed through the gaps, they interfered, as shown in the diagram.



Which of the following best describes how constructive interference occurred?

Ⓐ The crests of the waves passing through one gap met the wavelengths of the waves passing through the other gap.

Ⓑ The crests of the waves passing through one gap met the troughs of the waves passing through the other gap.

Ⓒ The crests of the waves passing through one gap met the nodes of the waves passing through the other gap.

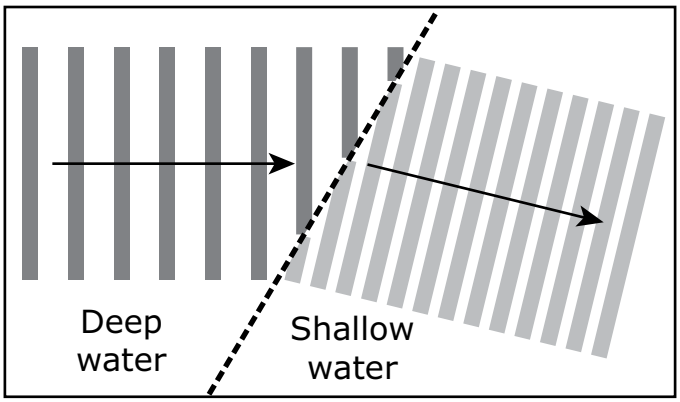
Ⓓ The crests of the waves passing through one gap met the crests of the waves passing through the other gap.

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

16 In demonstration 1, the students set the frequency of the paddle motion in the ripple tank to 8 Hz. The wavelength of the resulting wave was 0.11 m.

A. Calculate the velocity of the resulting wave. Show your calculations and include units in your answer.

B. The ripple tank used in demonstration 1 was replaced with a ripple tank that had a deep water section and a shallow water section. The diagram shown below represents the wave pattern produced when the new ripple tank was used.



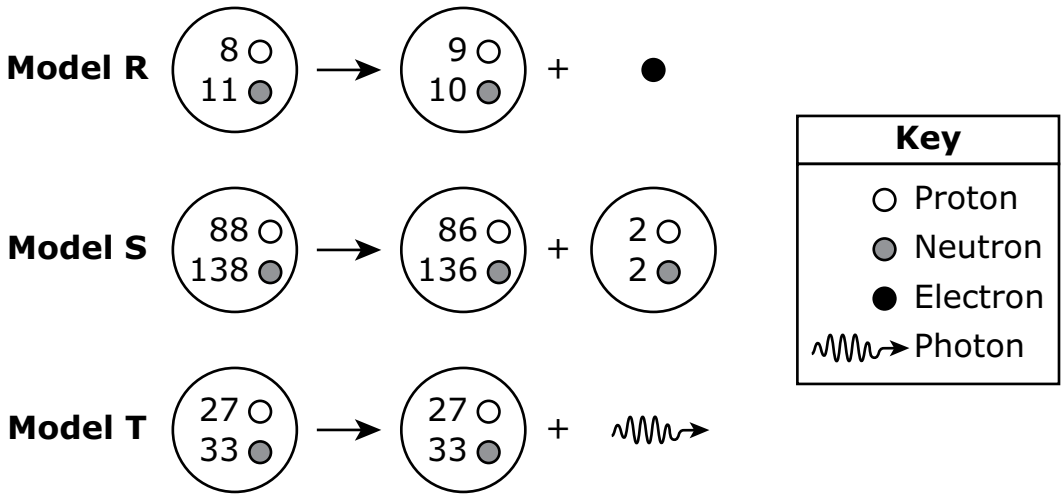
Based on the diagram, compare the wavelength of the waves in the shallow water with the wavelength of the waves in the deep water.

C. The frequency of the waves stayed the same as the waves moved from the deep water to the shallow water in the new ripple tank.

Compare the velocity of the waves that traveled in the deep water with the velocity of the waves that traveled in the shallow water. Explain your reasoning.

16

17 The models shown represent three types of nuclear decay.



Which type of decay does each model represent?

Ⓐ Model R: alpha decay
Model S: gamma decay
Model T: beta decay

Ⓑ Model R: beta decay
Model S: alpha decay
Model T: gamma decay

Ⓒ Model R: beta decay
Model S: gamma decay
Model T: alpha decay

Ⓓ Model R: gamma decay
Model S: beta decay
Model T: alpha decay

18 A rocket with a constant acceleration of 25 m/s^2 has an initial velocity of 200 m/s in the same direction as the acceleration. What is the magnitude of the rocket's velocity 10 s later?

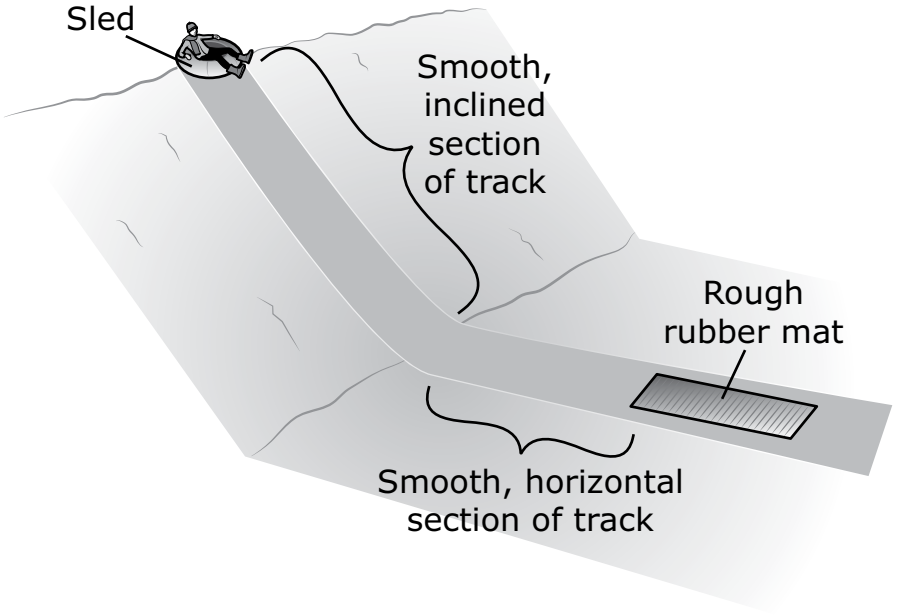
Ⓐ 250 m/s

Ⓑ 450 m/s

Ⓒ 1250 m/s

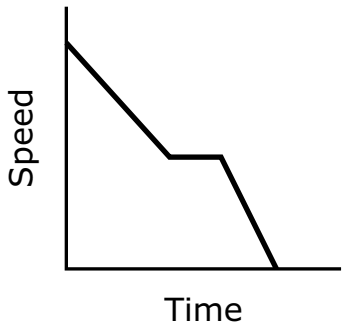
Ⓓ 1450 m/s

19 A person rode a sled down a track on a snowy hill. The person started at rest at the top of the hill and stopped on a rough rubber mat at the bottom of the hill. The track is shown in the diagram.

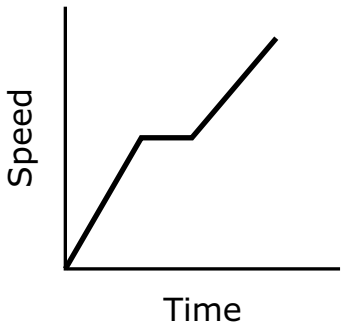


Which of the following graphs best represents the speed of the person on the sled from the top of the hill to the mat?

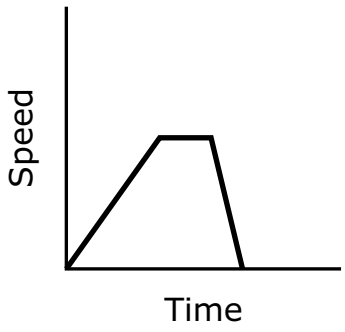
Ⓐ



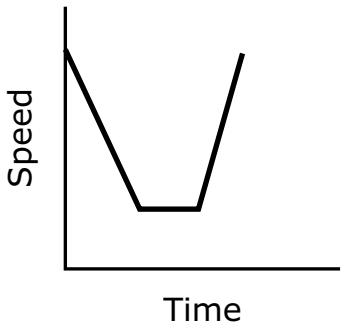
Ⓑ



Ⓒ



Ⓓ



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

20 The table shows data for the first four planets in the solar system.

Planet	Ratio of Planet's Mass to Earth's Mass	Ratio of Planet's Distance from the Sun to Earth's Distance from the Sun
Mercury	0.06	0.39
Venus	0.82	0.72
Earth	1.00	1.00
Mars	0.11	1.52

A. Identify the force that keeps the planets in orbit around the Sun.

B. Identify which force is stronger: the maximum attractive force between Venus and Earth or the maximum attractive force between Mars and Earth. Provide two reasons for your answer based on data in the table.

C. Suppose that the Sun had 30% less mass than it actually does.

How much would the attractive force between the Sun and the planets change? Explain your answer.

20

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

21 A student conducted an investigation to determine the specific heat of glass. The student placed five glass marbles with a total mass of 27.3 g into a beaker of boiling water. After the marbles reached 100°C, the student placed them in an insulated cup containing 75 g of water at 20°C. The water and the glass marbles in the cup eventually reached a temperature of 25.5°C.

A. In the insulated cup with water, did heat flow from the water to the marbles or from the marbles to the water? Explain your answer.

B. The specific heat of water is 4.19 J/g • °C.

Calculate the amount of thermal energy gained by the water in the cup. Show your calculations and include units in your answer.

C. Calculate the specific heat of the glass. Show your calculations and include units in your answer.

D. The investigation is repeated with ten glass marbles having a total mass of 54.6 g.

Compare the specific heat of the five glass marbles to the specific heat of the ten glass marbles. Explain your answer.

21

High School Introductory Physics

SESSION 2

This session contains 21 questions.

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 A student will drop water balloons into four containers to determine which container best minimizes the collision force on the water balloons so that they do not break.

Select **two** variables that the student must keep constant during testing to determine which container best minimizes the collision force on the water balloons.

Ⓐ the mass of each water balloon

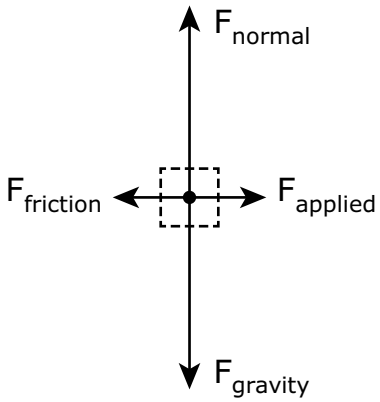
Ⓑ the temperature of each water balloon

Ⓒ the frequency of dropping water balloons

Ⓓ the height from which water balloons are dropped

Ⓔ the time between dropping one water balloon and the next

23 A person pushes a refrigerator across a floor with a horizontal force of 400 N. The free-body force diagram represents all of the forces acting on the refrigerator.



Based on the free-body force diagram, as the refrigerator moves across the floor, the refrigerator's velocity is

Ⓐ increasing.

Ⓑ decreasing.

Ⓒ constant.

If the person applies a greater force to the refrigerator, the arrow representing the applied force should be

Ⓐ longer than the arrow representing the friction force.

Ⓑ shorter than the arrow representing the friction force.

Ⓒ the same length as the arrow representing the friction force.

24 A 350 kg elevator carries a 50 kg person to a height of 4 m above the ground. What is the change in potential energy of both the elevator and the person?

Ⓐ 4,400 J

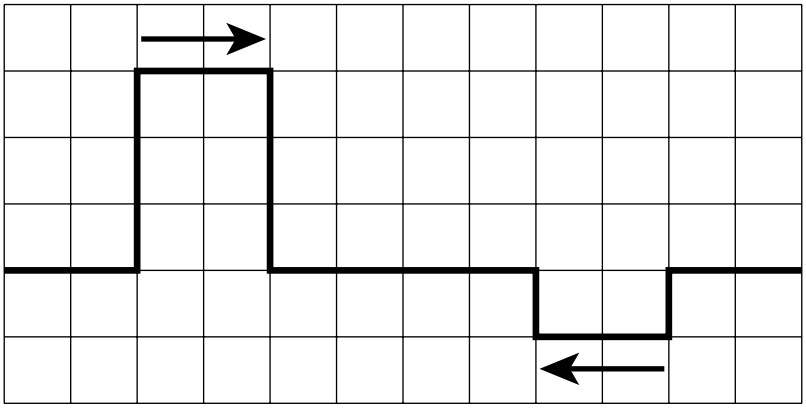
Ⓑ 12,000 J

Ⓒ 16,000 J

Ⓓ 70,000 J

This question has two parts.

25 Two wave pulses move toward each other with equal speed, as shown in the diagram.



Key
= 1 unit

Part A

Which wave behavior will occur when the waves reach each other?

Ⓐ diffraction

Ⓑ interference

Ⓒ reflection

Ⓓ refraction

Part B

What will the resulting amplitude be when the waves completely overlap?

Ⓐ 0 units

Ⓑ 2 units

Ⓒ 3 units

Ⓓ 4 units

26 A 60 Ω resistor is connected to a 1.5 V battery. If the internal resistance of the battery is ignored, what current will flow through the resistor?

Ⓐ 0.025 A

Ⓑ 0.040 A

Ⓒ 0.084 A

Ⓓ 0.090 A

27 The acceleration due to gravity is smaller on Mars than it is on Earth. If a 2 kg object were held 0.75 m above the surface of Mars, it would have 5.7 J of gravitational potential energy.

What is the acceleration due to gravity on Mars?

Ⓐ 0.26 m/s^2

Ⓑ 1.2 m/s^2

Ⓒ 3.8 m/s^2

Ⓓ 8.6 m/s^2

28 Newton's universal law of gravitation and Coulomb's law have mathematical formulas that look similar. Which of the following is a difference between the forces described by these two laws?

Ⓐ The force due to gravity requires two objects, but the force due to electric charge requires only one object.

Ⓑ The force due to gravity is only attractive, but the force due to electric charge can be attractive or repulsive.

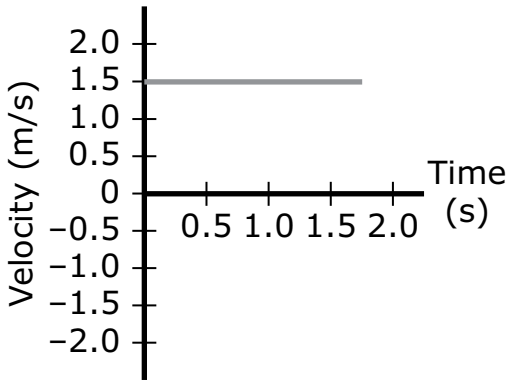
Ⓒ The force due to gravity varies inversely with the square of the distance, but the force due to electric charge does not.

Ⓓ The force due to gravity increases as distance decreases, but the force due to electric charge decreases as distance decreases.

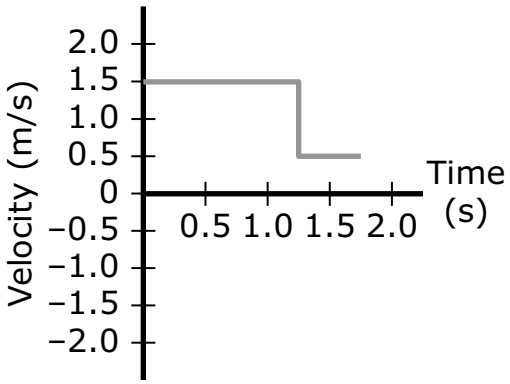
29 A 0.02 kg block was pushed so that it moved to the right with an initial velocity of 1.5 m/s. At 1.25 s, the 0.02 kg block collided with a 0.01 kg block, which caused the 0.01 kg block to move to the right at 2 m/s, as shown in the diagrams.

Which of the following graphs shows the velocity of the 0.02 kg block before and after the collision?

Ⓐ



Ⓑ



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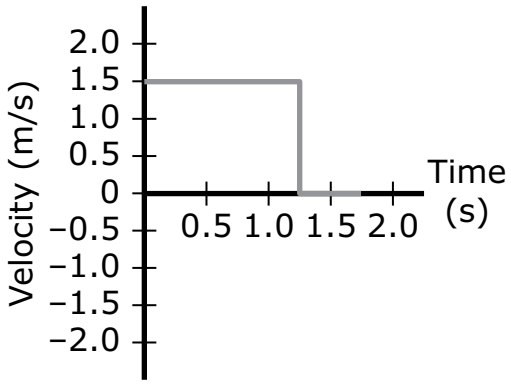

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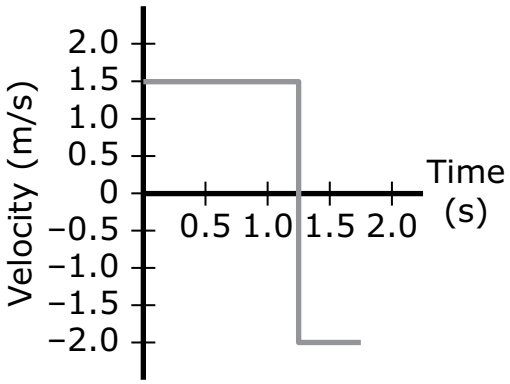
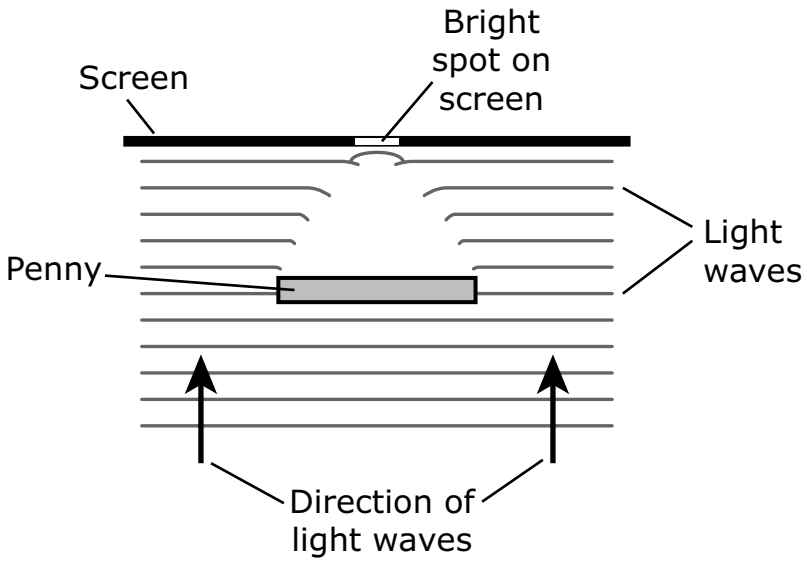


30 Some students set up a demonstration that involved shining light on a penny and a screen behind the penny. Based on their observations, the students made the model shown.



The students claim that the model shows light acting like a wave.

Select the **two** pieces of evidence that support the students' claim.

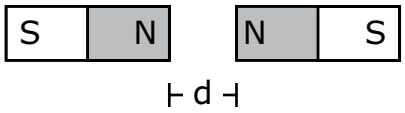
Ⓐ Light reflected around the penny.

Ⓑ Light diffracted around the penny.

Ⓒ A bright spot appeared on the screen because of constructive interference.

Ⓓ Photoelectrons were released from the penny because the light became excited.

31 In the diagram, the north pole of one magnet is shown facing the north pole of the other magnet. The two magnets are separated by a distance, d.



Which of the following changes would **increase** the potential energy stored in the field between the magnets?

Ⓐ increasing the distance between the magnets

Ⓑ decreasing the distance between the magnets

Ⓒ rotating one magnet so that its south pole faces the north pole of the other magnet

Ⓓ rotating both magnets so that the south pole of one magnet faces the south pole of the other magnet

32 A student studied the momentum and velocity of two objects, X and Y. The student collected the data in the table.

Object	Mass of Object (kg)	Net Force on Object (N)	Time Net Force Is Applied (s)
X	10	15	2
Y	6	8	3

The change in momentum of object X was

Ⓐ greater than the change in momentum of object Y.

Ⓑ equal to the change in momentum of object Y.

Ⓒ less than the change in momentum of object Y.

The change in velocity of object X was

Ⓐ greater than the change in velocity of object Y.

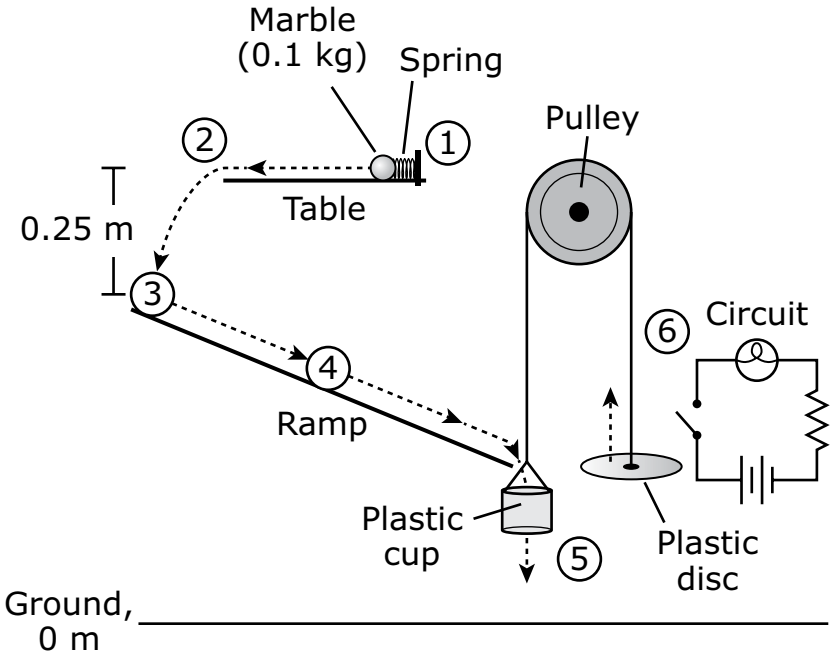
Ⓑ equal to the change in velocity of object Y.

Ⓒ less than the change in velocity of object Y.

The following section focuses on the physics of a machine designed to turn on a light bulb.

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

A student designed a complex machine to turn on a light bulb. A diagram of the student's design is shown.



The circled numbers in the diagram refer to the steps that occurred when the student used the machine to turn on the light bulb. Several types of energy conversion took place during the steps.

Step 1: The student released a compressed spring, which pushed a 0.1 kg marble to the left on a table.

Step 2: The marble fell off the table.

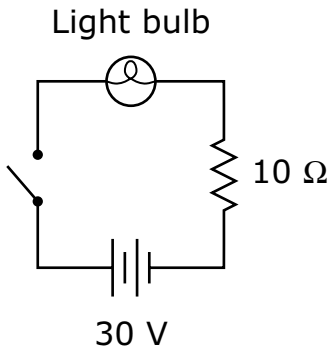
Step 3: The marble landed on a ramp.

Step 4: The marble rolled down the ramp and into a plastic cup.

Step 5: The plastic cup moved downward, which caused a plastic disc to move upward.

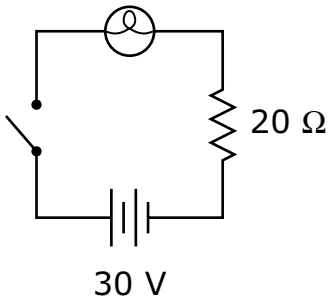
Step 6: The plastic disc collided with a switch in an electric circuit, closing the circuit. The light bulb turned on.

33 The student's machine turned on the light bulb by closing the circuit, but the student wanted the light bulb to be brighter. The original circuit is shown.



Which of the following circuits should the student use so that the light bulb will be brighter than it was in the original circuit?

Ⓐ



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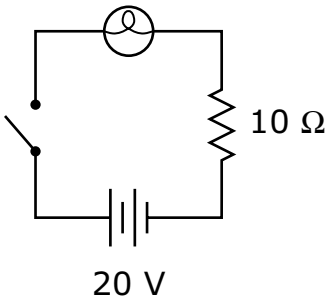

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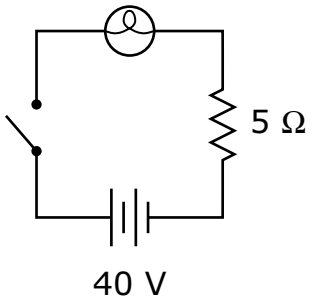
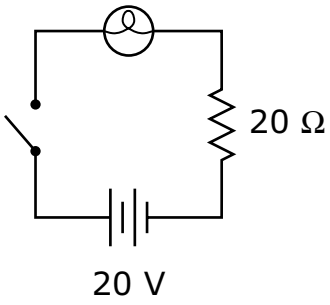


Ⓓ



34 The marble fell 0.25 m between steps 2 and 3. How much work did gravity do on the marble between steps 2 and 3?

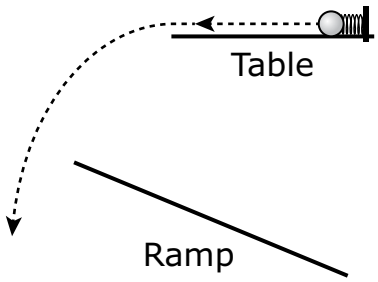
Ⓐ 0.025 J

Ⓑ 0.25 J

Ⓒ 2.5 J

Ⓓ 25 J

35 When the student first tested the machine, it did not turn on the light bulb. The marble was pushed off the table by the spring but went too far and missed the ramp, as shown.



Which of the following changes would result in the marble landing on the ramp?

Ⓐ use a heavier marble

Ⓑ compress the spring more tightly

Ⓒ use a spring that can store more energy

Ⓓ increase the height of the table above the ramp

This question has two parts.

36 The types of energy in the system changed during step 1.

Part A

Before the spring was released during step 1, the marble was at rest and had

Ⓐ kinetic energy.

Ⓑ elastic potential energy.

Ⓒ gravitational potential energy.

Which of the following best describes the energy during step 1 after the spring was released?

Ⓐ Some of the gravitational potential energy stored in the spring was transferred to the marble, giving the marble elastic potential energy.

Ⓑ Some of the gravitational potential energy stored in the spring was transferred to the marble, giving the marble kinetic energy.

Ⓒ Some of the kinetic energy stored in the spring was transferred to the marble, giving the marble gravitational potential energy.

Ⓓ Some of the elastic potential energy stored in the spring was transferred to the marble, giving the marble kinetic energy.

Part B

The energy stored in the spring was 2 J before the spring was released. The spring transferred 1.8 J of energy to the marble.

What was the efficiency of the spring?

Ⓐ 0.2

Ⓑ 0.9

Ⓒ 1.1

Ⓓ 3.6

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

37 Before the marble rolled into the plastic cup, the cup and the plastic disc were at rest.

A. Compare the magnitude of the net force on the cup with the magnitude of the net force on the disc when the cup and the disc were both at rest. Explain your reasoning.

B. Compare the mass of the cup with the mass of the disc when the cup and the disc were both at rest. Explain your reasoning.

C. The marble rolled into the cup.

Describe how the direction of the net force on the cup changed as the marble rolled into the cup. Explain your reasoning.

37

38 The mass, velocity, and kinetic energy for three types of vehicles are shown in the table.

Type of Vehicle	Mass (kg)	Velocity (m/s)	Kinetic Energy (kJ)
truck	1900	16	243.2
car	1200	24	345.6
van	1500	21	330.8

Which of the following best describes the momentum of two of the vehicles?

Ⓐ The car has the least momentum, and the van has the greatest momentum.

Ⓑ The car has the least momentum, and the truck has the greatest momentum.

Ⓒ The truck has the least momentum, and the car has the greatest momentum.

Ⓓ The van has the least momentum, and the truck has the greatest momentum.

39 Which of the following statements describes a difference between an electromagnetic wave and a mechanical wave?

Ⓐ An electromagnetic wave always travels more slowly than a mechanical wave.

Ⓑ An electromagnetic wave is a longitudinal wave, and a mechanical wave is not.

Ⓒ An electromagnetic wave can travel in a vacuum, and a mechanical wave cannot.

Ⓓ An electromagnetic wave always has a lower frequency than a mechanical wave.

40 A student is trying to determine the specific heat of a metal sample. The student heats the sample and then places it in an insulated container with 300 g of 20°C water. The student knows that the specific heat of water is 4.19 J/g • °C.

Select **three** additional measurements the student must make to determine the specific heat of the metal sample.

Ⓐ the mass of the sample

Ⓑ the volume of the water

Ⓒ the volume of the sample

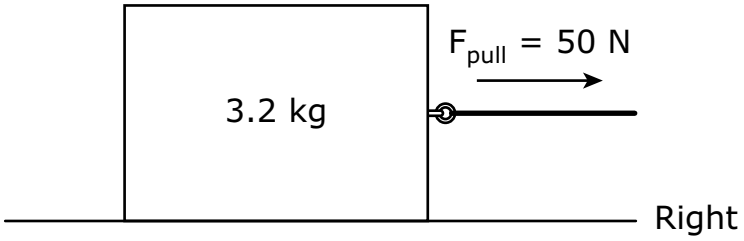
Ⓓ the initial temperature of the sample before it is placed in the insulated container

Ⓔ the amount of time it takes the sample and the water to reach thermal equilibrium

Ⓕ the final temperature of the water after the sample and the water reach thermal equilibrium

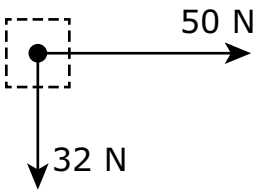
This question has two parts.

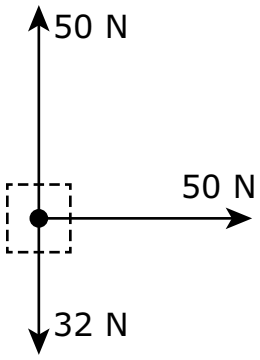
41 A 3.2 kg block is being pulled to the right on a frictionless surface by a force of 50 N, as shown.



Part A

Which free-body force diagram **best** represents the forces acting on the block as it is pulled to the right?

Ⓐ


Ⓑ


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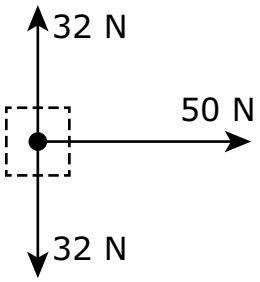

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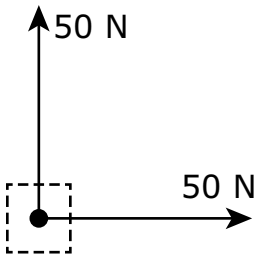


Part B

What is the acceleration of the block?

Ⓐ 1.6 m/s^2

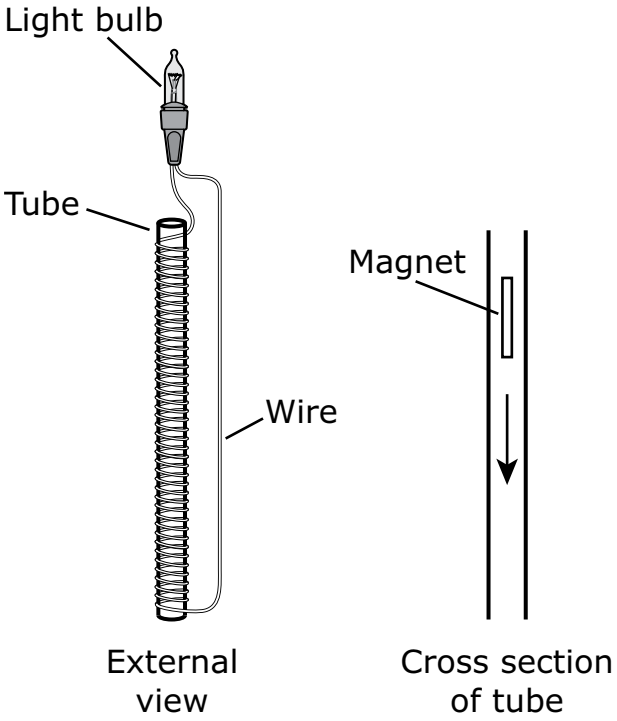
Ⓑ 15.6 m/s^2

Ⓒ 35.6 m/s^2

Ⓓ 160 m/s^2

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

42 In an investigation, a hollow plastic tube is wrapped in copper wire and a light bulb is connected to both ends of the wire. A magnet is then dropped inside the tube. The diagram shows two views of this setup.



When the magnet is falling through the tube, the light bulb turns on.

A. Explain why the light bulb turns on when the magnet is falling through the tube.

B. Describe **two** changes to the investigation that would increase the brightness of the light bulb.

C. Describe how the relationship between electricity and motion in this investigation is different from the relationship between electricity and motion in an electric motor.

42

MASSACHUSETTS Department of Elementary and Secondary Education

Massachusetts Comprehensive Assessment System
Introductory Physics Reference Sheet

Formulas

$s_{average} = \frac{d}{\Delta t}$

$v_{average} = \frac{\Delta x}{\Delta t}$

$a_{average} = \frac{\Delta v}{\Delta t}$

$v_f = v_i + a\Delta t$

$\Delta x = v_i\Delta t + \frac{1}{2}a\Delta t^2$

$p = mv$

$F\Delta t = \Delta p$

$F_{net} = ma$

$F_g = mg$

$F_g = G\frac{m_1 m_2}{d^2}$

$F_e = k\frac{q_1 q_2}{d^2}$

$KE = \frac{1}{2}mv^2$

$\Delta PE = mg\Delta h$

$W = \Delta E = Fd$

$eff = \frac{E_{out}}{E_{in}}$

$Q = mc\Delta T$

$v = \lambda f$

$T = \frac{1}{f}$

$V = IR$

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

coulomb, C

degree Celsius, °C

hertz, Hz

joule, J

kilogram, kg

meter, m

newton, N

ohm, Ω

second, s

volt, V

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 ≈ 10 m/s² at Earth's surface

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

1 J = 1 N • m

High School Introductory Physics
Spring 2023 Released Operational Items

PBT Item No.	Page No.	Reporting Category	Standard	Science Practice Category	Item Type*	Item Description	Correct Answer**
1	3	*Motion, Forces, and Interactions*	HS.PHY.2.2	B. Mathematics and Data	SR	Determine which object has the greatest momentum.	D
2	4	*Motion, Forces, and Interactions*	HS.PHY.2.4	C. Evidence, Reasoning, and Modeling	SR	Compare the forces between pairs of charged particles.	C
3	5	*Motion, Forces, and Interactions*	HS.PHY.2.5	C. Evidence, Reasoning, and Modeling	SR	Explain why a compass needle moves when it is placed near a current-carrying wire.	C
4	6	*Energy*	HS.PHY.3.1	C. Evidence, Reasoning, and Modeling	SR	Interpret a model to identify where a car has the most gravitational potential energy and where the car has the most kinetic energy.	A;D
5	7	*Motion, Forces, and Interactions*	HS.PHY.2.10	C. Evidence, Reasoning, and Modeling	SR	Determine that an object is accelerating upward based on its free-body force diagram.	A
6	8	*Energy*	HS.PHY.3.5	C. Evidence, Reasoning, and Modeling	SR	Describe how a test charge will move when placed next to a charge that is fixed in position, and describe how the distance and forces between the two charges will change.	B;B
7	9	*Motion, Forces, and Interactions*	HS.PHY.2.9	B. Mathematics and Data	SR	Determine the values of resistors in a series circuit.	A
8	9	*Motion, Forces, and Interactions*	HS.PHY.2.10	C. Evidence, Reasoning, and Modeling	SR	Interpret a velocity vs. time graph to determine when a vehicle has the greatest acceleration.	C
9	10	*Motion, Forces, and Interactions*	HS.PHY.2.10	C. Evidence, Reasoning, and Modeling	SR	Describe the velocity and forces acting on an object based on a position vs. time graph.	A;B
10	11	*Energy*	HS.PHY.3.1	B. Mathematics and Data	SR	Determine over which time interval the most work was done on an object.	A
11	12	*Energy*	HS.PHY.3.2	C. Evidence, Reasoning, and Modeling	SR	Interpret a temperature vs. thermal energy added graph to determine when a substance changed from a liquid to a gas.	C
12	15	*Waves*	HS.PHY.4.1	None	SR	Recognize that both mechanical and electromagnetic waves carry energy.	A
13	15	*Waves*	HS.PHY.4.1	None	SR	Recognize that the amount of time it takes a wave to complete one cycle can be found from the frequency of the wave.	B
14	15	*Waves*	HS.PHY.4.1	B. Mathematics and Data	SR	Calculate the wavelength of the light emitted from a laser.	B
15	16–17	*Waves*	HS.PHY.4.3	C. Evidence, Reasoning, and Modeling	SR	Describe how waves diffract as they pass through an opening and then constructively interfere.	A;A;D
16	18	*Waves*	HS.PHY.4.1	B. Mathematics and Data	CR	Calculate the velocity of a wave, interpret a model to compare the wavelengths of the wave in different situations, and explain how the velocity of the wave is changed as a result of the wavelength changing.	

PBT Item No.	Page No.	Reporting Category	Standard	Science Practice Category	Item Type*	Item Description	Correct Answer**
17	20	*Energy*	HS.PHY.1.8	C. Evidence, Reasoning, and Modeling	SR	Interpret models of radioactive decay to determine which models represent alpha decay, beta decay, and gamma decay.	B
18	20	*Motion, Forces, and Interactions*	HS.PHY.2.10	B. Mathematics and Data	SR	Calculate the velocity of a rocket after a certain time period when given the initial velocity and constant acceleration.	B
19	21	*Motion, Forces, and Interactions*	HS.PHY.2.1	C. Evidence, Reasoning, and Modeling	SR	Determine the speed vs. time graph that best matches a given situation.	C
20	22	*Motion, Forces, and Interactions*	HS.PHY.2.4	B. Mathematics and Data	CR	Identify the attractive force between objects, compare the magnitude of the force between different pairs of objects, and determine how the force would change if the mass of one object were reduced.	
21	24	*Energy*	HS.PHY.3.4	B. Mathematics and Data	CR	Determine the direction of heat flow between marbles and water in an investigation, calculate the amount of thermal energy transferred and the specific heat of the marbles, and describe whether changing the number of marbles would affect their specific heat.	
22	27	*Motion, Forces, and Interactions*	HS.PHY.2.3	A. Investigations and Questioning	SR	Determine two variables that must be kept constant while testing how well a device minimizes the collision force on an object.	A,D
23	28	*Motion, Forces, and Interactions*	HS.PHY.2.1	C. Evidence, Reasoning, and Modeling	SR	Describe the velocity of an object based on its free-body force diagram and explain how increasing the applied force should be represented in the object's free-body force diagram.	C;A
24	28	*Energy*	HS.PHY.3.2	B. Mathematics and Data	SR	Calculate the change in gravitational potential energy of a system of two objects.	C
25	29	*Waves*	HS.PHY.4.5	C. Evidence, Reasoning, and Modeling	SR	Recognize that two wave pulses interfere when they overlap and determine the amplitude of the resulting wave pulse.	B;B
26	30	*Motion, Forces, and Interactions*	HS.PHY.2.9	B. Mathematics and Data	SR	Calculate the current through a resistor.	A
27	30	*Energy*	HS.PHY.3.2	B. Mathematics and Data	SR	Calculate the acceleration of an object due to gravity on Mars.	C
28	30	*Motion, Forces, and Interactions*	HS.PHY.2.4	None	SR	Identify a difference between the forces described by Newton's law of gravitation and Coulomb's law.	B
29	31	*Motion, Forces, and Interactions*	HS.PHY.2.2	B. Mathematics and Data	SR	Analyze a collision using momentum conservation and model the velocity of one of the objects before and after the collision.	B

PBT Item No.	Page No.	Reporting Category	Standard	Science Practice Category	Item Type*	Item Description	Correct Answer**
30	32	*Waves*	HS.PHY.4.3	C. Evidence, Reasoning, and Modeling	SR	Determine two pieces of evidence from a model that support the claim that light acts like a wave.	B,C
31	33	*Energy*	HS.PHY.3.5	C. Evidence, Reasoning, and Modeling	SR	Describe how to increase the potential energy between two magnets.	B
32	34	*Motion, Forces, and Interactions*	HS.PHY.2.3	B. Mathematics and Data	SR	Compare the change in momentum and the change in velocity of two objects.	A;C
33	36	*Motion, Forces, and Interactions*	HS.PHY.2.9	C. Evidence, Reasoning, and Modeling	SR	Interpret circuit diagrams to determine the circuit with the brightest light bulb.	C
34	37	*Energy*	HS.PHY.3.1	B. Mathematics and Data	SR	Calculate the amount of work gravity did on an object.	B
35	37	*Energy*	HS.PHY.3.3	C. Evidence, Reasoning, and Modeling	SR	Describe how a setup can be changed to reduce how far an object rolls off a table.	A
36	38	*Energy*	HS.PHY.3.3	B. Mathematics and Data	SR	Describe how energy changes in a system and determine the efficiency of part of the system.	C,D;B
37	39	*Motion, Forces, and Interactions*	HS.PHY.2.1	C. Evidence, Reasoning, and Modeling	CR	Analyze a model of two objects that are at rest and connected by a pulley to compare the net force on and mass of each object, and describe how mass being added to an object would affect the direction of the net force on the object.	
38	41	*Motion, Forces, and Interactions*	HS.PHY.2.2	B. Mathematics and Data	SR	Compare the momentum of vehicles with different masses and velocities.	A
39	41	*Waves*	HS.PHY.4.1	None	SR	Describe a difference between an electromagnetic wave and a mechanical wave.	C
40	42	*Energy*	HS.PHY.3.4	A. Investigations and Questioning	SR	Determine which measurements a student must make to calculate the specific heat of a metal sample.	A,D,F
41	43	*Motion, Forces, and Interactions*	HS.PHY.2.10	C. Evidence, Reasoning, and Modeling	SR	Determine which free-body force diagram represents the forces on an object and calculate the acceleration of the object.	C;B
42	44	*Motion, Forces, and Interactions*	HS.PHY.2.5	None	CR	Explain why a light bulb turns on in a given setup, describe two changes to the setup that would increase the brightness of the bulb, and describe how the relationship between electricity and motion in the setup is different than in an electric motor.	

* Science and Technology/Engineering 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.