XX. Introductory Physics, High School

High School Introductory Physics Test

The spring 2018 high school Introductory Physics test was based on learning standards in the Introductory Physics content strand of the October 2006 version of the *Massachusetts Science and Technology/Engineering Curriculum Framework*. These learning standards appear in the 2006 framework, which is available on the Department website at www.doe.mass.edu/frameworks/archive.html. Massachusetts adopted a new curriculum framework in science and technology/engineering in 2016. A plan for transitioning the MCAS assessments to the new framework is available at www.doe.mass.edu/mcas/tdd/sci.html?section=transition.

Introductory Physics test results are reported under the following four MCAS reporting categories:

- Motion and Forces
- Heat and Heat Transfer
- Waves and Radiation
- Electromagnetism

The table at the conclusion of this chapter indicates each item's reporting category and the framework learning standard it assesses. The correct answers for multiple-choice questions are also displayed in the table.

Test Sessions

The high school Introductory Physics test included two separate test sessions, which were administered on consecutive days. Each session included multiple-choice and open-response questions.

Reference Materials and Tools

Each student taking the high school Introductory Physics test was provided with an Introductory Physics Formula Sheet. A copy of this formula sheet follows the final question in this chapter.

Each student also had sole access to a calculator with at least four functions and a square-root key.

During both Introductory Physics test sessions, the use of bilingual word-to-word dictionaries was allowed for current and former English learner students only. No other reference tools or materials were allowed.

Introductory Physics
Session 1

DIRECTIONS

This session contains twenty-one multiple-choice questions and two open-response questions. Mark your answers to these questions in the spaces provided in your Student Answer Booklet. You may work out solutions to multiple-choice questions in the test booklet.

1 How much voltage is needed to produce a current of 6.0 A through a 24 Ω resistor?

A. 4 V

B. 18 V

C. 30 V

D. 144 V

2 The Sun produces visible light with different wavelengths. As wavelengths become longer, which of the following properties of the waves **decreases**?

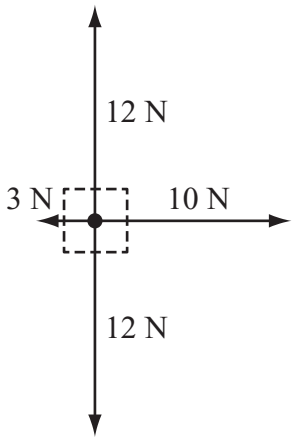
A. amplitude

B. frequency

C. period

D. speed

3 A student pushes a 12 N book to the right with a force of 10 N. The book experiences a frictional force of 3 N. The free-body force diagram below represents the forces acting on the book.



What is the magnitude of the net force acting on the book?

A. 7 N

B. 11 N

C. 13 N

D. 37 N

4 Which of the following describes the molecules in a sample of water as the temperature of the water changes from 20°C to 30°C?

A. The molecules speed up and their average kinetic energy increases.
B. The molecules slow down and their average kinetic energy decreases.
C. The molecules speed up and their average kinetic energy stays the same.
D. The molecules slow down and their average kinetic energy stays the same.

5 A short copper rod has a neutral charge. Negative charges are then applied to the right end of the rod.

Which of the following describes the charge on the copper rod 5 s later?

A. Both ends of the rod have a positive charge.
B. The negative charge is spread evenly along the rod.
C. Only the right end of the rod has a negative charge.
D. All of the positive charge is in the middle of the rod.

6 Which of the following is the best example of simple harmonic motion?

A. A cart accelerates on a track.
B. A ball collides with another ball.
C. A block moves up and down on a spring.
D. A piece of fruit falls from a tree to the ground.

7 A student and a teacher each lift a book from the floor and place it on the same shelf. The book lifted by the student has a greater mass than the book lifted by the teacher. The teacher takes less time to lift a book than the student does.

Which of the following compares the work performed by the student and the teacher?

A. The student did more work than the teacher because the student lifted a heavier book.
B. The teacher did more work than the student because the teacher lifted a book in less time.
C. The student and the teacher did the same amount of work because they each moved a book the same distance.
D. The student and the teacher did the same amount of work because they each lifted the same number of books.

8 A student is watching a thunderstorm. The student sees lightning before hearing thunder.

Which of the following **best** explains why the student sees the lightning before hearing the thunder?

A. Mechanical waves can travel in a vacuum, allowing the light waves to reach the student before the sound waves.

B. Electromagnetic waves can travel in a vacuum, allowing the light waves to reach the student before the sound waves.

C. Electromagnetic waves can travel faster than mechanical waves, allowing the light waves to reach the student before the sound waves.

D. Mechanical waves can travel faster than electromagnetic waves, allowing the light waves to reach the student before the sound waves.

9 A 0.2 kg block sliding on a horizontal table slows down from 25 m/s to 20 m/s. How much energy does the block lose due to friction?

A. 22.5 J

B. 25.0 J

C. 40.0 J

D. 62.5 J

10 Which of the following do **all** electromagnetic waves have in common?

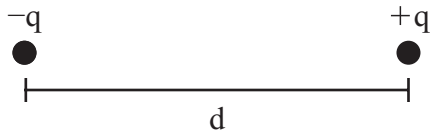
A. All electromagnetic waves travel toward Earth.

B. All electromagnetic waves are transverse waves.

C. All electromagnetic waves have the same frequency.

D. All electromagnetic waves have the same amplitude.

11 The diagram below shows two electric charges, $-q$ and $+q$, separated by a distance, d.



What happens to the electric force between the charges if the magnitude of each charge is doubled?

A. It becomes 16 times less.

B. It becomes 2 times less.

C. It becomes 4 times greater.

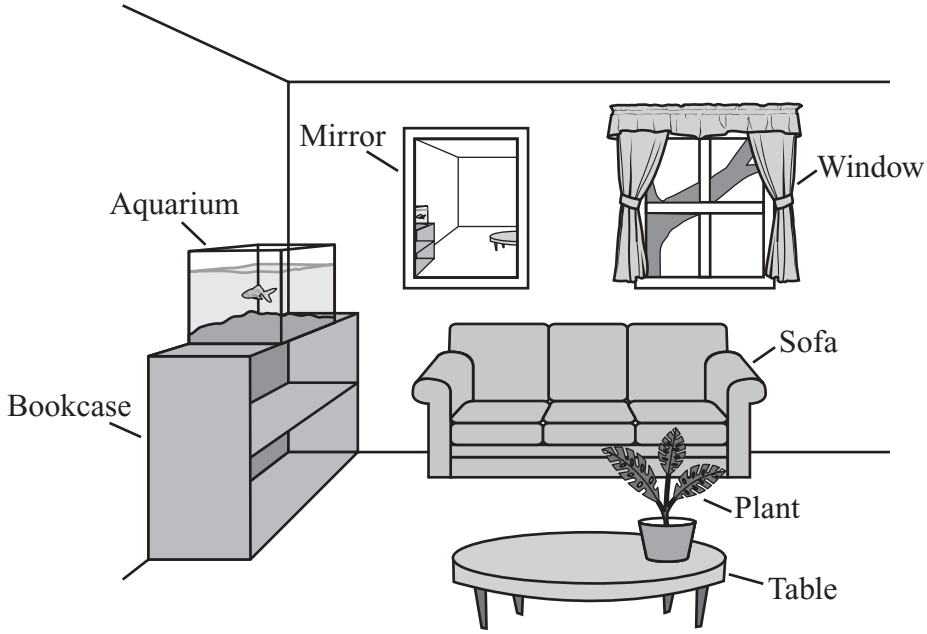
D. It becomes 8 times greater.

Question 12 is an open-response question.

- **BE SURE TO ANSWER AND LABEL ALL PARTS OF THE QUESTION.**
- **Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.**
- **If you do the work in your head, explain in writing how you did the work.**

Write your answer to question 12 in the space provided in your Student Answer Booklet.

12 The illustration below shows a living room.



a. Describe one example of light being reflected in the living room.

b. In your Student Answer Booklet, draw a reflected light ray. Label each of the following:

- incident ray
- incident angle
- normal line
- reflected ray
- reflected angle

c. Describe one example of light being refracted in the living room.

d. Describe what happens when light is refracted.

Mark your answers to multiple-choice questions 13 through 22 in the spaces provided in your Student Answer Booklet. Do not write your answers in this test booklet, but you may work out solutions to multiple-choice questions in the test booklet.

13 Iron filings are placed near a coil of copper wire. Which of the following will most likely cause the iron filings to move?

A. heating the copper wire until it emits light

B. making smaller turns in the copper wire coil

C. sending an electric current through the copper wire

D. increasing the number of turns in the copper wire coil

14 Three rocks with masses of 1 kg, 5 kg, and 10 kg fall from the same height. Which of the following describes the inertia of these rocks?

A. None of the rocks have inertia.

B. All the rocks have the same inertia.

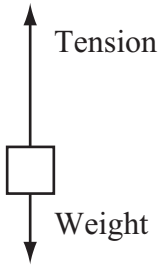
C. The 1 kg rock has more inertia than the other two rocks.

D. The 10 kg rock has more inertia than the other two rocks.

15 A student ties a string to a box. The student pulls on the string to accelerate the box upward.

Which of the following force diagrams illustrates the forces acting on the box?

A.



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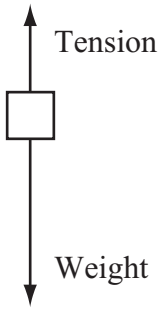
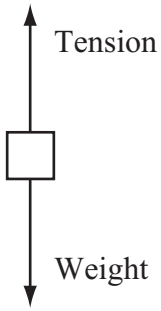
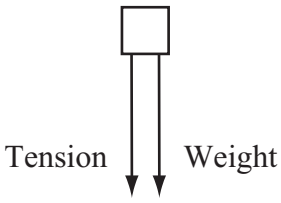


C.



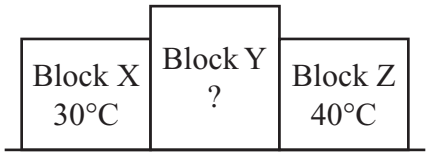
D.



16 A simple circuit is made using a battery, a light bulb, and some wire. Based on Ohm's law, which of the following should always **decrease** the brightness of the light bulb?

A. using less wire in the circuit
B. adding a second bulb in series
C. adding a second bulb in parallel
D. using a battery with a greater voltage

17 Three blocks are placed in contact, as shown in the diagram below. Block X is initially 30°C, and block Z is initially 40°C.



Heat energy flows from block Y to both blocks X and Z. Which of the following is a possible initial temperature of block Y?

A. 20°C
B. 30°C
C. 40°C
D. 50°C

18 A car moves at a constant velocity for 4 s. A student records data on the car's motion, as shown in the table below, but the student forgets to label the second column of the table.

Time (s)	**?**
1	30
2	60
3	90
4	120

Which of the following is the missing label?

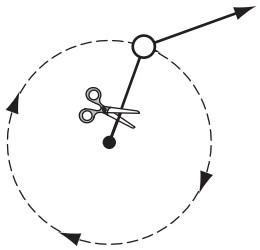
A. **Acceleration (m/s^2)**
B. **Distance (m)**
C. **Force (N)**
D. **Speed (m/s)**

19 What determines the momentum of an object?

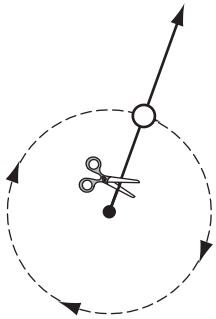
A. mass only
B. velocity only
C. the sum of mass and velocity
D. the product of mass and velocity

20 A student swings a ball on a string in a circular motion and then cuts the string. Which of the following diagrams shows the direction the ball will initially move when the string is cut?

A.



B.



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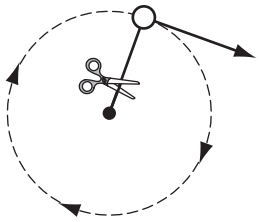
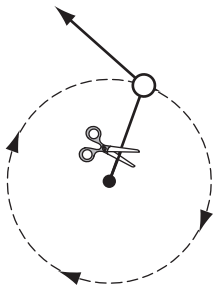
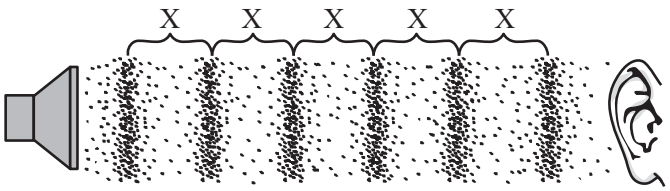


D.



21 The diagram below shows a sound wave being produced by a speaker and the density of air molecules as the sound wave travels to a listener's ear. Each section labeled with an X shows an interval between dense regions of the air molecules.



What wave property does X represent?

A. amplitude
B. frequency
C. velocity
D. wavelength

22 Which of the following is the **best** example of heat transfer by radiation?

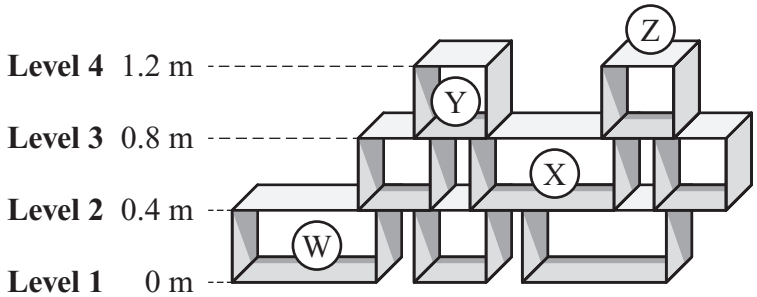
A. Steam rises from a cup of coffee.
B. Light from the Sun travels to Earth.
C. An electric heater blows warm air throughout a room.
D. The metal handle of a pan on an electric stove heats up.

Question 23 is an open-response question.

- **BE SURE TO ANSWER AND LABEL ALL PARTS OF THE QUESTION.**
- **Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.**
- **If you do the work in your head, explain in writing how you did the work.**

Write your answer to question 23 in the space provided in your Student Answer Booklet.

23 The figure below shows a shelving system with four levels. The height of each level is shown in the diagram, and four locations are labeled W, X, Y, and Z.



A person places an object on the shelves.

a. At which location on the shelves (W, X, Y, or Z) would the object have the **most** gravitational potential energy? Explain your answer.

A book with a mass of 0.21 kg is placed at location X. A magazine with a mass of 0.11 kg is placed at location Y.

b. Does the book or the magazine have more potential energy? Show your calculations and include units in your answer.

A 2.5 kg object is placed at location X where it has 10 J of potential energy. A person bumps the shelf, causing the object to fall to the ground.

c. Assuming air resistance is negligible, explain how conservation of energy is demonstrated as the object falls to the ground.

d. Calculate the speed of the 2.5 kg object just before it hits the ground. Show your calculations and include units in your answer.

Introductory Physics
Session 2

DIRECTIONS

This session contains nineteen multiple-choice questions and three open-response questions. Mark your answers to these questions in the spaces provided in your Student Answer Booklet. You may work out solutions to multiple-choice questions in the test booklet.

24 Two students move a box to the left. One student pushes with a force of 100 N to the left, and the other student pulls with a force of 85 N to the left. They move the box 20 m in 7 s.

What is the total amount of work done on the box by the students?

A. 300 J

B. 530 J

C. 3,700 J

D. 26,000 J

25 An acorn fell 5 m from a tree to the ground. What additional information is needed to calculate both the gravitational potential energy of the acorn before it fell and the kinetic energy of the acorn just before it hit the ground?

A. the volume of the acorn and the time the acorn was in the air

B. the mass of the acorn and the amount of energy lost to air resistance

C. the average acceleration of the acorn and the time the acorn was in the air

D. the average velocity of the acorn and the amount of energy lost to friction

26 A series circuit has a battery, a resistor, and a light bulb with a power rating of 3.0 W. If the current in the circuit is 0.90 A over a period of 20 s, what is the voltage across the light bulb?

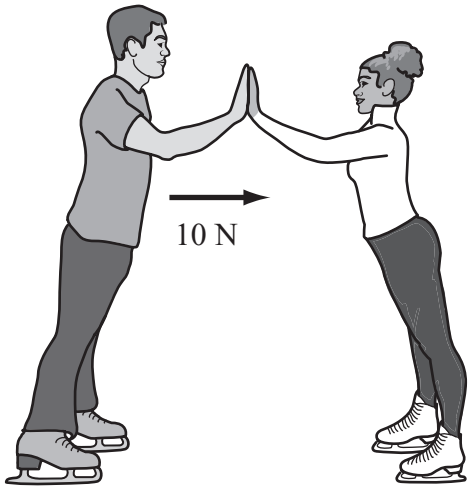
A. 0.015 V

B. 0.17 V

C. 0.30 V

D. 3.3 V

27 The diagram below shows an 80 kg ice skater applying a force of 10 N to a 60 kg ice skater.



Which statement best describes the results of applying the 10 N force?

A. The skaters will not move at all.

B. The skaters will accelerate away from each other at the same rate.

C. The skaters will accelerate away from each other, but the 60 kg skater will accelerate at a faster rate.

D. The 60 kg skater will accelerate away from the 80 kg skater, and the 80 kg skater will remain stationary.

28 An object is moving west at 30 km/h and another object is moving north at 30 km/h.

Which of the following statements describes the motion of both objects?

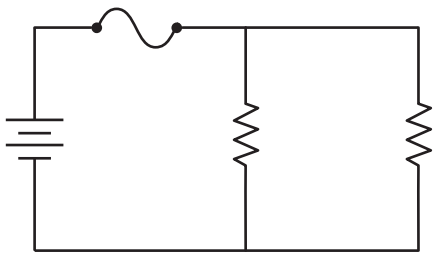
A. They have the same velocity and the same speed.

B. They have the same velocity but different speeds.

C. They have different velocities but the same speed.

D. They have different velocities and different speeds.

29 The diagram below shows an electrical circuit.



What is the primary function of the fuse in the circuit?

A. to prevent too much current from flowing through the circuit

B. to supply a greater potential difference across the entire circuit

C. to regulate the potential difference that is applied to the two resistors

D. to increase the amount of current that is passing through the two resistors

30 Radio stations use radio waves to transmit electromagnetic signals. Which of the following **best** compares radio waves to other waves on the electromagnetic spectrum?

A. Radio waves have the highest frequency of all electromagnetic waves.

B. Radio waves have the longest wavelength of all electromagnetic waves.

C. The frequency of radio waves is close to the frequency of ultraviolet radiation.

D. The wavelength of radio waves is close to the wavelength of visible light waves.

31 A student wants to determine the gravitational attraction between two objects. Which two quantities does the student need to know?

A. the mass and the charge of each object

B. the volume and the charge of each object

C. the mass of each object and the distance between the two objects

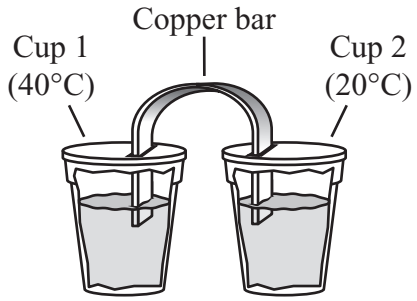
D. the volume of each object and the distance between the two objects

Question 32 is an open-response question.

- **BE SURE TO ANSWER AND LABEL ALL PARTS OF THE QUESTION.**
- **Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.**
- **If you do the work in your head, explain in writing how you did the work.**

Write your answer to question 32 in the space provided in your Student Answer Booklet.

32 A student is investigating heat transfer. The student places the ends of a curved copper bar into two insulated cups, as shown below. The copper bar is at 20°C. Cup 1 contains 40°C water and cup 2 contains 20°C water. Each cup contains the same amount of water.



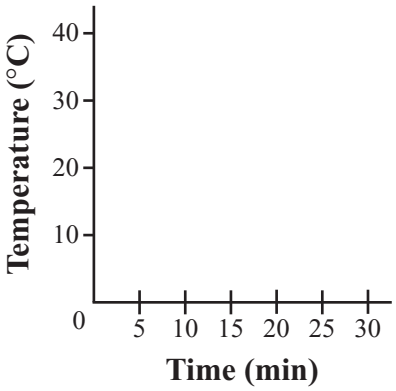
a. Describe the direction of heat flow between the cups of water in the first few minutes of the investigation.

b. Identify the **primary** method of heat transfer (conduction, convection, radiation) between the cups of water. Describe how the transfer of heat occurred for the method you identified.

c. After 25 minutes, the water in both cups reaches thermal equilibrium. Explain how the student can determine that thermal equilibrium has been reached between the cups.

d. On the grid in your Student Answer Booklet, copy the title, axes, and labels of the graph, as shown below. Draw **two** curves, one to represent the temperature of the water in cup 1 and the other to represent the temperature of the water in cup 2, over a 30-minute period. Assume no heat is lost to the surroundings.

Temperatures of Water in Cups 1 and 2



Mark your answers to multiple-choice questions 33 through 43 in the spaces provided in your Student Answer Booklet. Do not write your answers in this test booklet, but you may work out solutions to multiple-choice questions in the test booklet.

33 When astronauts speak to each other in space while outside their spaceship, they use radio headsets that rely on electromagnetic waves. Which of the following best explains why radio headsets are used by astronauts to speak with each other in space?

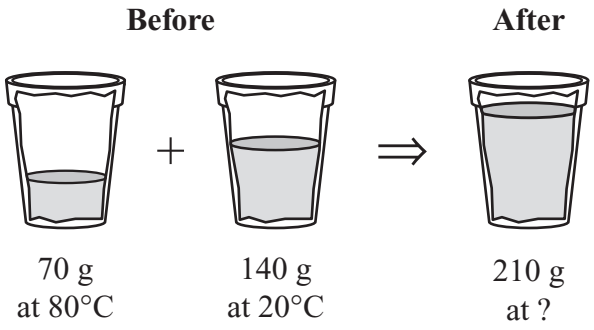
A. Electromagnetic waves can travel in a vacuum.

B. Electromagnetic waves are difficult to distort.

C. Electromagnetic waves travel quickly through air.

D. Electromagnetic waves require little energy to generate.

34 A student mixes 70 g of water at 80°C and 140 g of water at 20°C in an insulated cup, as shown in the diagram below.



What is the expected temperature of the water in the cup after 1 min?

A. 20°C

B. 40°C

C. 70°C

D. 80°C

35 Two students run up a flight of stairs. Student X's mass is the same as student Y's mass. Student X takes more time than student Y to run up the stairs.

Which of the following statements describes the power used and work done by the students to run up the stairs?

A. Both students use the same power, but student X does less work than student Y.

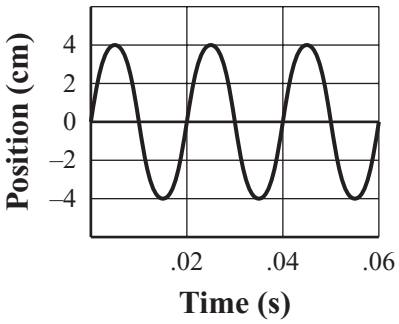
B. Both students use the same power, but student X does more work than student Y.

C. Student X uses less power than student Y, but both students do the same amount of work.

D. Student X uses more power than student Y, but both students do the same amount of work.

36 Which graph shows a wave with a frequency of 50 Hz and an amplitude of 4 cm?

A.



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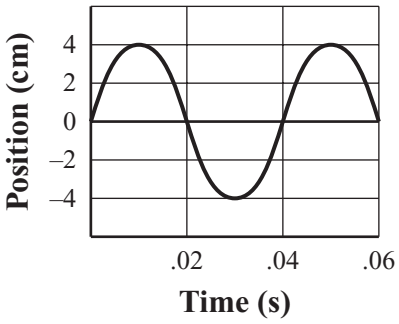

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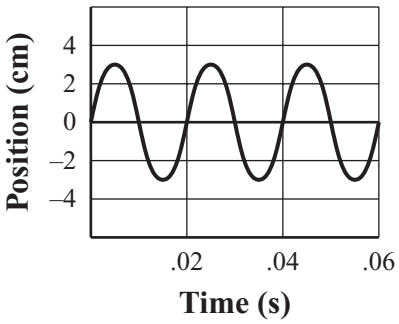
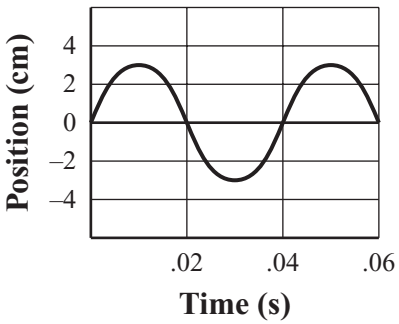


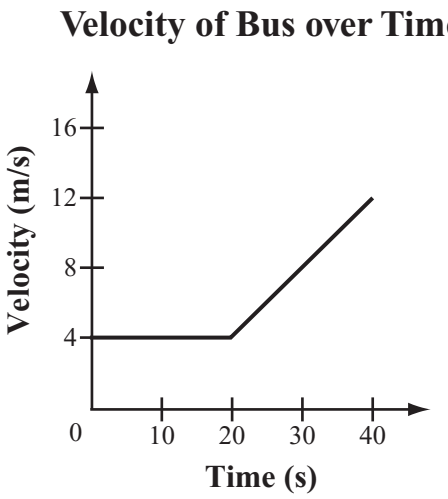
D.



37 Which of the following is an example of a longitudinal wave?

A. an infrared wave
B. a light wave
C. a microwave
D. a sound wave

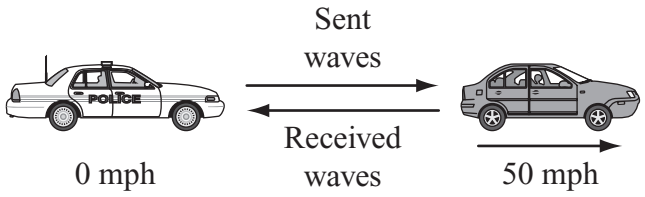
38 The velocity of a bus is represented in the graph below.



Which of the following best describes how the bus moves over time?

A. The bus stays in one place for 20 s and then travels at a constant speed.
B. The bus travels at a constant speed for 20 s and then accelerates at a constant rate.
C. The bus accelerates at a constant rate for 20 s and then travels at a constant speed.
D. The bus accelerates at a constant rate for 20 s and then accelerates at an increasing rate.

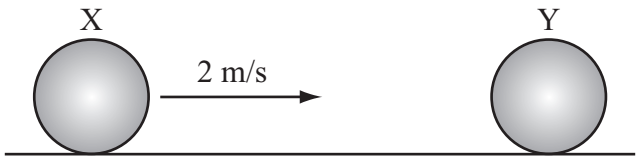
39 Police use radar devices that apply the Doppler effect to determine the speed of a car. The diagram below shows electromagnetic waves sent from a police car and the reflected waves received by the police car.



The police car is not moving and the other car is moving away from the police car. Which of the following best compares the waves sent and received by the police car?

A. The received waves have a lower frequency and a longer wavelength.
B. The received waves have a lower frequency and a shorter wavelength.
C. The received waves have a higher frequency and a longer wavelength.
D. The received waves have a higher frequency and a shorter wavelength.

40 The diagram below shows two balls of equal mass. Ball X is moving toward ball Y at 2 m/s. Ball Y is at rest.



When ball X collides with ball Y, ball X stops moving. Which of the following best describes the motion of ball Y **after** the collision?

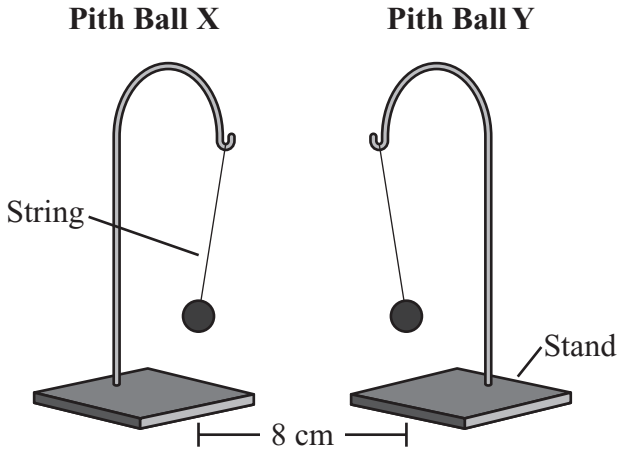
A. It will remain at rest.

B. It will move to the right at 0.5 m/s.

C. It will move to the right at 2 m/s.

D. It will move to the right at 4 m/s.

41 Pith ball stands may be used to demonstrate static electricity. Pith balls can hold charges while hanging from a string. The diagram below shows two pith ball stands.



The charge on pith ball X is 2q, and the charge on pith ball Y is 3q. The pith balls are separated by a distance of 8 cm.

What happens to the force between the pith balls when the charge of pith ball Y is changed from 3q to q?

A. The force decreases to about one-ninth of what it was.

B. The force decreases to about one-third of what it was.

C. The force increases to about three times what it was.

D. The force increases to about nine times what it was.

42 Which of the following **always** occurs when an object at 60°C remains in contact with another object at 10°C in a closed system?

A. Heat flows from the 60°C object to the 10°C object until both objects reach 50°C.

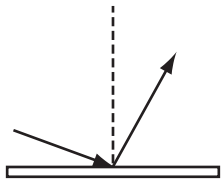
B. Cold flows from the 10°C object to the 60°C object until both objects reach 50°C.

C. Heat flows from the 60°C object to the 10°C object until both objects reach the same temperature.

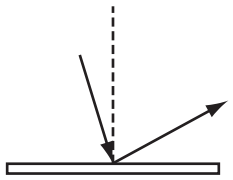
D. Cold flows from the 10°C object to the 60°C object until both objects reach the same temperature.

43 Which of the following diagrams shows how a light ray can reflect off a mirror?

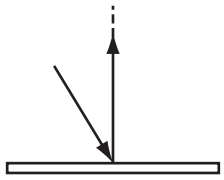
A.



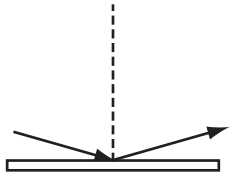
B.



C.



D.

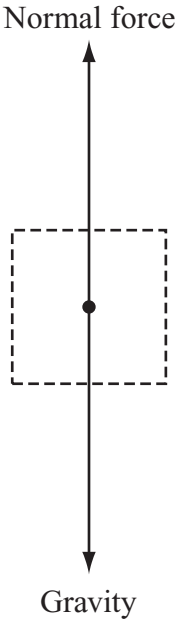


Questions 44 and 45 are open-response questions.

- **BE SURE TO ANSWER AND LABEL ALL PARTS OF EACH QUESTION.**
- **Show all your work (diagrams, tables, or computations) in your Student Answer Booklet.**
- **If you do the work in your head, explain in writing how you did the work.**

Write your answer to question 44 in the space provided in your Student Answer Booklet.

44 A free-body force diagram for a heavy wooden bookcase at rest in a classroom is below.



Two students push the bookcase across the floor of the classroom.

a. Compare the amount of force needed to start the bookcase moving to the amount of force needed to keep it moving at a constant speed.

b. On the grid in your Student Answer Booklet, copy the free-body force diagram. Add to your diagram the horizontal forces acting on the bookcase when it is pushed at a constant speed. Include labels and use the grid squares to represent the relative magnitude of **each** force acting on the bookcase.

c. Identify one change to the bookcase or the floor that would affect the amount of force required to move the bookcase.

d. Explain how the change you identified in part (c) affects the amount of force required to start the bookcase moving or to keep it moving.

Write your answer to question 45 in the space provided in your Student Answer Booklet.

45 A student connects a small solar panel to a 40 Ω resistor to make a simple circuit. The solar panel produces a voltage of 2 V.

a. Identify a different circuit component that could serve the same purpose as the solar panel in this circuit.

b. Calculate the current in the student's circuit. Show your calculations and include units in your answer.

c. Calculate the power produced by the student's circuit. Show your calculations and include units in your answer.

d. Describe one way the student can modify the circuit to increase the current through the resistor.

MASSACHUSETTS DEPARTMENT OF ELEMENTARY AND SECONDARY EDUCATION

Massachusetts Comprehensive Assessment System

Introductory Physics Formula Sheet

Formulas

Average Speed $= \frac{d}{\Delta t}$

Average Acceleration $= \frac{\Delta v}{\Delta t}$

Average Velocity $= \frac{\Delta x}{\Delta t}$

$v_f = v_i + a\Delta t$

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

$v_f^2 = v_i^2 + 2a\Delta x$

Average Velocity $= \frac{v_i + v_f}{2}$

$F = ma$

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

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

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

$PE = mg\Delta h$

$W = Fd$

$P = \frac{W}{\Delta t}$

$p = mv$

$V = IR$

$P = IV$

$Q = mc\Delta T$

$v = f\lambda$

$\lambda = \frac{c}{f}$

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

Variables

a = acceleration
c = specific heat
d = distance
f = frequency
F = force
Δh = change in height
I = current
KE = kinetic energy
λ = wavelength
m = mass
p = momentum
P = power
PE = gravitational potential energy
q = charge of particle
Q = heat
R = resistance
Δt = change in time
ΔT = change in temperature
T = period
v = velocity
v_i = initial velocity
v_f = final velocity
Δv = change in velocity
V = voltage
W = work
Δx = displacement

Definitions

c = speed of electromagnetic waves $= 3.00 \times 10^8$ m/s

G = Universal gravitational constant $= 6.67 \times 10^{-11} \frac{N \cdot m^2}{kg^2}$

k = Coulomb constant $= 8.99 \times 10^9 \frac{N \cdot m^2}{C^2}$

$g \approx 10\ m/s^2$ $\quad 1\ N = 1\frac{kg \cdot m}{s^2}$ $\quad 1\ J = 1\ N \cdot m$ $\quad 1\ W\ (watt) = 1\frac{J}{s}$