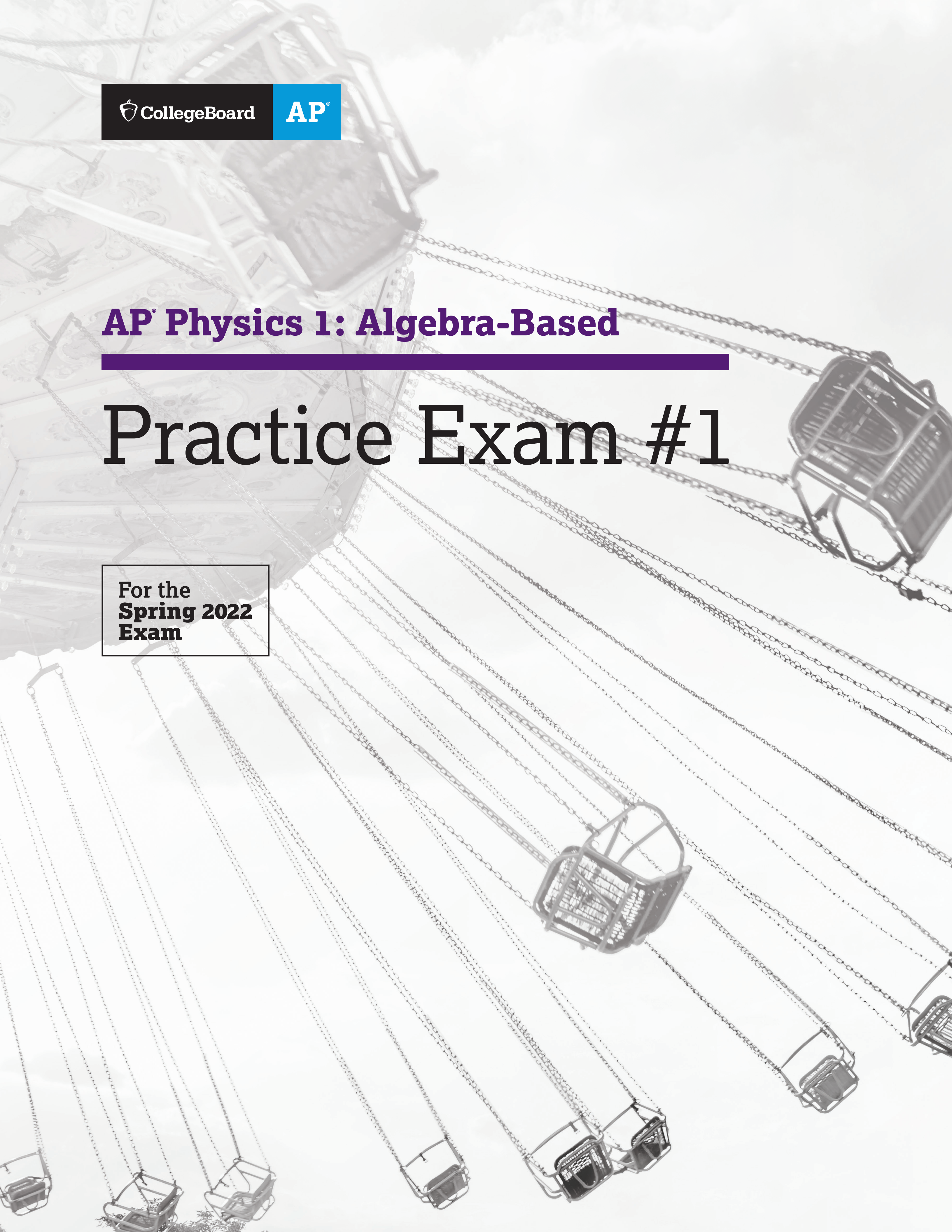


CollegeBoard AP

AP® Physics 1: Algebra-Based

Practice Exam #1

For the
Spring 2022
Exam

Please note: Some multiple-choice and free-response questions previously included in this practice exam have been removed because the content of the questions is no longer within the scope of the AP Physics 1 course. Additional questions have been added to create a practice exam that has the appropriate number of items in each section. Because this is a practice exam and has not been administered, the scoring worksheet found on p 130 provides only approximate AP Exam scores. Student performance on this practice exam does not necessarily predict performance on a different exam.

Additional information about the AP Physics 1 Course and Exam can be found here:

https://apcentral.collegeboard.org/courses/ap-physics-1

This exam may not be posted on school or personal websites, nor electronically redistributed for any reason. This exam is provided by College Board for AP Exam preparation. Teachers are permitted to download the materials and make copies to use with their students in a classroom setting only. To maintain the security of this exam, teachers should collect all materials after their administration and keep them in a secure location.

Further distribution of these materials outside of the secure College Board site disadvantages teachers who rely on uncirculated questions for classroom testing. Any additional distribution is in violation of College Board's copyright policies and may result in the termination of Practice Exam access for your school as well as the removal of access to other online services such as the AP Teacher Community and Online Score Reports.

Contents

Note: This publication shows the page numbers that appeared in the ***2020–21 AP Exam Instructions*** book and in the actual exam. This publication was not repaginated to begin with page 1.

AP Coordinators and Proctors:

Update: Managing the Exam Break

In the *2020-21 AP Exam Instructions*, you'll see information about the standard 10-minute break between Sections I and II of the paper-and-pencil AP Exams.

This year, local health and safety guidelines may require that only a limited number of students may access the restroom or hallways at the same time. In such cases, you may elect to double the time of the scheduled breaks (including accommodated breaks) to ensure that students can access the restroom or hallway in an orderly fashion.

As per standard AP policy, the break must be monitored. Please note that the decision to lengthen the break is optional, does not need to be applied to every testing room uniformly, and is not required to administer AP Exams. If your school chooses to provide a longer break, you're not required to use all the additional time.

AP Physics 1: Algebra-Based Exam

Administration 1 Exam Date: Wednesday afternoon, May 5, 2021

Administration 2 Exam Date: Monday afternoon, May 24, 2021

AP Physics 2: Algebra-Based Exam

Administration 1 Exam Date: Friday afternoon, May 7, 2021

Administration 2 Exam Date: Tuesday afternoon, May 25, 2021

Section I	**Total Time:** 1 hour and 30 minutes Calculator allowed **Number of Questions:** 50 **Percent of Total Score:** 50% **Writing Instrument:** Pencil required
Section II	**Total Time:** 1 hour and 30 minutes Calculator allowed **Number of Questions Physics 1:** 5 **Number of Questions Physics 2:** 4 **Percent of Total Score:** 50% **Writing Instrument:** Pen with black or dark blue ink, or pencil

What Proctors Need to Bring to This Exam

- ☐ Exam packets
- ☐ Answer sheets
- ☐ The personalized AP ID label sheet for each student taking the exam
- ☐ **Part 2** of the *2020-21 AP Coordinator's Manual*
- ☐ This book—*2020-21 AP Exam Instructions*
- ☐ AP Exam Seating Chart template
- ☐ Extra calculators
- ☐ Extra rulers or straightedges
- ☐ Pencil sharpener
- ☐ Container for students' electronic devices (if needed)
- ☐ Extra No. 2 pencils with erasers
- ☐ Extra pens with black or dark blue ink
- ☐ Unlined paper
- ☐ Stapler
- ☐ Watch
- ☐ Signs for the door to the testing room
  - "Exam in Progress"
  - "Phones of any kind are prohibited during the exam administration, including breaks"

NOTE: A four-function, scientific, or graphing calculator may be used on all sections of the AP Physics 1: Algebra-Based and Physics 2: Algebra-Based Exams. See “Calculator Policy” in **Part 2** of the *2020-21 AP Coordinator’s Manual* for details about the calculator policy.

Before Distributing Exams: Check that the title on all exam covers is ***Physics 1: Algebra-Based*** or ***Physics 2: Algebra-Based***. If there are any exam booklets with a different title, contact the AP coordinator immediately.

Calculator Use

Students are permitted to use rulers, straightedges, and four-function, scientific, or graphing calculators for these entire exams (Sections I and II). Before starting the exam administration, make sure each student has an appropriate calculator, and any student with a graphing calculator has a model from the approved list on the “AP-Approved Graphing Calculators” table in **Part 2** of the *2020-21 AP Coordinator’s Manual*. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, they must hand copy, date, and sign the “Calculator Release Statement” in **Part 2** of the *2020-21 AP Coordinator’s Manual*.

Students may have **no more than two** calculators on their desks. Calculators may not be shared. Calculator memories do not need to be cleared before or after the exam. Students with Hewlett-Packard 48–50 Series and Casio FX-9860 graphing calculators may use cards designed for use with these calculators. Proctors should make sure infrared ports (Hewlett-Packard) are not facing each other. **Since graphing calculators can be used to store data, including text, proctors should monitor that students are using their calculators appropriately. Attempts by students to use the calculator to remove exam questions and/or answers from the room may result in the cancellation of AP Exam scores.**

Tables containing equations commonly used in physics are included in the Section I Multiple Choice booklet and the Section II orange Reference booklet. The equation tables are provided for use during the entire exam. Students are **not** allowed to bring their own copies of the equation tables to the exam room.

SECTION I: Multiple Choice

Before starting the exam administration, make sure each student has an appropriate calculator for the exam. See details in the section above.

› **Do not begin the exam instructions below until you have completed the General Instructions.**

Make sure you administer the correct exam on the scheduled date and begin the exam at the designated time. Remember, you must complete a seating chart for this exam. See pages 273–274 for a seating chart template and instructions. See “Seating Policy” in **Part 2** of the *2020-21 AP Coordinator’s Manual* for exam seating requirements.

Physics 1: Algebra-Based

If you are giving the exam during Administration 1, say:

> **It is Wednesday afternoon, May 5, and you will be taking the AP Physics 1: Algebra-Based Exam. Look at your exam packet and confirm that the exam title is "AP Physics 1: Algebra-Based." Raise your hand if your exam packet contains any other exam title and I will help you.**

If you are giving the exam during Administration 2, say:

> **It is Monday afternoon, May 24, and you will be taking the AP Physics 1: Algebra-Based Exam. Look at your exam packet and confirm that the exam title is "AP Physics 1: Algebra-Based." Raise your hand if your exam packet contains any other exam title and I will help you.**

Physics 2: Algebra-Based

If you are giving the exam during Administration 1, say:

> **It is Friday afternoon, May 7, and you will be taking the AP Physics 2: Algebra-Based Exam. Look at your exam packet and confirm that the exam title is "AP Physics 2: Algebra-Based." Raise your hand if your exam packet contains any other exam title and I will help you.**

If you are giving the exam during Administration 2, say:

> **It is Tuesday afternoon, May 25, and you will be taking the AP Physics 2: Algebra-Based Exam. Look at your exam packet and confirm that the exam title is "AP Physics 2: Algebra-Based." Raise your hand if your exam packet contains any other exam title and I will help you.**

Once you confirm that all students have the correct exam, say:

> **In a moment, you will open the exam packet. By opening this packet, you agree to all of the AP Program's policies and procedures referenced in the AP Exam Terms and Conditions.**
>
> **You may now remove the shrinkwrap from the outside only of your exam packet. Do not open the Section I booklet; do not remove the shrinkwrap from the Section II booklets. Put the white seals and the shrinkwrapped Section II booklet booklets aside. . . .**
>
> **Carefully remove the AP Exam label found near the top left of your exam booklet cover. Place it on the front of your answer sheet on the light blue box near the bottom that reads "AP Exam Label.". . .**

If students accidentally place the exam label in the space for the AP ID label or vice versa, advise them to leave the labels in place. They should not try to remove the label; their exam can still be processed correctly.

> **Now turn over your answer sheet to the side marked page 2 and look at Item I at the top of the page. Print the name of this exam, the exam form, and the form code.**
>
> **The exam form and the form code are located on the front cover of the Section I booklet in the lower right corner; ignore the large number under these two items—it is not part of the form or form code.**
>
> **Look up when you have finished Item I. . . .**

When students have completed Item I, say:

> **Listen carefully to all my instructions. I will give you time to complete each step. Please look up after completing each step. Raise your hand if you have any questions.**

Give students enough time to complete each step. Don't move on until all students are ready.

> **Read the statements on the front cover of the Section I booklet. . . .**
>
> **Sign your name and write today's date. . . .**
>
> **Now print your full legal name where indicated. . . .**
>
> **Does anyone have any questions? . . .**
>
> **Turn to the back cover of your exam booklet and read it completely. . . .**

Give students a few minutes to read the entire back cover.

> **Are there any questions? . . .**
>
> **You will now take the multiple-choice portion of the exam. You should have in front of you the Section I: multiple-choice booklet and your answer sheet. You may never discuss the multiple-choice exam content at any time in any form with anyone, including your teacher and other students. If you disclose the multiple-choice exam content through any means, your AP Exam score will be canceled.**
>
> **You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses on page 2 of your answer sheet. Remember, for numbers 1 through 45, mark only the single best answer to each question. For numbers 131 through 135, mark the <u>two</u> best answer choices for each question. The answer sheet has circles marked A–E for each of these questions. For this exam, you will use only the circles marked A–D. Completely fill in the circles. If you need to erase, do so carefully and completely. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work.**
>
> **Your score on the multiple-choice section will be based solely on the number of questions answered correctly.**
>
> **Rulers, straightedges, and calculators may be used for the entire exam. You may place these items on your desk.**
>
> **Are there any questions? . . .**
>
> **You have 1 hour and 30 minutes for this section. Once final time is called for Section I, stop working immediately.**
>
> **Open your Section I booklet and begin.**

Note Start Time _______________ . Note Stop Time _______________ .

Check that students are marking their answers in pencil on their answer sheets and that they have not opened their shrinkwrapped Section II booklets. Make sure they've placed their AP ID label sheets under their chairs. Make sure that students are using their calculators appropriately. You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators.

After 1 hour and 20 minutes, say:

> **There are 10 minutes remaining.**

After 10 minutes, say:

> **Stop working. Close your exam booklet and put your answer sheet faceup on your desk. Make sure your AP ID label and AP Exam label are on your answer sheet. Sit quietly while I collect your answer sheets.**

Collect an answer sheet from each student. Check that each answer sheet has an AP ID label and an AP Exam label.

After all answer sheets have been collected, say:

> **Now you must seal your exam booklet using the white seals you set aside earlier. Affix one white seal to each area of your exam booklet cover marked "PLACE SEAL HERE." Fold each seal over the back cover. When you have finished, place the booklet faceup on your desk. I will now collect your Section I booklet. . . .**

Collect a Section I booklet from each student. Check that each student has signed the front cover of the sealed Section I booklet.

There is a 10-minute break between Sections I and II.

When all Section I materials have been collected and accounted for and you are ready for the break, say:

> **Please listen carefully to these instructions before we take a 10-minute break. Get your AP ID label sheet from under your chair and put it on your desk. You must leave your shrinkwrapped Section II packet and your AP ID label sheet on your desk during the break. Please put all of your calculators under your chair. Your calculators and all other items you placed under your chair at the beginning of this exam must stay there. You are not permitted to open or access them in any way. You are not allowed to consult teachers, other students, notes, textbooks, or any other resources during the break. You may not make phone calls, send text messages, use your calculators, check email, use a social networking site, or access any electronic or communication device. You may not leave the designated break area. Remember, you may never discuss the multiple-choice exam content with anyone, and if you disclose the content through any means, your AP Exam score will be canceled. Are there any questions? . . .**
>
> **You may begin your break. Testing will resume at ______________ .**

Make sure students understand where the designated break area is.

IMPORTANT: Both the exam room and students in the designated break area must be monitored.

At the start of the break, walk around the room to ensure all Section II books are accounted for on students' desks. Immediately contact the Office of Testing Integrity (OTI) if any book is missing. Testing must not resume until the book is located or OTI is contacted. (See contact information for OTI on the inside front cover.)

SECTION II: Free Response

After the break, say:

> **May I have everyone's attention? Please look at your AP ID label sheet and double-check that your name is printed at the top to ensure you've returned to the correct seat. . . .**

Confirm that students have their AP ID label sheet, then say:

> **For this section of the exam you may use a pen with black or dark blue ink or a No. 2 pencil to write your responses. Does everyone have a pen or pencil? . . .**
>
> **You may now remove the shrinkwrap from the Section II packet, but do not open any booklets until you are told to do so. . . .**

You should now have in front of you:

- **your AP ID label sheet,**
- **the orange Section II: Free Response, Reference booklet, and**
- **the Section II: Free Response booklet with a shaded block of information on the cover. This booklet is where you'll write your responses.**

First, look at the front cover of the free-response booklet. Read the bulleted statements. Look up when you have finished. . . .

Read the last statement. . . .

Print the first, middle, and last initials of your legal name in the boxes and print today's date where indicated. This constitutes your signature and your agreement to the statements on the front cover. . . .

Now take an AP ID label from your label sheet and place it on the shaded box marked "AP ID Label" at the bottom of your free-response booklet. If you don't have any AP ID labels, write your AP ID in the box. Look up when you have finished. . . .

Now turn to the back cover of your free-response booklet and complete Items 1 through 3 under "Important Identification Information." For Item 3, your school code is printed at the top right of your AP ID label sheet. . . .

Give students time to complete Items 1 through 3.

Read Item 4. . . .

Are there any questions? . . .

Now I will collect your AP ID label sheet. Leave your label sheet on your desk. While I collect them, read the remaining information on the back cover of your free-response booklet. Do not open any booklets until you are told to do so. Look up when you have finished. . . .

At this point, collect the AP ID label sheet from every student.

When you've finished collecting AP ID label sheets, say:

Are there any questions? . . .

Read the information on the front cover of the orange Reference booklet. Look up when you have finished. . . .

Rulers, straightedges, and calculators may be used for Section II. Be sure these items are on your desk. . . .

You have 1 hour and 30 minutes to complete Section II. You are responsible for pacing yourself, and you may proceed freely from one question to the next.

If you are giving the ***AP Physics 1: Algebra-Based Exam***, say:

Section II has 5 questions. It is suggested that you spend approximately 25 minutes each for questions 2 and 3, and 13 minutes each for questions 1, 4, and 5.

If you are giving the ***AP Physics 2: Algebra-Based Exam***, say:

Section II has 4 questions. It is suggested that you spend approximately 25 minutes each for questions 2 and 3, and 20 minutes each for questions 1 and 4.

The orange booklet has reference material only. You may make notes in the orange booklet, but no credit will be given for any work written in the orange booklet.

You must write your responses in the free-response booklet. You must use a pen with black or dark blue ink or a No. 2 pencil. If you use a pencil, be sure that your writing is dark enough to be easily read.

The questions are printed in the free-response booklet. The question number at the top of the page indicates which question to answer on that page. Write your responses in the space provided for each question.

If you run out of space, raise your hand.

Once final time is called, stop working immediately.

Are there any questions? . . .

Open both booklets and begin.

Note Start Time ____________ . Note Stop Time ____________ .

Check that students are writing their answers in their free-response booklet, **not** in their orange booklet.

Make sure that students are using their calculators appropriately. You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators.

If a student runs out of space and raises their hand, give them extra paper and instruct them to write the following on the top of each sheet they use:

- their AP ID,
- the exam title, and
- the question number they are working on.

They must not write their name.

After 1 hour and 20 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working and close both booklets. Place them faceup on your desk. Keep your booklets separate; don't put one inside the other. . . .

If any students used extra paper for a question in the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their free-response booklets. Complete an Incident Report after the exam and return these free-response booklets with the extra sheets attached in the Incident Report return envelope (see page 270).

Then say:

Remain in your seat, without talking, while the exam materials are collected.

Collect a free-response booklet and an orange booklet from each student. Check for the following:

- Free-response booklet front cover: The student printed their initials and today's date and placed an AP ID label on the shaded box at the bottom.
- Free-response booklet back cover: The student completed the "Important Identification Information" area.
- The student wrote responses in the free-response booklet and not in the orange booklet.

If any students wrote their responses in the orange booklet instead of the free-response booklet, refer to the Administration Incidents table for instructions. (See "Answers written in an orange booklet instead of in the free-response booklet" on page 269.)

The orange booklet must be returned with the rest of your exam materials. Keep the orange booklets separate from the free-response booklets. Do not place free-response booklets inside the orange booklets or vice versa.

Then say:

> **I have a few last important reminders:**
>
> **You can have one AP score report sent for free. June 20 is the deadline to indicate or change the college, university, or scholarship program that you'd like to receive your free score report. This needs to be done through "My AP."**

If you are giving the Administration 1 exam, say:

> **You may not discuss or share the free-response exam content with anyone unless it is released on the College Board website in about two days. Your AP Exam scores for this year will be available online in July.**

If you are giving the Administration 2 exam say:

> **None of the content in this exam may ever be discussed or shared in any way at any time. Your AP Exam scores for this year will be available online in July.**

When all exam materials have been collected and accounted for, return to students any electronic devices you may have collected before the start of the exam.

Then say:

> **You are now dismissed.**

After-Exam Tasks

Return the AP ID label sheets to the AP coordinator so the label sheets can be organized for each upcoming exam administration. Keep in mind that the schedule printed on the label sheet may not reflect recent changes to a student's exam schedule. If you need to confirm a student's exam schedule, reference the AP coordinator's master exam list.

Be sure to give the completed seating chart to the AP coordinator. Schools must retain seating charts for at least six months (unless the state or district requires that they be retained for a longer period of time). Schools should not return any seating charts in their exam shipments unless they are required as part of an Incident Report.

NOTE: If you administered exams to students with accommodations, review **Part 2** of the *2020-21 AP Coordinator's Manual* and the *2020-21 AP SSD Guidelines* for information about completing the Nonstandard Administration Report (NAR) form and returning these exams.

The exam proctor should complete the following tasks if asked to do so by the AP coordinator. Otherwise, the AP coordinator must complete these tasks:

- Complete an Incident Report for any students who used extra paper for the free-response section. (Incident Report forms are provided in the coordinator packets sent with the exam shipments.) **These forms must be completed with a No. 2 pencil.** It is best to complete a single Incident Report for multiple students per exam subject, per administration, as long as all required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 270).
- Return all exam materials to secure storage until they are shipped back to the AP Program. (See "Storing Exam Materials" in **Part 2** of the *2020-21 AP Coordinator's Manual* for more information about secure storage.)

Name:______________________________

Answer Sheet for AP Physics 1: Algebra-Based

Practice Exam, Section I

No.	Answer
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	

No.	Answer	
26		
27		
28		
29		
30		
31		
32		
33		
34		
35		
36		
37		
38		
39		
40		
41		
42		
43		
44		
45		
131		
132		
133		
134		
135		

AP® Physics 1: Algebra-Based Exam

SECTION I: Multiple Choice

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour and 30 minutes
Number of Questions
50
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 50 multiple-choice questions. Pages containing equations and other information are also printed in this booklet. Calculators, rulers, and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work.

Because this section offers only four answer options for each question, do not mark the (E) answer circle for any question. If you change an answer, be sure that the previous mark is erased completely.

For questions 1 through 45, select the single best answer choice for each question. After you have decided which of the choices is best, completely fill in the corresponding circle on the answer sheet. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent	Ⓐ ● Ⓒ Ⓓ Ⓔ

For questions 131 through 135, select the two best answer choices for each question. After you have decided which two choices are best, completely fill in the two corresponding circles on the answer sheet. Here is a sample question and answer.

Sample Question	Sample Answer
New York is a (A) state (B) city (C) country (D) continent	● ● Ⓒ Ⓓ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on Section I is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

AP® PHYSICS 1 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	Coulomb's law constant, $k = 1/4\pi\varepsilon_0 = 9.0 \times 10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2$
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant, $G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Speed of light, $c = 3.00 \times 10^{8}$ m/s	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$

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

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done on a system.
IV. The direction of current is conventional current: the direction in which positive charge would drift.
V. Assume all batteries and meters are ideal unless otherwise stated.

AP® PHYSICS 1 EQUATIONS

MECHANICS

$$v_x = v_{x0} + a_x t$$

$$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$$

$$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$$

$$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$$

$$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_n\right|$$

$$a_c = \frac{v^2}{r}$$

$$\vec{p} = m\vec{v}$$

$$\Delta\vec{p} = \vec{F}\,\Delta t$$

$$K = \frac{1}{2} m v^2$$

$$\Delta E = W = F_{\parallel} d = F d \cos\theta$$

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

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$x = A\cos(2\pi f t)$$

$$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$$

$$\tau = r_{\perp} F = r F \sin\theta$$

$$L = I\omega$$

$$\Delta L = \tau\,\Delta t$$

$$K = \frac{1}{2} I \omega^2$$

$$\left|\vec{F}_s\right| = k\left|\vec{x}\right|$$

$$U_s = \frac{1}{2} k x^2$$

$$\rho = \frac{m}{V}$$

a = acceleration
A = amplitude
d = distance
E = energy
f = frequency
F = force
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
V = volume
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
ρ = density
τ = torque
ω = angular speed

$$\Delta U_g = mg\,\Delta y$$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$T_p = 2\pi\sqrt{\frac{\ell}{g}}$$

$$\left|\vec{F}_g\right| = G\frac{m_1 m_2}{r^2}$$

$$\vec{g} = \frac{\vec{F}_g}{m}$$

$$U_G = -\frac{G m_1 m_2}{r}$$

ELECTRICITY

$$\left|\vec{F}_E\right| = k\left|\frac{q_1 q_2}{r^2}\right|$$

$$I = \frac{\Delta q}{\Delta t}$$

$$R = \frac{\rho\ell}{A}$$

$$I = \frac{\Delta V}{R}$$

$$P = I\,\Delta V$$

$$R_s = \sum_i R_i$$

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$

A = area
F = force
I = current
ℓ = length
P = power
q = charge
R = resistance
r = separation
t = time
V = electric potential
ρ = resistivity

WAVES

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

f = frequency
v = speed
λ = wavelength

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2}bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular solid
$V = \ell w h$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

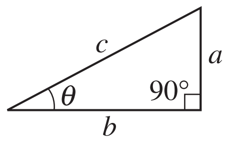
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



PHYSICS 1

SECTION I

Time—1 hour and 30 minutes

50 Questions

Note: To simplify calculations, you may use $g = 10 \text{ m/s}^2$ in all problems.

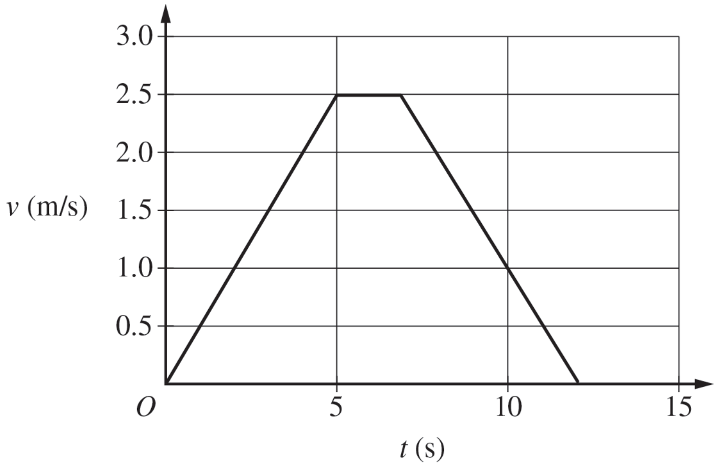
Directions: Each of the questions or incomplete statements below is followed by four suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

1. A blue sphere and a red sphere with the same diameter are released from rest at the top of a ramp. The red sphere takes a longer time to reach the bottom of the ramp. The spheres are then rolled off a horizontal table at the same time with the same speed and fall freely to the floor. Which sphere reaches the floor first?

   (A) The red sphere
   (B) The blue sphere
   (C) The sphere with the greater mass
   (D) Neither; the spheres reach the floor at the same time.

2. A 12 kg box sliding on a horizontal floor has an initial speed of 4.0 m / s. The coefficient of friction between the box and the floor is 0.20. The box moves a distance of 4.0 m in 2.0 s. The magnitude of the change in momentum of the box during this time is most nearly

   (A) 12 kg · m / s
   (B) 48 kg · m / s
   (C) 60 kg · m / s
   (D) 96 kg · m / s



3. The motion of an object is shown in the velocity-time graph. Which best describes the motion of the object?

   (A) The object is either speeding up or slowing down the entire time.
   (B) The object starts and finishes at the same position.
   (C) The object travels in the same direction for the entire time.
   (D) The object undergoes positive acceleration the entire time.

4. A rubber ball with mass 0.20 kg is dropped vertically from a height of 1.5 m above a floor. The ball bounces off of the floor, and during the bounce 0.60 J of energy is dissipated. What is the maximum height of the ball after the bounce?

(A) 0.30 m
(B) 0.90 m
(C) 1.2 m
(D) 1.5 m

5. A sled slides down a hill with friction between the sled and hill but negligible air resistance. Which of the following must be correct about the resulting change in energy of the sled-Earth system?

(A) The sum of the kinetic energy and the gravitational potential energy changes by an amount equal to the energy dissipated by friction.
(B) The gravitational potential energy decreases and the kinetic energy is constant.
(C) The decrease in the gravitational potential energy is equal to the increase in kinetic energy.
(D) The gravitational potential energy and the kinetic energy must both decrease.

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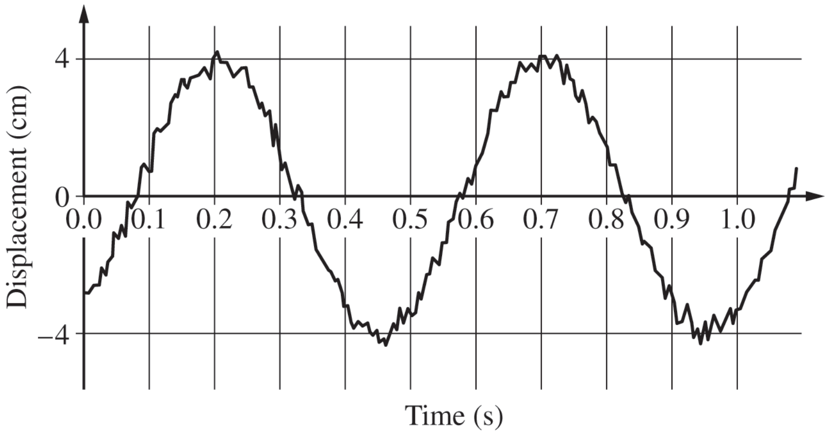
Questions 6 through 8 refer to the following material.



A student sets an object attached to a spring into oscillatory motion and uses a position sensor to record the displacement of the object from equilibrium as a function of time. A portion of the recorded data is shown in the figure above.

6. The speed of the object at time $t = 0.65$ s is most nearly equal to which of the following?

   (A) The value of the graph at 0.65 s
   (B) The slope of the line connecting the origin and the point on the graph at 0.65 s
   (C) The slope of the line connecting the point where the graph crosses the time axis near 0.57 s and the point on the graph at 0.65 s
   (D) The slope of the tangent to a best-fit sinusoidal curve at 0.65 s

7. The total distance traveled by the object between 0.35 s and 0.40 s is most nearly

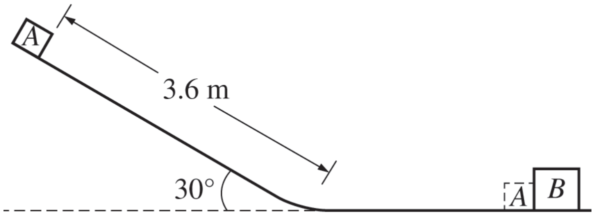
   (A) 0 cm
   (B) 2 cm
   (C) 4 cm
   (D) 6 cm

8. The frequency of oscillation is most nearly

   (A) 0.5 Hz
   (B) 0.7 Hz
   (C) 1.4 Hz
   (D) 2.0 Hz

9. An object is moving to the west at a constant speed. Three forces are exerted on the object. One force is 10 N directed due north, and another is 10 N directed due west. What is the magnitude and direction of the third force if the object is to continue moving to the west at a constant speed?

   (A) $10\sqrt{3}$ N, directed northwest
   (B) $10\sqrt{3}$ N, directed southeast
   (C) $10\sqrt{2}$ N, directed northwest
   (D) $10\sqrt{2}$ N, directed southeast



10. Block A of mass 2.0 kg is released from rest at the top of a 3.6 m long plane inclined at an angle of 30°, as shown in the figure above. After sliding on the horizontal surface, block A hits and sticks to block B, which is at rest and has mass 3.0 kg. Assume friction is negligible. The speed of the blocks after the collision is most nearly

    (A) 2.4 m / s
    (B) 3.2 m / s
    (C) 3.8 m / s
    (D) 6.0 m / s

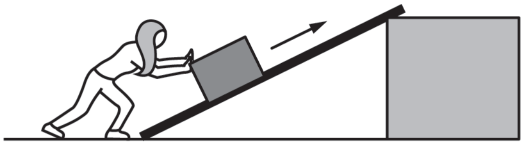


Figure 1

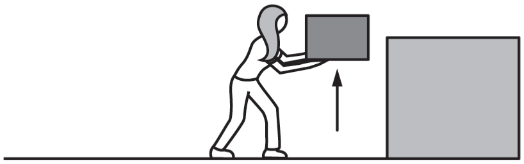


Figure 2

11. A student is asked to move a box from ground level to the top of a loading dock platform, as shown in the figures above. In Figure 1, the student pushes the box up an incline with negligible friction. In Figure 2, the student lifts the box straight up from ground level to the loading dock platform. In which case does the student do more work on the box, and why?

    (A) Lifting the box straight up, because it requires a larger applied force to lift it straight up
    (B) Pushing the box up the incline, because the force is applied for a longer distance
    (C) Lifting the box straight up, because the incline acts as a simple machine and reduces the force required
    (D) Neither method, because the work is the same in both cases, since using the ramp decreases the force by the same factor that it increases the distance

Position (m)	Time (s)
0.0	0.0
0.1	1.0
0.4	2.0
0.9	3.0
1.6	4.0

12. A block of mass 2.0 kg, starting from rest, is pushed with a constant force across a horizontal track. The position of the block as a function of time is recorded, and the data are shown in the table. What is the magnitude of the change in momentum of the block between zero and 4.0 seconds?

(A) 0.8 kg·m/s

(B) 1.2 kg·m/s

(C) 1.6 kg·m/s

(D) 3.2 kg·m/s

13. The wheel on a vehicle has a rotational inertia of $2.0\ \text{kg} \cdot \text{m}^2$. At the instant the wheel has a counterclockwise angular velocity of 6.0 rad / s, an average counterclockwise torque of $5.0\ \text{N} \cdot \text{m}$ is applied, and continues for 4.0 s. What is the change in angular momentum of the wheel?

(A) $12\ \text{kg} \cdot \text{m}^2 / \text{s}$

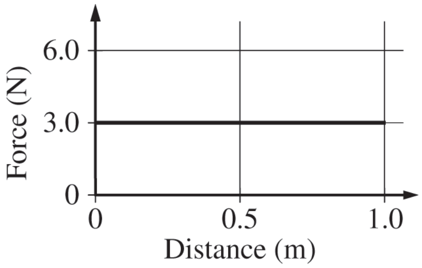
(B) $16\ \text{kg} \cdot \text{m}^2 / \text{s}$

(C) $20\ \text{kg} \cdot \text{m}^2 / \text{s}$

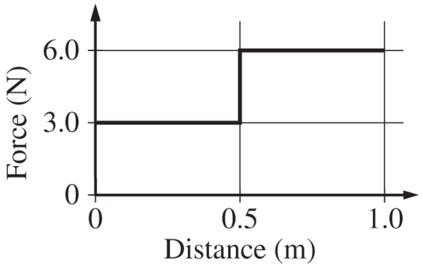
(D) $32\ \text{kg} \cdot \text{m}^2 / \text{s}$

14. A student uses a spring scale to exert a horizontal force on a block, pulling the block over a smooth floor. The student repeats the procedure several times, each time pulling the block from rest through a distance of 1.0 m. For which of the following graphs of force as a function of distance will the block be moving the fastest at the end of the 1.0 m ?

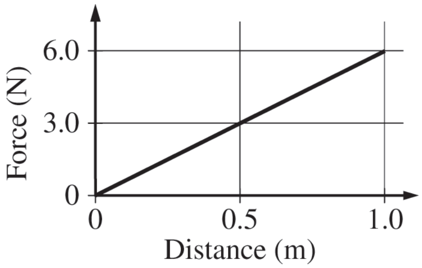
(A)



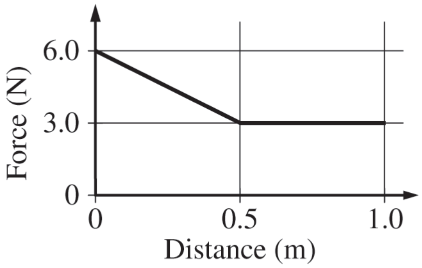
(B)



(C)



(D)

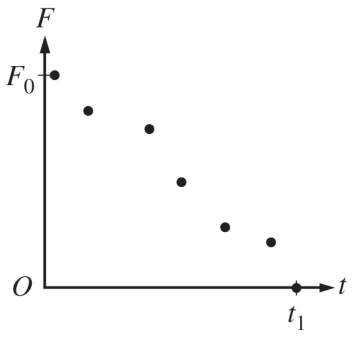


15. A projectile fired into the air explodes and splits into two halves of equal mass that hit the ground at the same time. If the projectile had not exploded, it would have landed at point X, which is a distance R to the right of the launch point. After the explosion, one of the halves lands at point Y, which is a distance $2R$ to the right of the launch point. If air resistance is negligible, where did the other half land?

(A) To the left of the launch point
(B) At the launch point
(C) Between the launch point and point X
(D) Between points X and Y

16. An elevator carrying a person of mass m is moving upward and slowing down. How does the magnitude F of the force exerted on the person by the elevator floor compare with the magnitude mg of the gravitational force?

(A) $F < mg$
(B) $F = mg$
(C) $F > mg$
(D) F can be greater than or less than mg, depending on the speed of the elevator.



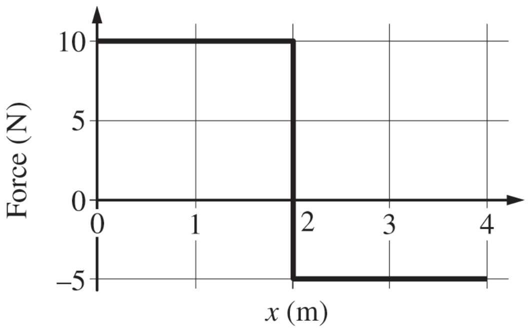
17. A soft foam block of mass m slides without friction in the positive x-direction with speed v. At time $t = 0$, a student briefly pushes the block with a force probe in the positive x-direction. The graph above shows the force probe's measurements as a function of time during the push. Which of the following statements is true about the block's momentum between $t = 0$ and $t = t_1$?

(A) The momentum of the block has decreased to zero at time t_1.

(B) The momentum of the block has increased by approximately $\frac{1}{2}F_0 t_1$.

(C) The momentum of the block has decreased by approximately $\frac{1}{2}F_0 t_1$.

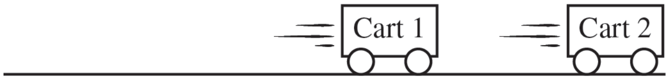
(D) The change in momentum cannot be determined without knowing the distance by which the force probe compressed the block.



18. A cart is moving on a level track in the positive x-direction. A force acting parallel to the x-axis is exerted on the cart. The graph above shows the net force exerted on the cart as a function of displacement. As the cart travels from $x = 0$ m to $x = 4$ m, what is the net change in the kinetic energy of the cart?

(A) An increase of 20 J
(B) An increase of 10 J
(C) A decrease of 20 J
(D) A decrease of 10 J

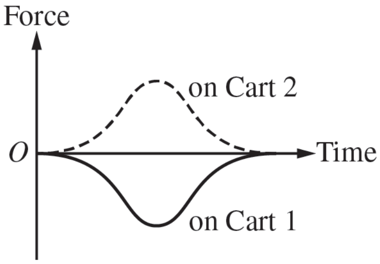
Before Collision



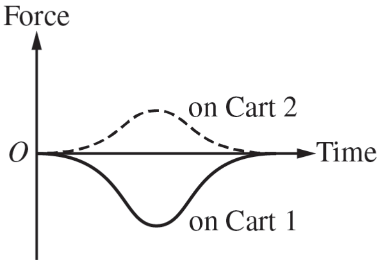
After Collision

19. Carts 1 and 2 are initially moving toward each other, as shown in the top figure. The carts collide and afterward are both moving to the right, as shown in the bottom figure. If the positive direction is to the right, which of the following best represents the force exerted on each cart by the other during the collision as a function of time?

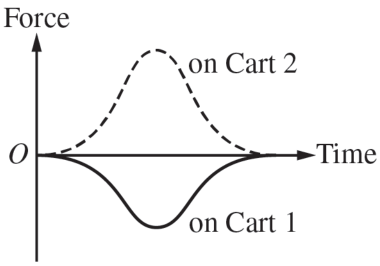
(A)



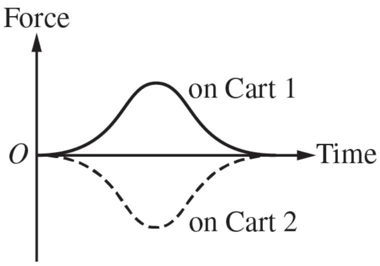
(B)

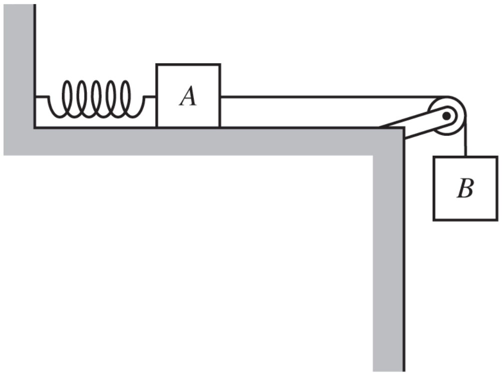


(C)



(D)





20. Block A is set on a rough horizontal table and is connected to a horizontal spring that is fixed to a wall, as shown. Block A is then also connected to hanging block B by a lightweight string that passes over an ideal pulley, as shown. The friction force exerted on block A by the table is not negligible. The blocks are initially held at rest so that the spring is not stretched. When the blocks are released, hanging block B moves downward and block A on the table moves to the right until the system comes again to rest. Let E_1 be the mechanical energy of the blocks-spring system, and let E_2 be the mechanical energy of the blocks-spring-Earth system. How do these two energies change from when the blocks are held at rest to when the blocks come to rest again?

	Blocks-Spring System	Blocks-Spring-Earth System
(A)	Increases	Decreases
(B)	Decreases	Increases
(C)	Remains constant	Decreases
(D)	Remains constant	Remains constant

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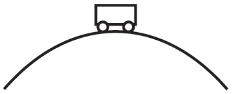


Case 1

Case 2

Case 3

21. The figures show a cart moving over the top of a hill (Case 1), moving at the bottom of a dip (Case 2), and moving at the top of a vertical loop (Case 3). In each case, the normal force acting on the car is F_n and the weight of the car is F_g. In which case is it always true that $F_n > F_g$, and in which case is it always true that $F_n < F_g$?

(A)

$F_n > F_g$ Always	$F_n < F_g$ Always
Case 1	Case 3

(B)

$F_n > F_g$ Always	$F_n < F_g$ Always
Case 2	Case 1

(C)

$F_n > F_g$ Always	$F_n < F_g$ Always
Case 2	Case 3

(D)

$F_n > F_g$ Always	$F_n < F_g$ Always
Case 3	Case 1

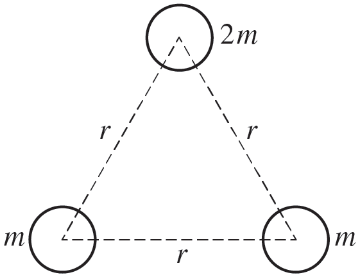
22. Two objects, *A* and *B*, move toward one another. Object *A* has twice the mass and half the speed of object *B*. Which of the following describes the forces the objects exert on each other when they collide and provides the best explanation?

(A) The force exerted by *A* on *B* will be twice as great as the force exerted by *B* on *A*, because *A* has twice the mass of *B*.

(B) The force exerted by *A* on *B* will be half as great as the force exerted by *B* on *A*, because *A* has half the speed of *B*.

(C) The forces exerted by each object on the other are the same, because the product of mass and speed is the same for both objects.

(D) The forces exerted by each object on the other are the same, because interacting objects cannot exert forces of different magnitude on each other.



23. Three spheres, with masses indicated above, are initially far away from each other, and the gravitational potential energy of the three-sphere system is zero. The spheres are then brought together until each sphere is a distance r from the other two, as shown above. What is the new gravitational potential energy of the three-sphere system?

(A) $-\dfrac{Gm^2}{r}$

(B) $-\dfrac{2Gm^2}{r}$

(C) $-\dfrac{4Gm^2}{r}$

(D) $-\dfrac{5Gm^2}{r}$

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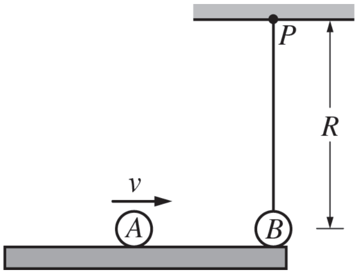


24. Steel sphere A of mass M is moving along a horizontal surface with constant speed v. Identical steel sphere B is at rest and hangs on a string of length R attached to a support at point P, as shown in the figure above. The spheres collide, and as a result sphere A stops and sphere B swings a vertical height h before coming momentarily to rest. Knowing values for which of the following will allow determination of the angular impulse on sphere B with respect to P due to the collision?

(A) M and v only

(B) M, v, and h

(C) R and h

(D) R, M, and v

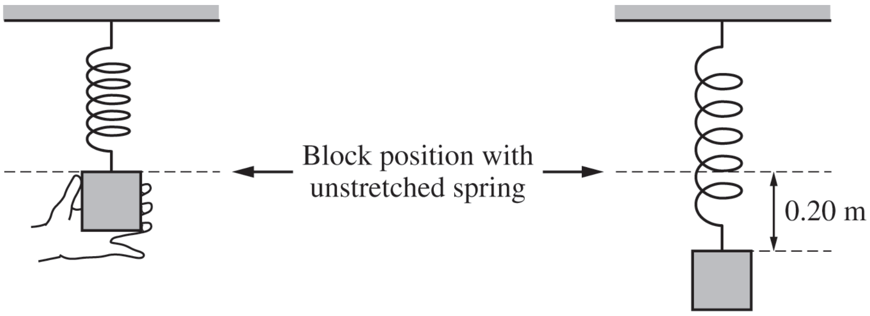
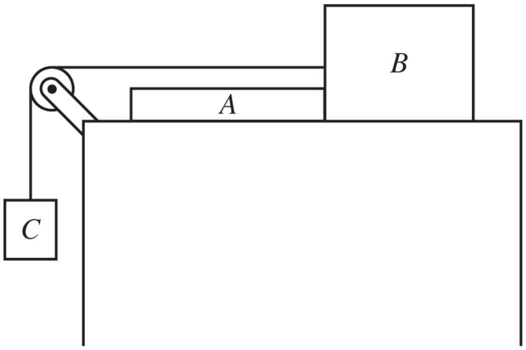


Figure 1

Figure 2

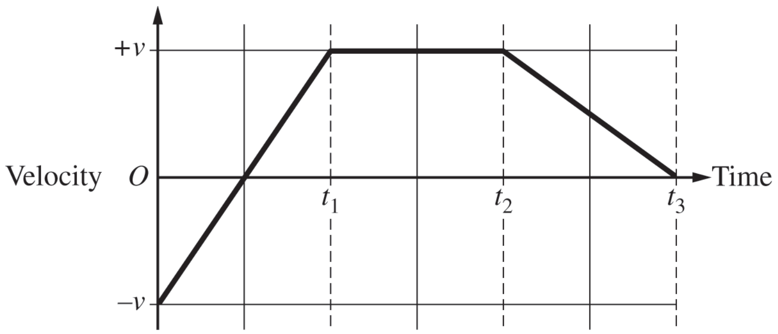
25. A 1.0 kg block is attached to an unstretched spring of spring constant 50 N / m and released from rest from the position shown in Figure 1 above. The block oscillates for a while and eventually stops moving 0.20 m below its starting point, as shown in Figure 2. What is the change in potential energy of the block-spring-Earth system between Figure 1 and Figure 2 ?

    (A) -1.0 J
    (B) 0 J
    (C) 1.0 J
    (D) 3.0 J



26. Blocks *A* and *B*, of masses m_A and m_B, are at rest on a frictionless surface, as shown above, with block *A* fixed to the table. Block *C* of mass m_C is suspended by a string that is tied to block *B* over an ideal pulley. Which of the following gives the magnitude of the force exerted by block *A* on block *B* ?

    (A) $m_B g$
    (B) $m_C g$
    (C) $\dfrac{m_A m_C}{m_A m_B} g$
    (D) $\dfrac{m_B m_C}{m_A m_B} g$



27. A box experiences a varying net force that changes its velocity. The graph shows the velocity of the box as a function of time.

Which of the following correctly describes the net work, W_{net}, done on the box for the given intervals of time?

(A)

Between 0 and t_1	Between t_1 and t_2	Between t_2 and t_3
$W_{\text{net}} > 0$	$W_{\text{net}} = 0$	$W_{\text{net}} < 0$

(B)

Between 0 and t_1	Between t_1 and t_2	Between t_2 and t_3
$W_{\text{net}} = 0$	$W_{\text{net}} > 0$	$W_{\text{net}} > 0$

(C)

Between 0 and t_1	Between t_1 and t_2	Between t_2 and t_3
$W_{\text{net}} = 0$	$W_{\text{net}} = 0$	$W_{\text{net}} < 0$

(D)

Between 0 and t_1	Between t_1 and t_2	Between t_2 and t_3
$W_{\text{net}} > 0$	$W_{\text{net}} > 0$	$W_{\text{net}} > 0$

28. A cart of mass m is moving with negligible friction along a track with known speed v_1 to the right. It collides with and sticks to a cart of mass $4m$ moving with known speed v_2 to the right. Which of the two principles, conservation of momentum and conservation of mechanical energy, must be applied to determine the final speed of the carts, and why?

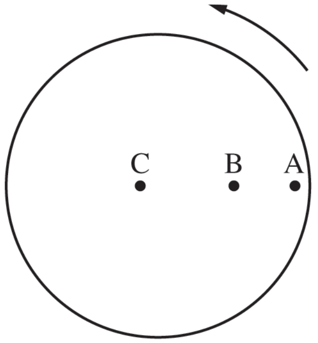
(A) Only conservation of momentum, because the momentum lost by one cart is gained by the other and there is only one unknown quantity.

(B) Both conservation of mechanical energy and conservation of momentum, because both principles apply in any collision.

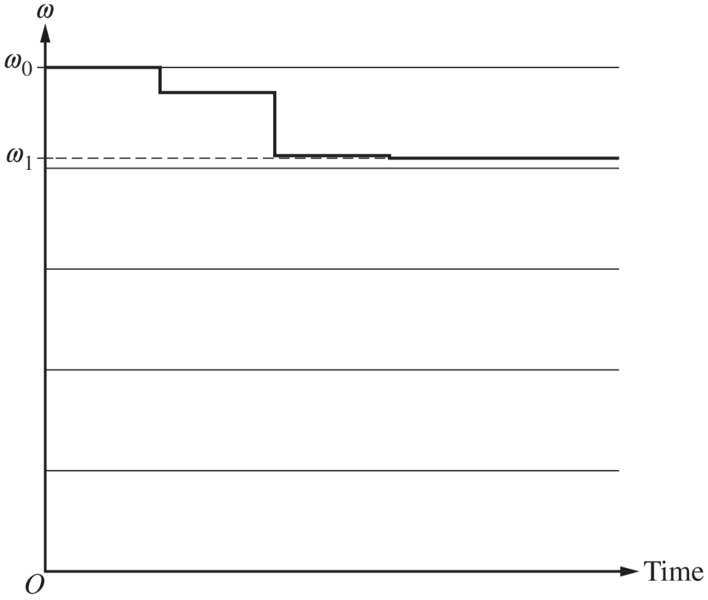
(C) Both conservation of mechanical energy and conservation of momentum, because neither cart changes direction.

(D) Either conservation of momentum or conservation of mechanical energy, because only one equation is required to solve for the one unknown variable.

Questions 29 and 30 refer to the following.



Top View



A solid disk whose plane is parallel to the ground spins with an initial angular speed ω_0. Three identical blocks are dropped onto the disk at locations A, B, and C, one at a time, not necessarily in that order. Each block instantaneously sticks to the surface of the disk, slowing the disk's rotation. A graph of the angular speed of the disk as a function of time is shown.

29. Based on the data presented in the graph, which of the following lists the points in the order in which the blocks are dropped onto the disk?

(A) A, B, C

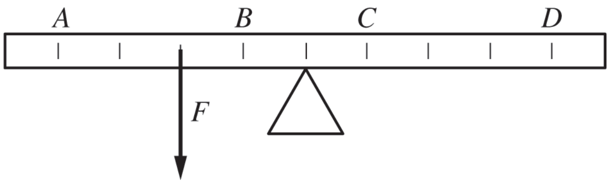
(B) B, C, A

(C) C, A, B

(D) B, A, C

30. The blocks are now dropped in the reverse order and the final angular speed of the disk is ω_2. How does ω_2 compare to ω_1, the final angular speed shown on the graph from the initial experiment?

(A) $\omega_2 < \omega_1$
(B) $\omega_2 = \omega_1$
(C) $\omega_2 > \omega_1$
(D) The final angular speed cannot be compared without knowing the distances from the disk's center to points A, B, and C.

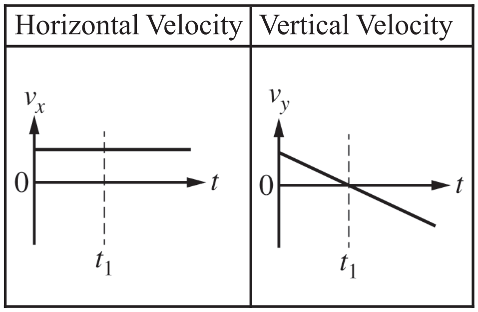


31. The figure above shows a uniform meterstick that is set on a fulcrum at its center. A force of magnitude toward the bottom of the page is exerted on the meterstick at the position shown. At which of the labeled positions must an upward force of magnitude $2F$ be exerted on the meterstick to keep the meterstick in equilibrium?

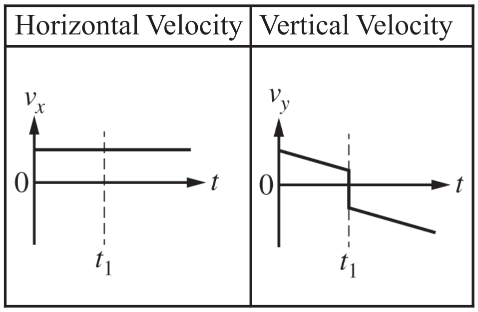
(A) *A*
(B) *B*
(C) *C*
(D) *D*

32. In a classroom at time $t = 0$, a sphere is thrown upward at a 45° angle to the horizontal. At time t_1, while the sphere is still rising, it bounces off the ceiling elastically and with no friction. Which of the following pairs of graphs could represent the sphere’s horizontal velocity and vertical velocity as functions of time t ?

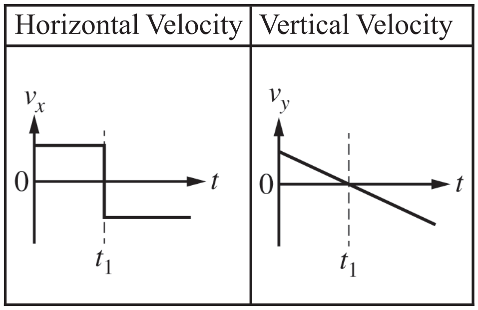
(A)



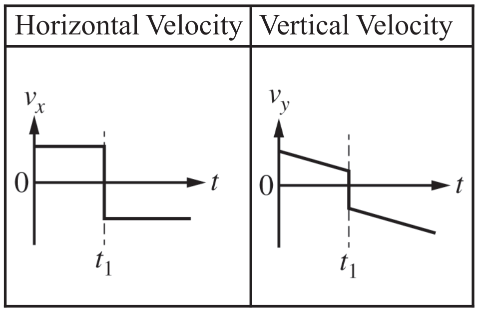
(B)



(C)



(D)



33. Two satellites are in circular orbits around Earth. Satellite *A* has speed v_A. Satellite *B* has an orbital radius nine times that of satellite *A*. What is the speed of satellite *B* ?

(A) $v_A / 9$

(B) $v_A / 3$

(C) $3v_A$

(D) $9v_A$

34. In trial 1 of an experiment, a cart moves with speed v_0 on a frictionless, horizontal track and collides elastically with another cart that is initially at rest. In trial 2, the setup is identical except that the carts stick together during the collision. How does the speed of the two-cart system's center of mass change, if at all, during the collision in each trial?

(A)

Trial 1	Trial 2
Does not change	Does not change

(B)

Trial 1	Trial 2
Does not change	Decreases

(C)

Trial 1	Trial 2
Decreases	Does not change

(D)

Trial 1	Trial 2
Decreases	Decreases

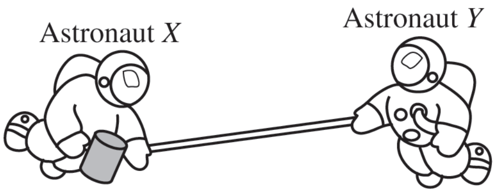


Figure 1

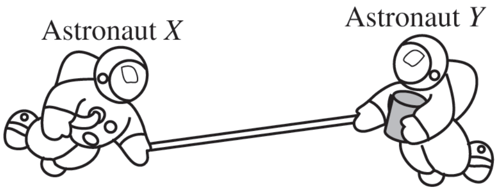


Figure 2

35. Two astronauts are connected by a taut cable and are initially at rest with respect to a nearby space station. Astronaut *X* throws a large container to Astronaut *Y*. Figure 1 above shows the astronauts immediately after the container is thrown by Astronaut *X*, and Figure 2 shows the astronauts immediately after the container is caught by Astronaut *Y*. Which of the following describes the motion of Astronaut *Y* in Figures 1 and 2 ?

(A)

Figure 1	Figure 2
Does not move	Moves to the right

(B)

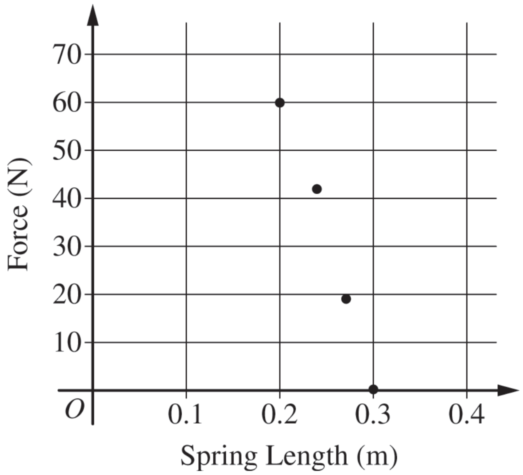
Figure 1	Figure 2
Moves to the right	Moves to the right

(C)

Figure 1	Figure 2
Does not move	Does not move

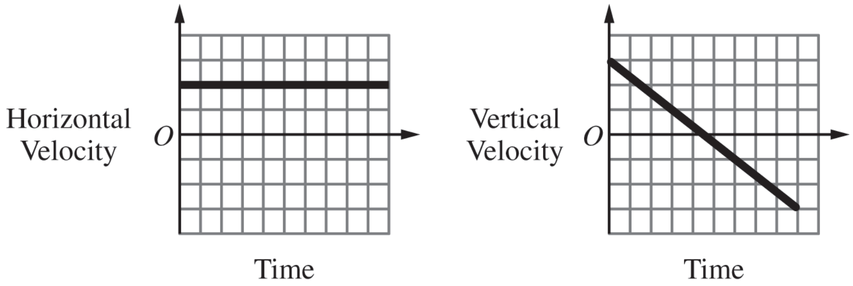
(D)

Figure 1	Figure 2
Moves to the left	Does not move



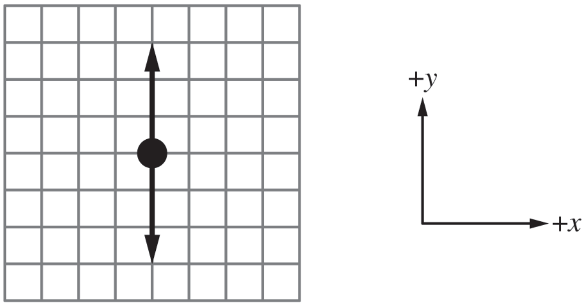
36. The graph above shows the force exerted by a spring as a function of the length of the spring. A block on a frictionless table is pushed against the spring that is fastened to a wall. The spring is compressed until its length is 20 cm. The block is then released. Which of the following values is closest to the kinetic energy with which the block leaves the spring?

    (A) 3 J
    (B) 6 J
    (C) 12 J
    (D) 15 J

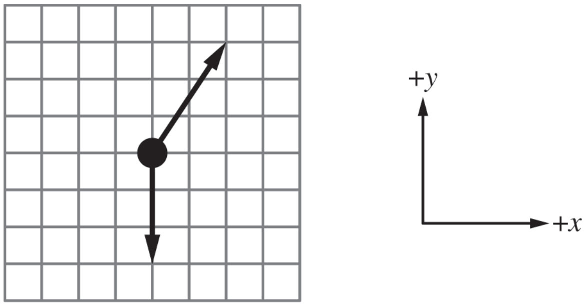


37. An object is subject to multiple forces that result in the object having horizontal and vertical velocity components v_x and v_y, respectively as a function of time, as shown. Which of the following free-body diagrams could represent the forces exerted on the object?

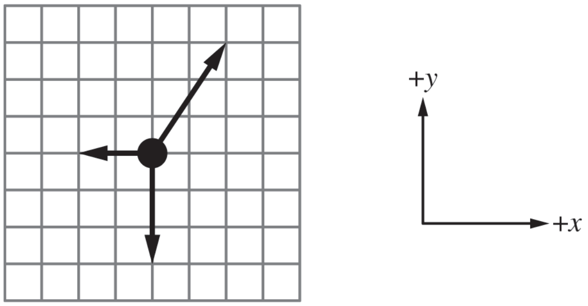
(A)



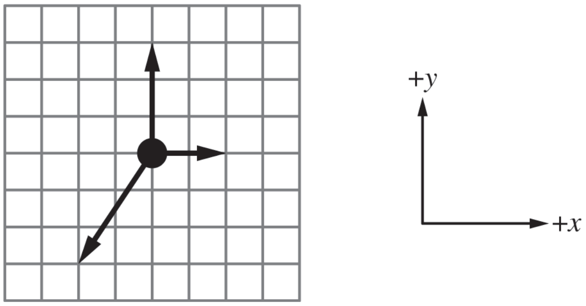
(B)



(C)

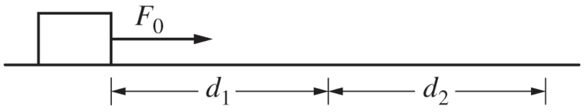


(D)



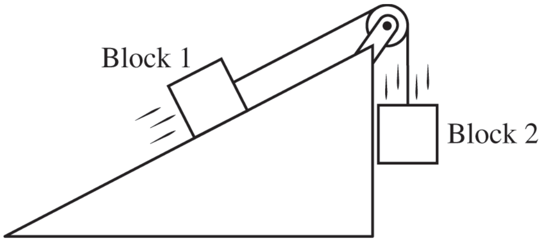
38. Two identical blocks A and B are connected by a lightweight rope. Block A is pulled to the right by a constant force F_0. The blocks are moving to the right across a rough surface and approach point P, where the rough surface transitions to a surface with negligible friction. How does the tension, T, in the rope connecting the blocks change, if at all, as block A passes point P ?

(A) T decreases.
(B) T increases.
(C) T remains constant.
(D) The change in T cannot be determined without knowing the coefficient of friction and the mass of the blocks.



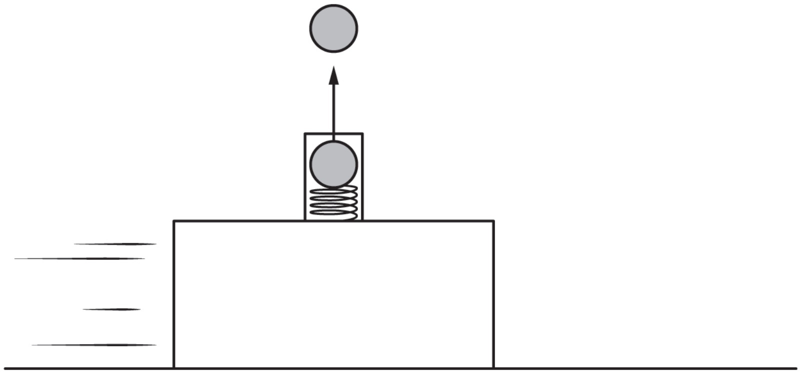
39. A force F_0 is applied continuously to a box initially at rest on a horizontal surface. The box slides with negligible friction for equal distances d_1 and d_2, as shown. How does the kinetic energy gained by the block over distance interval d_2, ΔK_2, compare to the kinetic energy gained over distance interval d_1, ΔK_1, and why?

(A) $\Delta K_2 = \Delta K_1$, because the velocity increases by the same amount over intervals d_1 and d_2.
(B) $\Delta K_2 = \Delta K_1$, because the applied force does the same work on the block over intervals d_1 and d_2.
(C) $\Delta K_2 > \Delta K_1$, because the block is moving faster on average over interval d_2.
(D) $\Delta K_2 > \Delta K_1$, because the rate of change of kinetic energy is greater over interval d_2.



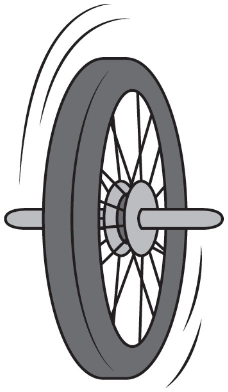
40. Two identical blocks are connected by a lightweight string that passes over a lightweight pulley that can rotate about its axle with negligible friction. The two-block system is released from rest and the blocks accelerate. Which of the following correctly relates the potential energy gained by the block 1-Earth system $|\Delta U_1|$ to the potential energy lost by the block 2-Earth system $|\Delta U_2|$ and provides correct evidence?

(A) $|\Delta U_1| = |\Delta U_2|$, because both blocks travel the same distance.
(B) $|\Delta U_1| = |\Delta U_2|$, because both blocks gain the same amount of kinetic energy.
(C) $|\Delta U_1| < |\Delta U_2|$, because the two-block system gains kinetic energy.
(D) $|\Delta U_1| < |\Delta U_2|$, because the tension exerted on block 1 by the string is less than the tension exerted on block 2 by the string.



41. A vertical spring launcher is attached to the top of a block and a ball is placed in the launcher, as shown in the figure. While the block slides at constant speed to the right across a horizontal surface with negligible friction between the block and the surface, the ball is launched upward. When the ball reaches its maximum height, what will be the position of the ball relative to the spring launcher?

(A) Above and to the right of the spring launcher
(B) Directly above the spring launcher
(C) Above and to the left of the spring launcher
(D) The relative position of the ball depends on the horizontal speed of the block.



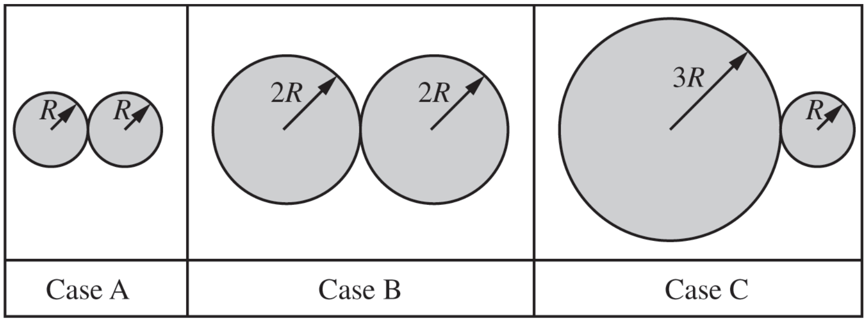
42. A bicycle wheel of known rotational inertia is free to rotate about its central axis. With the wheel initially at rest, a student wraps a string around the wheel and pulls the string with a spring scale, causing the wheel to rotate. The student records the tension in the string and the time for which the string was pulled. Without measuring the wheel's final angular speed, can the student find the magnitude of the wheel's final angular momentum, and what is a correct explanation?

    (A) Yes. The student has sufficient information already.

    (B) Yes. The student also needs to measure the wheel's radius to calculate the torque exerted on the wheel.

    (C) No. Angular momentum can only be found by measuring rotational inertia and angular speed.

    (D) No. Measuring the radius would allow the student to calculate the torque, not the angular momentum.



43. The figure shows three cases where two spheres are touching and attract each other with the gravitational force. The radii of the spheres in each case are shown. All of the spheres are made of material with the same density. Which of the following correctly ranks these cases based on the gravitational force between the spheres?

(A) (A = B) > C

(B) A > C > B

(C) B > C > A

(D) C > (A = B)

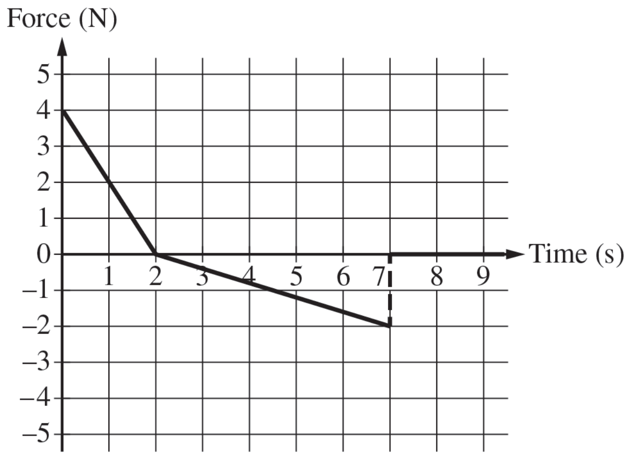
44. On Earth, when a box slides across a horizontal board, the board exerts a frictional force of magnitude F_0 on the box. The board and the box are moved to a planet with twice the radius but one-third the mass of Earth. When the box slides across the board, the frictional force exerted by the board on the box is now

(A) $\frac{1}{12}F_0$

(B) $\frac{1}{6}F_0$

(C) $\frac{2}{3}F_0$

(D) F_0



45. An object is initially at rest. A varying force is applied to the object as shown in the graph. Which of the following correctly explains the momentum of the object at time $t = 7$ s ?

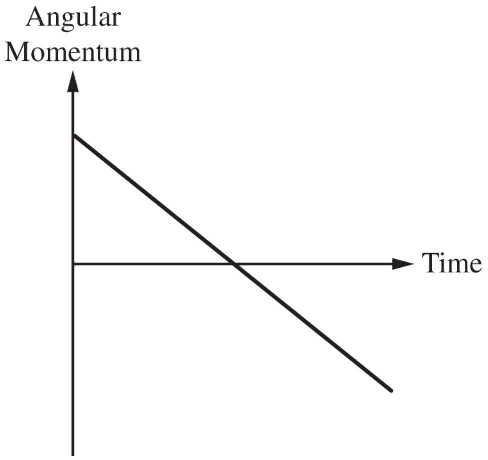
(A) The final momentum of the object is negative because the slope of the graph is negative the entire time from $t = 0$ s to $t = 7$ s.

(B) The final momentum of the object is positive because the maximum magnitude of the force in the positive direction is twice the maximum magnitude of the force in the negative direction.

(C) The final momentum of the object is negative because the magnitude of the area bounded by the graph and the horizontal axis is less from $t = 0$ s to $t = 2$ s than from $t = 2$ s to $t = 7$ s.

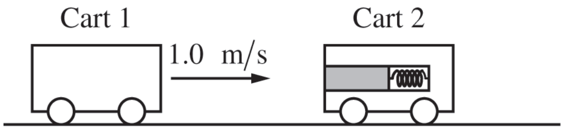
(D) The final momentum of the object is positive because the average magnitude of the force is higher from $t = 0$ s to $t = 2$ s than the average magnitude of the force from $t = 2$ s to $t = 7$ s.

Directions: For each of the questions or incomplete statements below, two of the suggested answers will be correct. For each of these questions, you must select both correct choices to earn credit. No partial credit will be earned if only one correct choice is selected. Select the two that are best in each case and then fill in the corresponding circles that begin with number 131 on the answer sheet.

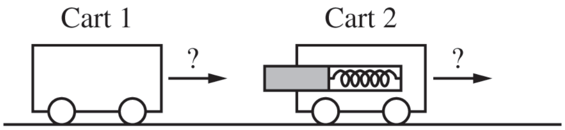


131. The angular momentum of a rigid body rotating around a fixed point as a function of time is shown in the graph. Which of the following statements are true? Select two answers.

(A) The angular speed of the object is constant.
(B) The angular acceleration of the object is constant.
(C) The angular position of the object is constant.
(D) The net torque applied to the object is constant.



Before Collision



After Collision

132. Two lab carts have the same mass and are free to move on a horizontal track. The carts' wheels have negligible mass. Cart 1 travels to the right at 1.0 m / s and collides with cart 2, which is initially at rest, as shown at left above. Cart 2 has a compressed spring-loaded plunger with a nonnegligible amount of stored energy. During the collision, the spring-loaded plunger pops out, staying in contact with cart 1 for 0.10 s as the spring decompresses. Negligible mechanical energy dissipates during the collision. Taking rightward as positive, the carts' velocities after the collision could be which of the following? Select two answers.

(A)

Cart 1	Cart 2
0	1.0 m / s

(B)

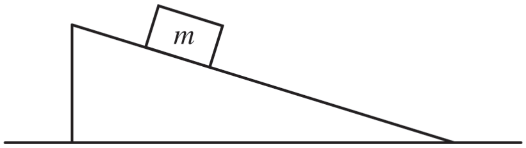
Cart 1	Cart 2
0.5 m / s	0.5 m / s

(C)

Cart 1	Cart 2
−0.5 m / s	1.5 m / s

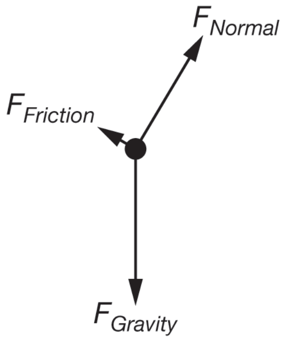
(D)

Cart 1	Cart 2
−1.0 m / s	2.0 m / s



133. A block of mass m is at rest on a rough incline, as shown in the figure above. Which of the following forces must have a magnitude equal to mg ? Select two answers.

(A) The total force exerted on the block by the incline
(B) The normal force exerted on the block by the incline
(C) The force of friction exerted on the block by the incline
(D) The gravitational force exerted on Earth by the block



134. The diagram shows the forces exerted on a block that starts from rest and speeds up as it moves down a rough incline near Earth's surface. Which of the following statements are true? Select two answers.

(A) The momentum of Earth remains constant as the block slides down the incline.

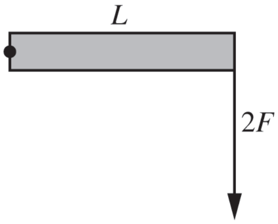
(B) The total mechanical energy of the block-Earth system decreases as the block slides down the incline.

(C) The momentum of the block increases as the block slides down the incline.

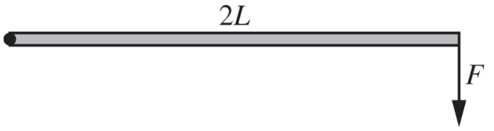
(D) The total mechanical energy of the block-Earth system remains constant as the block slides down the incline.

135. Four rods, each of mass M, are pinned at the left end to the horizontal surface of a table and are shown from above in the following figures. Each rod is free to rotate about a pivot at its left end with negligible friction. In each case, forces are exerted on the rod with different magnitudes and in different directions as shown. The rotational inertia of a rod of mass M and length L about the end of the rod is $(1/3)ML^2$. In which cases do the rods experience equal initial angular accelerations? Select two answers.

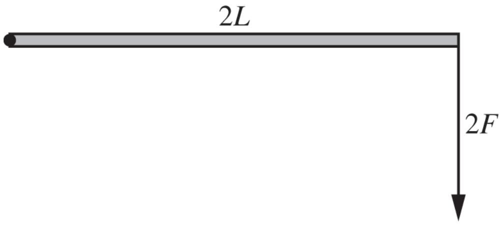
(A)



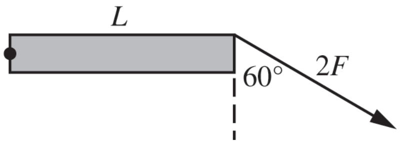
(B)



(C)



(D)



END OF SECTION I

IF YOU FINISH BEFORE TIME IS CALLED, YOU MAY
CHECK YOUR WORK ON THIS SECTION.

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

MAKE SURE YOU HAVE DONE THE FOLLOWING:

- PLACED YOUR AP ID LABEL ON YOUR ANSWER SHEET
- WRITTEN AND GRIDDED YOUR AP ID CORRECTLY ON YOUR ANSWER SHEET
- TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET

AP® Physics 1: Algebra-Based Exam

SECTION II: Free Response

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
1 hour and 30 minutes

Number of Questions
5

Percent of Total Score
50%

Writing Instrument
Either pencil or pen with black or dark blue ink

Electronic Device
Calculator allowed

Suggested Time
Approximately 25 minutes each for questions 2 and 3 and 13 minutes each for questions 1, 4, and 5

Weight
Approximate weights:
Questions 2 and 3: 26% each
Questions 1, 4, and 5: 16% each

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐

   First letter of your first name ☐

2. Date of birth

   ☐☐ Month ☐☐ Day

3. Six-digit school code

   ☐☐☐☐☐☐

4. Unless I fill in the circle below, I grant College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark “No” with no effect on my score or its reporting.

   No, I do not grant College Board these rights. ○

Instructions

The questions for Section II are printed in this booklet. A table of information and lists of equations that may be helpful are printed in the orange Reference booklet. You may use any blank space in the orange booklet for scratch work, but you must write your answers in the spaces provided for each answer in this Free Response booklet. **No credit will be given for any work written in the orange booklet**. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Do not write outside the box. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

AP® PHYSICS 1 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS			
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	Coulomb's law constant,	$k = 1/4\pi\varepsilon_0 = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ \text{m}^3/\text{kg}\cdot\text{s}^2$
Speed of light,	$c = 3.00 \times 10^8$ m/s	Acceleration due to gravity at Earth's surface,	$g = 9.8\ \text{m/s}^2$

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

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam.

I. The frame of reference of any problem is assumed to be inertial unless otherwise stated.
II. Assume air resistance is negligible unless otherwise stated.
III. In all situations, positive work is defined as work done on a system.
IV. The direction of current is conventional current: the direction in which positive charge would drift.
V. Assume all batteries and meters are ideal unless otherwise stated.

AP® PHYSICS 1 EQUATIONS

MECHANICS

$$v_x = v_{x0} + a_x t$$

$$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$$

$$v_x^2 = v_{x0}^2 + 2a_x (x - x_0)$$

$$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$$

$$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_n\right|$$

$$a_c = \frac{v^2}{r}$$

$$\vec{p} = m\vec{v}$$

$$\Delta\vec{p} = \vec{F}\,\Delta t$$

$$K = \frac{1}{2} m v^2$$

$$\Delta E = W = F_{\parallel} d = Fd\cos\theta$$

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

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$x = A\cos(2\pi f t)$$

$$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$$

$$\tau = r_{\perp} F = rF\sin\theta$$

$$L = I\omega$$

$$\Delta L = \tau\,\Delta t$$

$$K = \frac{1}{2} I \omega^2$$

$$\left|\vec{F}_s\right| = k\left|\vec{x}\right|$$

$$U_s = \frac{1}{2} k x^2$$

$$\rho = \frac{m}{V}$$

a = acceleration
A = amplitude
d = distance
E = energy
f = frequency
F = force
I = rotational inertia
K = kinetic energy
k = spring constant
L = angular momentum
ℓ = length
m = mass
P = power
p = momentum
r = radius or separation
T = period
t = time
U = potential energy
V = volume
v = speed
W = work done on a system
x = position
y = height
α = angular acceleration
μ = coefficient of friction
θ = angle
ρ = density
τ = torque
ω = angular speed

$$\Delta U_g = mg\,\Delta y$$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$T_s = 2\pi\sqrt{\frac{m}{k}}$$

$$T_p = 2\pi\sqrt{\frac{\ell}{g}}$$

$$\left|\vec{F}_g\right| = G\frac{m_1 m_2}{r^2}$$

$$\vec{g} = \frac{\vec{F}_g}{m}$$

$$U_G = -\frac{G m_1 m_2}{r}$$

ELECTRICITY

$$\left|\vec{F}_E\right| = k\left|\frac{q_1 q_2}{r^2}\right|$$

$$I = \frac{\Delta q}{\Delta t}$$

$$R = \frac{\rho\ell}{A}$$

$$I = \frac{\Delta V}{R}$$

$$P = I\,\Delta V$$

$$R_s = \sum_i R_i$$

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$

A = area
F = force
I = current
ℓ = length
P = power
q = charge
R = resistance
r = separation
t = time
V = electric potential
ρ = resistivity

WAVES

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

f = frequency
v = speed
λ = wavelength

GEOMETRY AND TRIGONOMETRY

Rectangle
$A = bh$

Triangle
$A = \frac{1}{2} bh$

Circle
$A = \pi r^2$
$C = 2\pi r$

Rectangular solid
$V = \ell w h$

Cylinder
$V = \pi r^2 \ell$
$S = 2\pi r\ell + 2\pi r^2$

Sphere
$V = \frac{4}{3}\pi r^3$
$S = 4\pi r^2$

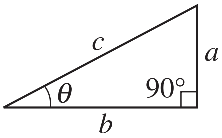
A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius

Right triangle
$c^2 = a^2 + b^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



Begin your response to **QUESTION 1** on this page.

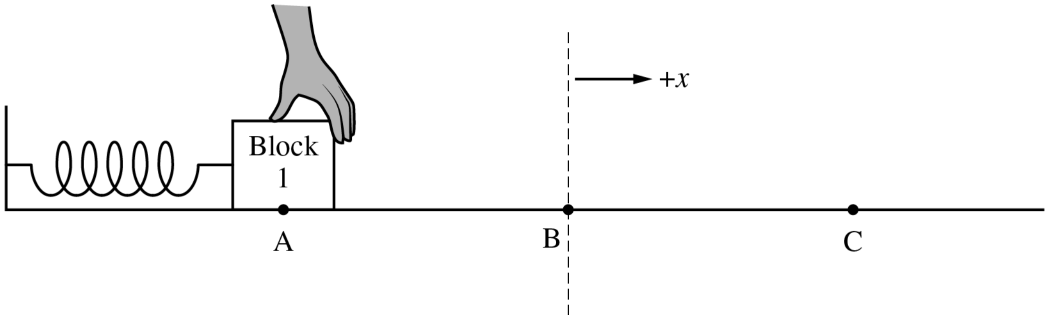
PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



1. (7 points, suggested time 13 minutes)

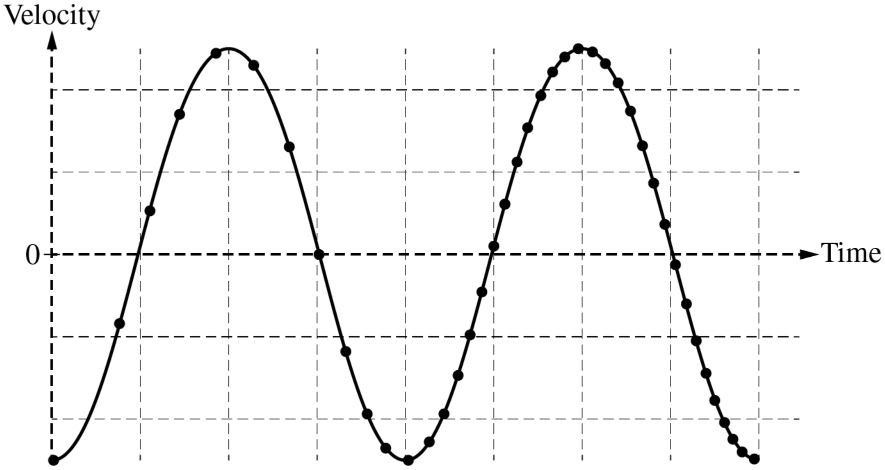
Block 1 is at rest on a horizontal surface and is connected to a wall by an ideal spring. Friction between block 1 and the surface is negligible. Block 1 is held at rest at point A, to the left of point B which is the equilibrium position of the spring-block system, as shown in the figure. Block 1 is then released and allowed to oscillate. Some time later, block 1 is momentarily at rest at point C. Consider the positive horizontal direction to be toward the right.

(a) The dot below represents block 1 just after it is released. On the dot, draw an arrow indicating the direction of the net force exerted on the block just after it is released. The arrow should start on, and point away from, the dot.

Net Force on Block 1

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 1** on this page.

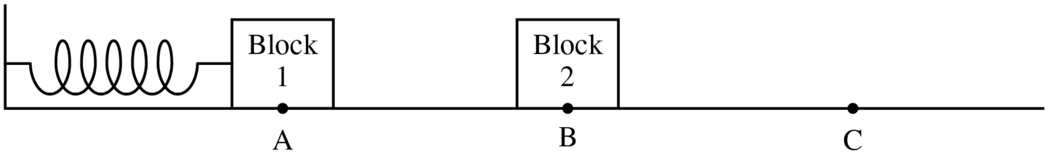


After the block has been oscillating on the table, a motion detector is turned on and the velocity of block 1 as a function of time is measured and plotted in a graph. The students correctly draw a best-fit curve that represents the collected data, as shown above.

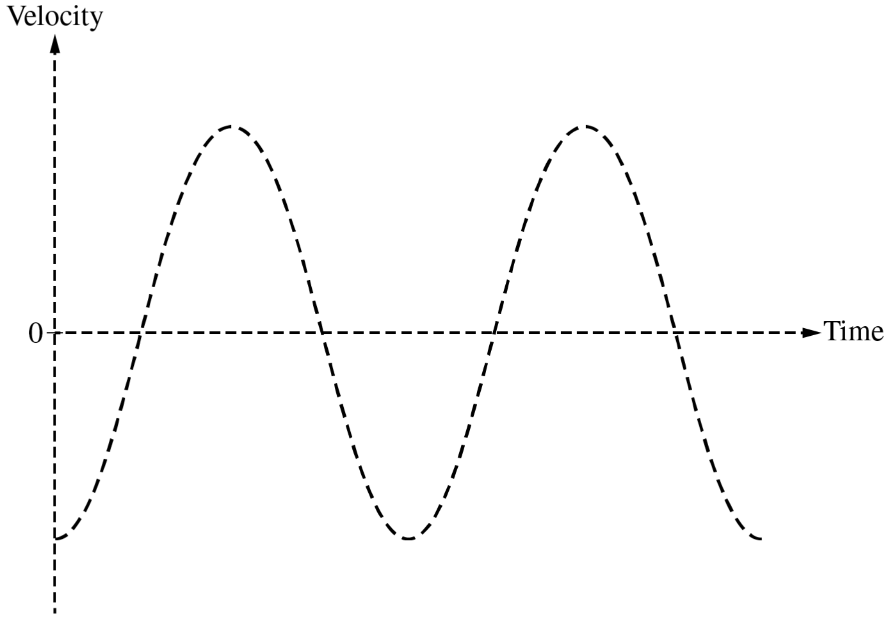
(b) A student looking at the graph of velocity as a function of time makes the following claim.

“*The motion sensor was turned on when the block was at point A and was moving to the left*.”

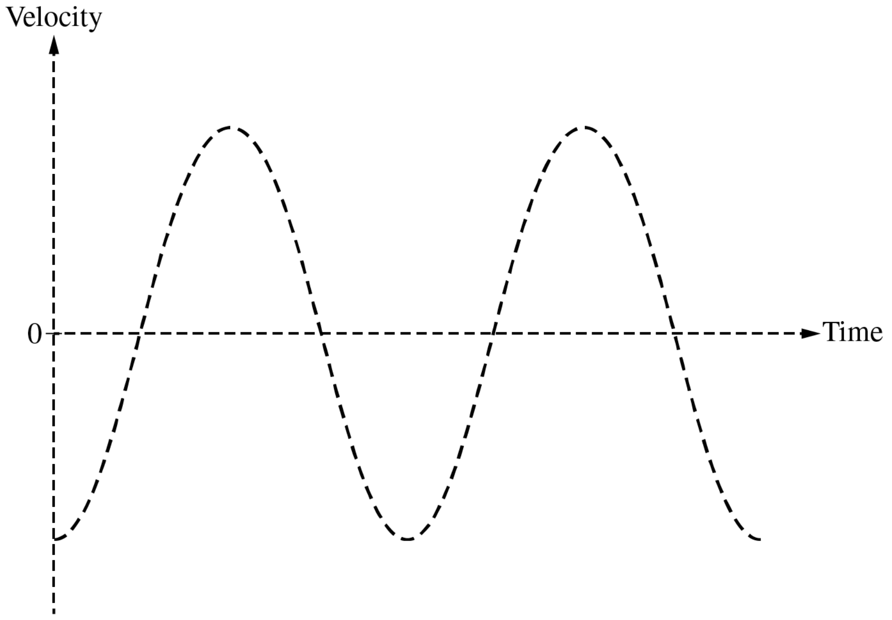
Does the data in this graph support the student’s claim about the location AND the direction of the block’s motion when the motion sensor was turned on? For any incorrect claims, if any, state the correct position and/or direction of motion. Justify your answer.



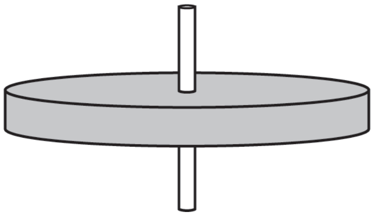
(c) Block 1 is stopped, and again block 1 is held at rest at point A. A second identical block, block 2, is placed at point B. Block 1 is released from rest, and then collides with and sticks to Block 2. After the collision, the two blocks oscillate together on the spring. On the graph below, sketch a curve to indicate the new velocity as a function of time of the two blocks after the collision. For reference, the dashed curve represents the students' best-fit curve of the velocity as a function of time described in part (b).



Note: Do any scratch (practice) work on the graph below. Sketches made below will NOT be graded.



Begin your response to **QUESTION 2** on this page.



2. (12 points, suggested time 25 minutes)

A disk-shaped platform has a known rotational inertia. The platform is mounted on a fixed axle and rotates in a horizontal plane, as shown above. A student wishes to determine the frictional torque exerted on the platform by the axle as the platform rotates. The student has access to equipment that would usually be found in a school physics laboratory.

(a) Describe an experimental procedure the student could use to collect the data needed to find the frictional torque exerted on the platform while it rotates.

i. What quantities would be measured?

ii. What equipment would be used for the measurements, and how would that equipment be used?

iii. Describe the overall procedure to be used, including any steps necessary to reduce experimental uncertainty. Give enough detail so that another student could replicate the experiment.

(b) Describe how the data from the measurements could be analyzed to determine the frictional torque exerted on the rotating platform.

Begin your response to **QUESTION 2** on this page.

It is often assumed that the frictional force between two surfaces is independent of their relative speed. However, the details of the axle's construction are unknown, and it is possible that the frictional torque for the axle depends on the platform's angular speed.

(c) Does the experiment described in parts (a) and (b) depend on the assumption that the frictional torque is independent of the platform's angular speed?

___ Yes   ___ No

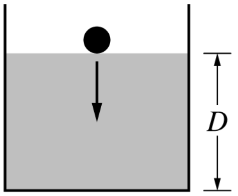
Note: Either answer may be correct, depending on your experimental design.

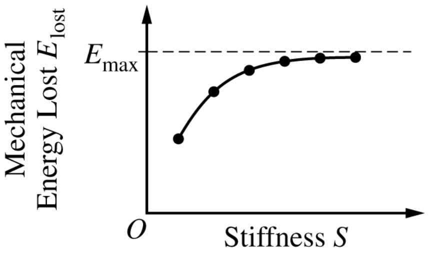
If you answered yes, describe which part of your analysis depends on this assumption.

If you answered no, explain how your analysis does not depend on this assumption.

(d) Briefly describe how the experimental procedure described in parts (a) and (b) could be modified to determine whether the frictional torque stays constant as the angular speed changes. If no modification is necessary, state that explicitly. In either case, describe how the data could be analyzed to determine whether the frictional torque stays constant as the angular speed changes.

Begin your response to **QUESTION 3** on this page.





3. (12 points, suggested time 25 minutes)

Food scientists have created a new oil. At room temperature, the oil is a liquid. As the oil gets colder, however, it stiffens (thickens) into a sticky gel.

To explore the properties of the oil, the scientists fill a container with the oil to a height D, as shown in the figure above on the left. They drop a small steel ball of mass M from rest at the top of the oil. Using video to capture the ball's motion, the scientists calculate E_{lost}, the mechanical energy lost by the ball-Earth system from the time the ball enters the oil to the time just before the ball strikes the bottom of the container.

The scientists also define the "stiffness" S of the oil as a quantity proportional to the force required to move a rod through the oil at a standard constant speed. The scientists calculate E_{lost} and S at several different temperatures, ranging from room temperature to the lowest temperature at which the ball still falls through the oil. The graph above on the right shows as a function of S for the calculated data points and a best-fit curve.

(a) Give a physical reason why the curve in the graph would not reach the vertical (E_{lost}) axis even if the scientists had taken data over a broader range of temperatures.

(b) As S increases, E_{lost} approaches a maximum value labeled E_{max} on the graph above. Write an equation for E_{max} in terms of M, D, and physical constants, as appropriate.

Justify your answer.

Continue your response to **QUESTION 3** on this page.

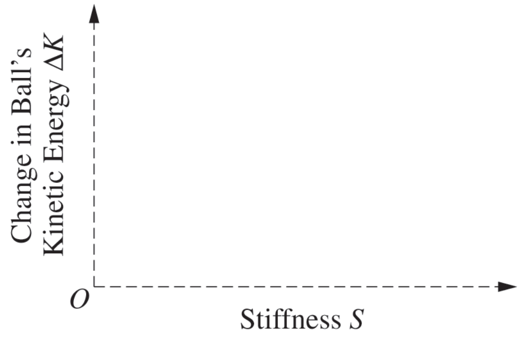
(c) One of the scientists, in trying to represent the relationship between the oil sqffness and the mechanical energy lost, writes down the equation $E_{\text{lost}} = CS^2$ where C is a constant with appropriate units. Another scientist points out that this equation cannot be correct. Give two reasons why the equation cannot be correct.

(d) Further attempting to model the baii$s motion, the scientists write the following equation for the time t the ball takes to fall through the oil: $t = \dfrac{Z}{S}$, where Z is a constant with appropriate units. Is this equation plausible—in other words, does it make physical sense?

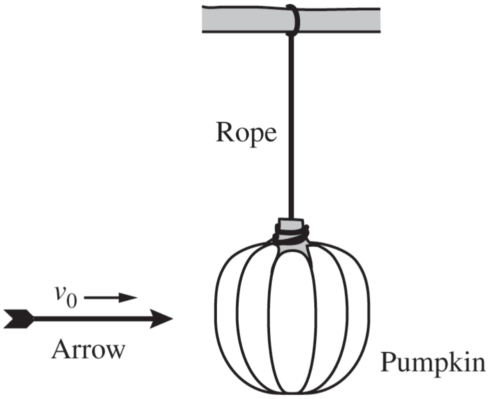
___ Plausible ___ Not plausible

Briefly explain your reasoning.

(e) is the change in kinetic bkbodvof the ball between the time it is released from rest and the time just before the ball strikes the bottom of the container. On the axes below, sketch ΔK as a function of S, the oil stiffness.



Begin your response to **QUESTION 4** on this page.



4. (7 points, suggested time 13 minutes)

An archer tests various arrowheads by shooting arrows at a pumpkin that is suspended from a tree branch by a rope, as shown to the right. When struck head-on by the arrow, the pumpkin swings upward on the rope. The maximum angle θ that the rope makes with the vertical is different for each arrowhead that the archer tests. Each arrow, including its arrowhead, has the same mass m and is shot with the same velocity v_0 toward the right. The arrowheads are made of different materials, however, and each behaves differently when it strikes the pumpkin, as described below.

- *Embedded arrow*: Strikes the pumpkin and remains embedded, while the pumpkin swings to angle θ_{emb}.
- *Pass arrow*: Passes all the way through the pumpkin and continues traveling away from the archer, while the pumpkin swings to angle θ_{pass}.
- *Bounce arrow*: Bounces off the pumpkin back toward the archer, while the pumpkin swings to angle θ_{bounce}.

(a) Rank the three angles θ_{emb}, θ_{pass}, and θ_{bounce} from greatest to least in the spaces indicated below. Use "1" for the greatest angle, "2" for the next greatest, and so on. If any two or all three angles are the same, use the same number for their ranking.

____θ_{emb} ____θ_{pass} ____ θ_{bounce}

(b) In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify your ranking.

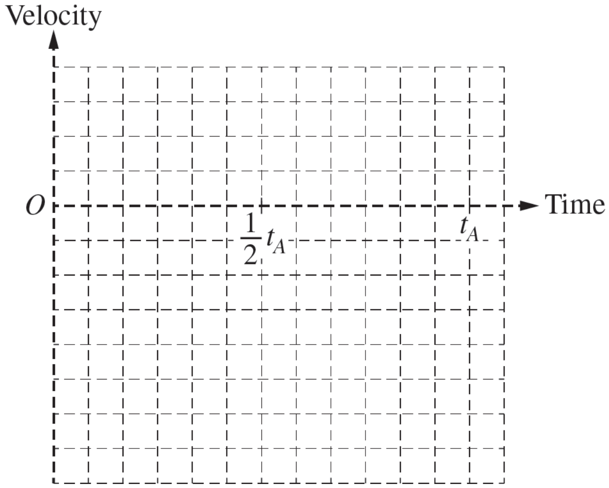
Begin your response to **QUESTION 5** on this page.

5. (7 points, suggested time 13 minutes)

In an experiment two identical rocks are simultaneously thrown from the edge of a cliff a distance h_0 above the ground. Rock A is thrown vertically upward with speed v_0 and rock B is thrown vertically downward with speed v_0. Rock A and rock B strike the ground at times t_A and t_B, respectively. Consider the positive vertical direction to be upward.

(a) On the axes given below, sketch and label graphs of the velocity as a function of time for rock A and rock B.

Label the time t_B. Times t_A and $\frac{1}{2}t_A$ are given on the graph.



(b) Rock B hits the ground at time t_B. Derive an equation for the time t_A it takes rock A to hit the ground in terms of v_0, t_B, and physical constants, as appropriate.

DO NOT WRITE ON THIS PAGE.

STOP

END OF EXAM

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.**

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THIS SECTION II: FREE RESPONSE BOOKLET. MAKE SURE YOU HAVE DONE THE FOLLOWING:

- **COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THIS FREE RESPONSE BOOKLET**
- **CHECKED THAT YOUR AP ID LABEL IS IN THE BOX ON THE FRONT COVER**

Answer Key for AP Physics 1: Algebra-Based

Practice Exam, Section I

Question 1: D
Question 2: B
Question 3: C
Question 4: C
Question 5: A
Question 6: D
Question 7: B
Question 8: D
Question 9: D
Question 10: A
Question 11: D
Question 12: C
Question 13: C
Question 14: B
Question 15: B
Question 16: A
Question 17: B
Question 18: B
Question 19: A
Question 20: A
Question 21: B
Question 22: D
Question 23: D
Question 24: D
Question 25: A
Question 26: B
Question 27: C
Question 28: A
Question 29: D
Question 30: B
Question 31: B
Question 32: B
Question 33: B
Question 34: A
Question 35: D
Question 36: A
Question 37: D
Question 38: B
Question 39: B
Question 40: C
Question 41: B
Question 42: B
Question 43: C
Question 44: A
Question 45: C
Question 131: B, D
Question 132: C, D
Question 133: A, D
Question 134: B, C
Question 135: C, D

Multiple-Choice Section for Physics 1

Course Framework Alignment and Rationales

Question 1

Science Practice	Learning Objective	Topic
6.4	3.A.1.1 4.A.2.1	1.2

(A)	Incorrect. The time an object takes to land on the floor when projected horizontally off the edge of a table depends only on the height of the table. Since both spheres are launched horizontally from the edge of the same table at the same time, they reach the floor at the same time.
(B)	Incorrect. The time an object takes to land on the floor when projected horizontally off the edge of a table depends only on the height of the table. Since both spheres are launched horizontally from the edge of the same table at the same time, they reach the floor at the same time.
(C)	Incorrect. The time an object takes to land on the floor when projected horizontally off the edge of a table depends only on the height of the table. Since both spheres are launched horizontally from the edge of the same table at the same time, they reach the floor at the same time.
(D)	**Correct.** The time an object takes to land on the floor when projected horizontally off the edge of a table depends only on the height of the table. Since both spheres are launched horizontally from the edge of the same table at the same time, they reach the floor at the same time.

Question 2

Science Practice	**Learning Objective**	**Topic**
1.4	3.A.1.1 3.B.2.1 4.B.2.1	5.2

(A)	Incorrect. The coefficient of friction between the box and the floor is $\mu = 0.2$. The force exerted by friction between the box and the floor is equal to $F_f = \mu F_N = 0.2(120\text{ N}) = 24\text{ N}$. The impulse or change in momentum of the box is equal to the net force exerted by the force of friction on the box times 2.0 s. Impulse $= \Delta p = (F_f)(t) = (24\text{ N})(2.0\text{ s}) = 48\text{ kg}\frac{\text{m}}{\text{s}}$.
(B)	**Correct.** The coefficient of friction between the box and the floor is $\mu = 0.2$. The force exerted by friction between the box and the floor is equal to $F_f = \mu F_N = 0.2(120\text{ N}) = 24\text{ N}$. The impulse or change in momentum of the box is equal to the net force exerted by the force of friction on the box times 2.0 s. Impulse $= \Delta p = (F_f)(t) = (24\text{ N})(2.0\text{ s}) = 48\text{ kg}\frac{\text{m}}{\text{s}}$.
(C)	Incorrect. The coefficient of friction between the box and the floor is $\mu = 0.2$. The force exerted by friction between the box and the floor is equal to $F_f = \mu F_N = 0.2(120\text{ N}) = 24\text{ N}$. The impulse or change in momentum of the box is equal to the net force exerted by the force of friction on the box times 2.0 s. Impulse $= \Delta p = (F_f)(t) = (24\text{ N})(2.0\text{ s}) = 48\text{ kg}\frac{\text{m}}{\text{s}}$.
(D)	Incorrect. The coefficient of friction between the box and the floor is $\mu = 0.2$. The force exerted by friction between the box and the floor is equal to $F_f = \mu F_N = 0.2(120\text{ N}) = 24\text{ N}$. The impulse or change in momentum of the box is equal to the net force exerted by the force of friction on the box times 2.0 s. Impulse $= \Delta p = (F_f)(t) = (24\text{ N})(2.0\text{ s}) = 48\text{ kg}\frac{\text{m}}{\text{s}}$.

Question 3

Science Practice	**Learning Objective**	**Topic**
1.4	3.A.1.1	1.1

(A)	Incorrect. Just after $t = 5\ s$ the object has a constant speed for a short interval.
(B)	Incorrect. The area bounded by the graph of the velocity of the object as a function of time represents the displacement of the object. Since the area is positive, the object has a positive displacement and does not start and finish at the same position.
(C)	**Correct.** During the time interval shown, the velocity increases, is constant, and then decreases. However, the velocity of the object is always positive which indicates the object is always moving in the positive direction.
(D)	Incorrect. The slope of the graph of the velocity of the object as a function of time represents the acceleration of the object. During the first 5 seconds the slope of the velocity graph as a function of time has a positive slope, which means the acceleration is positive. During the next short segment, the slope is zero, which means the acceleration of the object is zero. During the last 5 seconds of the motion the slope is negative, meaning that the acceleration of the object is negative.

Question 4

<table>
<tr><th colspan="2">Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td colspan="2">1.4</td><td>4.C.1.1</td><td>4.2</td></tr>
<tr><td>(A)</td><td colspan="3">Incorrect. The initial energy of the ball-Earth system is equal to $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})(1.5\text{ m}) = 3\text{ J}$. Since 0.6 J of energy is lost in the collision, the total mechanical energy of the ball-Earth system after the ball bounces off the floor is $3\text{ J} - 0.6\text{ J} = 2.4\text{ J}$. The maximum height of the ball will occur when all 2.4 J of energy is again gravitational potential energy of the ball-Earth system. $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})h = 2.4\text{ J}$ so $h = 1.2\text{ m}$.</td></tr>
<tr><td>(B)</td><td colspan="3">Incorrect. The initial energy of the ball-Earth system is equal to $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})(1.5\text{ m}) = 3\text{ J}$. Since 0.6 J of energy is lost in the collision, the total mechanical energy of the ball-Earth system after the ball bounces off the floor is $3\text{ J} - 0.6\text{ J} = 2.4\text{ J}$. The maximum height of the ball will occur when all 2.4 J of energy is again gravitational potential energy of the ball-Earth system. $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})h = 2.4\text{ J}$ so $h = 1.2\text{ m}$.</td></tr>
<tr><td>**(C)**</td><td colspan="3">**Correct.** The initial energy of the ball-Earth system is equal to $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})(1.5\text{ m}) = 3\text{ J}$. Since 0.6 J of energy is lost in the collision, the total mechanical energy of the ball-Earth system after the ball bounces off the floor is $3\text{ J} - 0.6\text{ J} = 2.4\text{ J}$. The maximum height of the ball will occur when all 2.4 J of energy is again gravitational potential energy of the ball-Earth system. $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})h = 2.4\text{ J}$ so $h = 1.2\text{ m}$.</td></tr>
<tr><td>(D)</td><td colspan="3">Incorrect. The initial energy of the ball-Earth system is equal to $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})(1.5\text{ m}) = 3\text{ J}$. Since 0.6 J of energy is lost in the collision, the total mechanical energy of the ball-Earth system after the ball bounces off the floor is $3\text{ J} - 0.6\text{ J} = 2.4\text{ J}$. The maximum height of the ball will occur when all 2.4 J of energy is again gravitational potential energy of the ball-Earth system. $mgh = (0.2\text{ kg})(10\ \frac{\text{m}}{\text{s}^2})h = 2.4\text{ J}$ so $h = 1.2\text{ m}$.</td></tr>
</table>

Question 5

Science Practice	**Learning Objective**	**Topic**
7.2	5.B.5.4	4.3

(A)	**Correct.** If the surface had negligible friction, the sum of the gravitational potential energy and kinetic energy (mechanical energy) would remain constant, since there are no external forces exerted on the sled–Earth system. On a hill with friction, an external force is exerted on the sled–Earth system, which dissipates mechanical energy from the system as thermal energy. The total mechanical energy decreases by the same amount dissipated by the force of friction.
(B)	Incorrect. While the gravitational potential energy of the sled-Earth system does decrease, without knowing more about the situation we cannot claim that the kinetic energy must be constant.
(C)	Incorrect. If the surface had negligible friction, the sum of the gravitational potential energy and kinetic energy (mechanical energy) would remain constant, since there are no external forces exerted on the sled–Earth system. On a hill with friction, an external force is exerted on the sled–Earth system, which dissipates mechanical energy from the system as thermal energy. The total mechanical energy decreases by the same amount dissipated by the force of friction.
(D)	Incorrect. While the gravitational potential energy of the sled-Earth system does decrease, without knowing more about the situation we cannot claim that the kinetic energy must decrease.

Question 6

Science Practice	**Learning Objective**	**Topic**
5.1	3.A.1.1 3.A.1.3 3.B.3.3	1.1

(A)	Incorrect. The slope of a displacement as a function of time graph equals velocity. Speed is the absolute value of the slope of a line tangent to the best fit curve of the data of displacement as a function of time.
(B)	Incorrect. The slope of a displacement as a function of time graph equals velocity. Speed is the absolute value of the slope of a line tangent to the best fit curve of the data of displacement as a function of time.
(C)	Incorrect. The slope of a displacement as a function of time graph equals velocity. Speed is the absolute value of the slope of a line tangent to the best fit curve of the data of displacement as a function of time.
(D)	**Correct.** The slope of a displacement as a function of time graph equals velocity. Speed is the absolute value of the slope of a line tangent to the best fit curve of the data of displacement as a function of time.

Question 7

Science Practice	**Learning Objective**	**Topic**
5.1	3.A.1.1 3.A.1.3	1.1

(A)	Incorrect. At time $t = 0.35$ s, the object is at a displacement of approximately -1.5 cm, while at time $t = 0.40$ s the object is at a displacement of approximately -3.5 cm. The distance the object traveled during this time interval is approximately 2 cm.
(B)	**Correct.** At time $t = 0.35$ s, the object is at a displacement of approximately -1.5 cm, while at time $t = 0.40$ s the object is at a displacement of approximately -3.5 cm. The distance the object traveled during this time interval is approximately 2 cm.
(C)	Incorrect. At time $t = 0.35$ s, the object is at a displacement of approximately -1.5 cm, while at time $t = 0.40$ s the object is at a displacement of approximately -3.5 cm. The distance the object traveled during this time interval is approximately 2 cm.
(D)	Incorrect. At time $t = 0.35$ s, the object is at a displacement of approximately -1.5 cm, while at time $t = 0.40$ s the object is at a displacement of approximately -3.5 cm. The distance the object traveled during this time interval is approximately 2 cm.

Question 8

Science Practice	**Learning Objective**	**Topic**
5.1	3.B.3.3	6.1

(A)	Incorrect. Frequency is the inverse of the period of oscillation. As shown by the data, the period of this object is approximately 0.5 s. Frequency is equal to $f = \frac{1}{T} = \frac{1}{0.5\ \text{s}} = 2$ Hz.
(B)	Incorrect. Frequency is the inverse of the period of oscillation. As shown by the data, the period of this object is approximately 0.5 s. Frequency is equal to $f = \frac{1}{T} = \frac{1}{0.5\ \text{s}} = 2$ Hz.
(C)	Incorrect. Frequency is the inverse of the period of oscillation. As shown by the data, the period of this object is approximately 0.5 s. Frequency is equal to $f = \frac{1}{T} = \frac{1}{0.5\ \text{s}} = 2$ Hz.
(D)	**Correct.** Frequency is the inverse of the period of oscillation. As shown by the data, the period of this object is approximately 0.5 s. Frequency is equal to $f = \frac{1}{T} = \frac{1}{0.5\ \text{s}} = 2$ Hz.

Question 9

Science Practice	**Learning Objective**	**Topic**
2.2	3.A.3.1 3.B.1.3	2.5

(A)	Incorrect. For the object to move at a constant speed, the forces exerted on the object must sum to zero and the object is in equilibrium. Since there is a 10 N force directed north and a 10 N force directed west, the third force must have components directed 10 N south and 10 N east in order for the object to be in equilibrium. Vector addition is then used to find the magnitude of the third force: $F = \sqrt{10^2 + 10^2}\ \text{N} = 10\sqrt{2}\ \text{N}$ directed southeast.
(B)	Incorrect. For the object to move at a constant speed, the forces exerted on the object must sum to zero and the object is in equilibrium. Since there is a 10 N force directed north and a 10 N force directed west, the third force must have components directed 10 N south and 10 N east in order for the object to be in equilibrium. Vector addition is then used to find the magnitude of the third force: $F = \sqrt{10^2 + 10^2}\ \text{N} = 10\sqrt{2}\ \text{N}$ directed southeast.
(C)	Incorrect. For the object to move at a constant speed, the forces exerted on the object must sum to zero and the object is in equilibrium. Since there is a 10 N force directed north and a 10 N force directed west, the third force must have components directed 10 N south and 10 N east in order for the object to be in equilibrium. Vector addition is then used to find the magnitude of the third force: $F = \sqrt{10^2 + 10^2}\ \text{N} = 10\sqrt{2}\ \text{N}$ directed southeast.
(D)	**Correct.** For the object to move at a constant speed, the forces exerted on the object must sum to zero and the object is in equilibrium. Since there is a 10 N force directed north and a 10 N force directed west, the third force must have components directed 10 N south and 10 N east in order for the object to be in equilibrium. Vector addition is then used to find the magnitude of the third force: $F = \sqrt{10^2 + 10^2}\ \text{N} = 10\sqrt{2}\ \text{N}$ directed southeast.

Question 10

Science Practice	**Learning Objective**	**Topic**
2.2	5.D.2.5	5.4

(A)	**Correct.** The mechanical energy of the Block A – Earth system is constant from the time block A is at the top of the plane until it reaches the bottom of the plane because there are no external forces doing work on the system. $E_{top} = E_{bottom}$ $mgh = \frac{1}{2}m{v_A}^2$ $(2.0\text{ kg})(10\frac{\text{m}}{\text{s}^2})(3.6\text{ m})\sin 30° = \frac{1}{2}(2.0\text{ kg}){v_A}^2$ $v_A = 6.0\ \frac{\text{m}}{\text{s}}$ At the bottom of the plane, block A is traveling at 6.0 $\frac{\text{m}}{\text{s}}$. During the collision the momentum of the block A – block B system remains constant. The speed of the two-block system after the collision can then be determined using conservation of momentum. $p_i = p_f$ $m_A v_A = (m_A + m_B)v_f$ $(2.0\text{ kg})(6.0\ \frac{\text{m}}{\text{s}}) = (2.0\text{ kg} + 3.0\text{ kg})v_f$ $v_f = 2.4\ \frac{\text{m}}{\text{s}}$
(B)	Incorrect. The mechanical energy of the Block A – Earth system is constant from the time block A is at the top of the plane until it reaches the bottom of the plane because there are no external forces doing work on the system. $E_{top} = E_{bottom}$ $mgh = \frac{1}{2}m{v_A}^2$ $(2.0\text{ kg})(10\frac{\text{m}}{\text{s}^2})(3.6\text{ m})\sin 30° = \frac{1}{2}(2.0\text{ kg}){v_A}^2$ $v_A = 6.0\ \frac{\text{m}}{\text{s}}$ At the bottom of the plane, block A is traveling at 6.0 $\frac{\text{m}}{\text{s}}$. During the collision the momentum of the block A – block B system remains constant. The speed of the two-block system after the collision can then be determined using conservation of momentum. $p_i = p_f$ $m_A v_A = (m_A + m_B)v_f$ $(2.0\text{ kg})(6.0\ \frac{\text{m}}{\text{s}}) = (2.0\text{ kg} + 3.0\text{ kg})v_f$ $v_f = 2.4\ \frac{\text{m}}{\text{s}}$

Question 10 (continued)

(C)	Incorrect. The mechanical energy of the Block A – Earth system is constant from the time block A is at the top of the plane until it reaches the bottom of the plane because there are no external forces doing work on the system. $E_{top} = E_{bottom}$ $mgh = \frac{1}{2}mv_A{}^2$ $(2.0\ \text{kg})(10\frac{\text{m}}{\text{s}^2})(3.6\ \text{m})\sin 30° = \frac{1}{2}(2.0\ \text{kg})v_A{}^2$ $v_A = 6.0\ \frac{\text{m}}{\text{s}}$ At the bottom of the plane, block A is traveling at 6.0 $\frac{\text{m}}{\text{s}}$. During the collision the momentum of the block A – block B system remains constant. The speed of the two-block system after the collision can then be determined using conservation of momentum. $p_i = p_f$ $m_A v_A = (m_A + m_B)v_f$ $(2.0\ \text{kg})(6.0\ \frac{\text{m}}{\text{s}}) = (2.0\ \text{kg} + 3.0\ \text{kg})v_f$ $v_f = 2.4\ \frac{\text{m}}{\text{s}}$
(D)	Incorrect. The mechanical energy of the Block A – Earth system is constant from the time block A is at the top of the plane until it reaches the bottom of the plane because there are no external forces doing work on the system. $E_{top} = E_{bottom}$ $mgh = \frac{1}{2}mv_A{}^2$ $(2.0\ \text{kg})(10\frac{\text{m}}{\text{s}^2})(3.6\ \text{m})\sin 30° = \frac{1}{2}(2.0\ \text{kg})v_A{}^2$ $v_A = 6.0\ \frac{\text{m}}{\text{s}}$ At the bottom of the plane, block A is traveling at 6.0 $\frac{\text{m}}{\text{s}}$. During the collision the momentum of the block A – block B system remains constant. The speed of the two-block system after the collision can then be determined using conservation of momentum. $p_i = p_f$ $m_A v_A = (m_A + m_B)v_f$ $(2.0\ \text{kg})(6.0\ \frac{\text{m}}{\text{s}}) = (2.0\ \text{kg} + 3.0\ \text{kg})v_f$ $v_f = 2.4\ \frac{\text{m}}{\text{s}}$

Question 11

Science Practice	**Learning Objective**	**Topic**
6.4	5.B.5.5	4.3

(A)	Incorrect. Although lifting the box straight up does require a larger force, the student lifts a shorter distance and so the net work done by the student is the same in both cases.
(B)	Incorrect. Although pushing the box up the incline does result in the box having a larger displacement, the student is able to exert a smaller force on the box, and so the work done by the student is the same in both cases.
(C)	Incorrect. Although lifting the box straight up does require a larger force, the student lifts a shorter distance and so the net work done by the student is the same in both cases.
(D)	**Correct.** The amount of work done by the student on the box is equal to the change in energy of the box-Earth system. $W = \Delta E$ $W_{\text{student-on-box}} = mg\Delta h_{\text{box}}$ The amount of energy required to change the location of the box relative to the ground is independent of the path taken to make that change, as described in the correct answer.

Question 12

Science Practice	**Learning Objective**	**Topic**
5.1	4.B.1.2	5.2

(A)	Incorrect. The change in the velocity of the block cannot be calculated by using the equation $v = \frac{\Delta x}{\Delta t}$ as this represents the average velocity, not the total change in the velocity.
(B)	Incorrect. The block is pushed with a constant force, so the acceleration can be assumed to be constant. Using kinematics: $x_f = x_i + v_{i_x}t + \frac{1}{2}a_x t^2$ $(1.6\text{m}) = (0.0\text{m}) + (0) + \frac{1}{2}a_x(4.0\text{s})^2$ $a_x = 0.2\frac{\text{m}}{\text{s}^2}$ The net force on the block is then equal to: $\sum F_x = ma_x = (2.0\text{kg})\left(0.2\frac{\text{m}}{\text{s}^2}\right) = 0.4\text{N}$ And the impulse, or change in momentum is equal to: $\Delta p = F_x \Delta t = (0.4\text{N})(4\text{s}) = 1.6\frac{\text{kgm}}{\text{s}}$
(C)	**Correct.** The block is pushed with a constant force, so the acceleration can be assumed to be constant. Using kinematics: $x_f = x_i + v_{i_x}t + \frac{1}{2}a_x t^2$ $(1.6\text{m}) = (0.0\text{m}) + (0) + \frac{1}{2}a_x(4.0\text{s})^2$ $a_x = 0.2\frac{\text{m}}{\text{s}^2}$ The net force on the block is then equal to: $\sum F_x = ma_x = (2.0\text{kg})\left(0.2\frac{\text{m}}{\text{s}^2}\right) = 0.4\text{N}$ And the impulse, or change in momentum is equal to: $\Delta p = F_x \Delta t = (0.4\text{N})(4\text{s}) = 1.6\frac{\text{kgm}}{\text{s}}$
(D)	Incorrect. The block is pushed with a constant force, so the acceleration can be assumed to be constant. Using kinematics: $x_f = x_i + v_{i_x}t + \frac{1}{2}a_x t^2$ $(1.6\text{m}) = (0.0\text{m}) + (0) + \frac{1}{2}a_x(4.0\text{s})^2$ $a_x = 0.2\frac{\text{m}}{\text{s}^2}$ The net force on the block is then equal to: $\sum F_x = ma_x = (2.0\text{kg})\left(0.2\frac{\text{m}}{\text{s}^2}\right) = 0.4\text{N}$ And the impulse, or change in momentum is equal to: $\Delta p = F_x \Delta t = (0.4\text{N})(4\text{s}) = 1.6\frac{\text{kgm}}{\text{s}}$

Question 13

Science Practice	**Learning Objective**	**Topic**
2.2	4.D.3.1	7.3

(A)	Incorrect. The initial angular momentum of the wheel is given by: $L = I\omega = \left(2.0\text{kg m}^2\right)\left(6.0\frac{\text{rad}}{\text{s}}\right) = 12.0\frac{\text{kgm}^2}{\text{s}}$, however to find the change in the angular momentum, the angular impulse given to the wheel must be calculated. $\Delta L = \tau\Delta t = (5.0\text{Nm})(4.0\text{s}) = 20.0\frac{\text{kgm}^2}{\text{s}}$
(B)	Incorrect. The change in angular momentum is equal to the angular impulse given to the wheel by the applied torque. $\Delta L = \tau\Delta t = (5.0\text{Nm})(4.0\text{s}) = 20.0\frac{\text{kg}\cdot\text{m}^2}{\text{s}}$
(C)	**Correct.** The change in angular momentum is equal to the angular impulse given to the wheel by the applied torque. $\Delta L = \tau\Delta t = (5.0\text{Nm})(4.0\text{s}) = 20.0\frac{\text{kg}\cdot\text{m}^2}{\text{s}}$
(D)	Incorrect. The final angular momentum of the wheel is $L_f = 32.0\frac{\text{kgm}^2}{\text{s}}$, however, the question asks for the change in the angular momentum of the wheel which can be determined by calculating the angular impulse given to the wheel by the applied torque. $\Delta L = \tau\Delta t = (5.0\text{Nm})(4.0\text{s}) = 20.0\frac{\text{kgm}^2}{\text{s}}$

Question 14

Science Practice	Learning Objective	Topic
1.4	5.B.5.3	4.3

(A)	Incorrect. The area between the force as a function of time graph and the horizontal axis represents the work done on the block by the force. The smooth surface does not exert a force of friction on the block, therefore the net force exerted on the block is equal to the force exerted on the block by the spring scale. The area under the graph is then: Area $= W_{net} = \Delta K$. Since the block starts from rest in each case, the block with the greatest final kinetic energy will be moving the fastest. The graph with the largest area under the curve is graph B which will lead to the block moving the fastest at the end of the 1.0 m.
(B)	**Correct.** The area between the force as a function of time graph and the horizontal axis represents the work done on the block by the force. The smooth surface does not exert a force of friction on the block, therefore the net force exerted on the block is equal to the force exerted on the block by the spring scale. The area under the graph is then: Area $= W_{net} = \Delta K$. Since the block starts from rest in each case, the block with the greatest final kinetic energy will be moving the fastest. The graph with the largest area under the curve is graph B which will lead to the block moving the fastest at the end of the 1.0 m.
(C)	Incorrect. The area between the force as a function of time graph and the horizontal axis represents the work done on the block by the force. The smooth surface does not exert a force of friction on the block, therefore the net force exerted on the block is equal to the force exerted on the block by the spring scale. The area under the graph is then: Area $= W_{net} = \Delta K$. Since the block starts from rest in each case, the block with the greatest final kinetic energy will be moving the fastest. The graph with the largest area under the curve is graph B which will lead to the block moving the fastest at the end of the 1.0 m.
(D)	Incorrect. The area between the force as a function of time graph and the horizontal axis represents the work done on the block by the force. The smooth surface does not exert a force of friction on the block, therefore the net force exerted on the block is equal to the force exerted on the block by the spring scale. The area under the graph is then: Area $= W_{net} = \Delta K$. Since the block starts from rest in each case, the block with the greatest final kinetic energy will be moving the fastest. The graph with the largest area under the curve is graph B which will lead to the block moving the fastest at the end of the 1.0 m.

Question 15

Science Practice	**Learning Objective**	**Topic**
6.4	5.D.3.1	5.4

(A)	Incorrect. The center of mass of the system would have landed at point X. Because there are no external horizontal forces exerted on the system, the center of mass of the system must still be at point X after the two pieces land. Because one of the equal mass pieces lands a distance $2R$ from the launch point, and the center of mass of the system is a distance R from the launch point, the other piece of the projectile must land at the launch point.
(B)	**Correct.** The center of mass of the system would have landed at point X. Because there are no external horizontal forces exerted on the system, the center of mass of the system must still be at point X after the two pieces land. Because one of the equal mass pieces lands a distance $2R$ from the launch point, and the center of mass of the system is a distance R from the launch point, the other piece of the projectile must land at the launch point.
(C)	Incorrect. The center of mass of the system would have landed at point X. Because there are no external horizontal forces exerted on the system, the center of mass of the system must still be at point X after the two pieces land. Because one of the equal mass pieces lands a distance $2R$ from the launch point, and the center of mass of the system is a distance R from the launch point, the other piece of the projectile must land at the launch point.
(D)	Incorrect. The center of mass of the system would have landed at point X. Because there are no external horizontal forces exerted on the system, the center of mass of the system must still be at point X after the two pieces land. Because one of the equal mass pieces lands a distance $2R$ from the launch point, and the center of mass of the system is a distance R from the launch point, the other piece of the projectile must land at the launch point.

Question 16

Science Practice	**Learning Objective**	**Topic**
6.4	2.B.1.1 3.B.1.1 3.B.2.1	2.6

(A)	**Correct.** As the elevator moves upward and slows down the velocity is directed upwards and the acceleration is directed downwards. According to Newton's second law, the acceleration of an object is caused by a net force in the same direction. There are two forces exerted on the person in the elevator, the force F from the elevator acting upward, and the force of gravity mg which is exerted downward. For the acceleration to be downwards, the force F from the elevator must be smaller in magnitude than the force of gravity $mg. F < mg$
(B)	Incorrect. As the elevator moves upward and slows down the velocity is directed upwards and the acceleration is directed downwards. According to Newton's second law, the acceleration of an object is caused by a net force in the same direction. There are two forces exerted on the person in the elevator, the force F from the elevator acting upward, and the force of gravity mg which is exerted downward. For the acceleration to be downwards, the force F from the elevator must be smaller in magnitude than the force of gravity $mg. F < mg$
(C)	Incorrect. As the elevator moves upward and slows down the velocity is directed upwards and the acceleration is directed downwards. According to Newton's second law, the acceleration of an object is caused by a net force in the same direction. There are two forces exerted on the person in the elevator, the force F from the elevator acting upward, and the force of gravity mg which is exerted downward. For the acceleration to be downwards, the force F from the elevator must be smaller in magnitude than the force of gravity $mg. F < mg$
(D)	Incorrect. As the elevator moves upward and slows down the velocity is directed upwards and the acceleration is directed downwards. According to Newton's second law, the acceleration of an object is caused by a net force in the same direction. There are two forces exerted on the person in the elevator, the force F from the elevator acting upward, and the force of gravity mg which is exerted downward. For the acceleration to be downwards, the force F from the elevator must be smaller in magnitude than the force of gravity $mg. F < mg$

Question 17

Science Practice	**Learning Objective**	**Topic**
5.1	4.B.2.2	5.2

(A)	Incorrect. Although the force exerted on the block is equal to zero at time $t = t_1$, it does not mean that the block has come to rest.
(B)	**Correct.** The block is originally moving in the positive x-direction and then at time $t = 0$ a force is exerted, also in the positive x-direction. The area between the best fit line of force as a function of time and the horizontal axis represents the impulse given to the block which is equal to the change in the momentum of the block. The area is equal to $\frac{1}{2}F_0t_1$.
(C)	Incorrect. Although the force is decreasing from time $t = 0$ to $t = t_1$, the force is positive the entire time, which means that the change in momentum is positive.
(D)	Incorrect. The change in momentum of the object is only related to the net external force exerted on the object and the time for which that force is exerted. The change in momentum is independent of the distance by which the force probe compressed the block.

Question 18

Science Practice	**Learning Objective**	**Topic**
1.4	3.E.1.3 3.E.1.4 4.C.2.1	4.2

(A)	Incorrect. The area between the graph of force and displacement is equal to the net work done on the cart or the change in kinetic energy of the cart. The net work done on the cart is equal to: $W = \Delta E = (10\text{N})(2\text{m}) - (5\text{N})(2\text{m}) = +10\text{J}$
(B)	**Correct.** The area between the graph of force and displacement is equal to the net work done on the cart or the change in kinetic energy of the cart. The net work done on the cart is equal to: $W = \Delta E = (10\text{N})(2\text{m}) - (5\text{N})(2\text{m}) = +10\text{J}$
(C)	Incorrect. The area between the graph of force and displacement is equal to the net work done on the cart or the change in kinetic energy of the cart. The net work done on the cart is equal to: $W = \Delta E = (10\text{N})(2\text{m}) - (5\text{N})(2\text{m}) = +10\text{J}$
(D)	Incorrect. The area between the graph of force and displacement is equal to the net work done on the cart or the change in kinetic energy of the cart. The net work done on the cart is equal to: $W = \Delta E = (10\text{N})(2\text{m}) - (5\text{N})(2\text{m}) = +10\text{J}$

Question 19

<table>
<tr><th>Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td>7.2</td><td>3.A.4.2</td><td>2.5</td></tr>
<tr><td>(A)</td><td colspan="2">Correct. The forces that cart 1 exerts on cart 2, and the forces that cart 2 exerts on cart 1 are a Newton’s third law pair and are equal in magnitude and opposite in direction. Since cart 1 is initially moving to the right, cart 1 will exert a force that is in the positive direction on cart 2, and cart 2 will exert a force on cart 1 that is in the negative direction.</td></tr>
<tr><td>(B)</td><td colspan="2">Incorrect. The forces that cart 1 exerts on cart 2, and the forces that cart 2 exerts on cart 1 are a Newton’s third law pair and are equal in magnitude and opposite in direction. Since cart 1 is initially moving to the right, cart 1 will exert a force that is in the positive direction on cart 2, and cart 2 will exert a force on cart 1 that is in the negative direction.</td></tr>
<tr><td>(C)</td><td colspan="2">Incorrect. The forces that cart 1 exerts on cart 2, and the forces that cart 2 exerts on cart 1 are a Newton’s third law pair and are equal in magnitude and opposite in direction. Since cart 1 is initially moving to the right, cart 1 will exert a force that is in the positive direction on cart 2, and cart 2 will exert a force on cart 1 that is in the negative direction.</td></tr>
<tr><td>(D)</td><td colspan="2">Incorrect. The forces that cart 1 exerts on cart 2, and the forces that cart 2 exerts on cart 1 are a Newton’s third law pair and are equal in magnitude and opposite in direction. Since cart 1 is initially moving to the right, cart 1 will exert a force that is in the positive direction on cart 2, and cart 2 will exert a force on cart 1 that is in the negative direction.</td></tr>
</table>

Question 20

Science Practice	**Learning Objective**	**Topic**
6.4	4.C.2.1	4.2

(A)	**Correct.** Initially the energy E_1 of the blocks-spring system is zero. The spring is not stretched, and the blocks are not moving so there is no spring potential energy, or kinetic energy. Since Earth is not part of the system there is no gravitational potential energy. The system is released and comes to rest again. At the time when the system again comes to rest, the spring is stretched, so there is spring potential energy stored in the system, but no kinetic energy because the system is again at rest. E_1 has increased. Initially the energy E_2 of the blocks-spring-Earth system includes only gravitational potential energy because the system is at rest and the spring is unstretched. After the system moves and again comes to rest, there is still zero kinetic energy. As block B is lowered and the spring stretches, the gravitational potential energy of the system decreases and there is non-zero spring energy. However, the total energy of the system must decrease because friction exerted on block A by the rough table dissipates some of the system's mechanical energy into thermal energy. E_2 decreases from when the blocks are held at rest to when they come to rest again.
(B)	Incorrect. Initially the energy E_1 of the blocks-spring system is zero. The spring is not stretched, and the blocks are not moving so there is no spring potential energy, or kinetic energy. Since Earth is not part of the system there is no gravitational potential energy. The system is released and comes to rest again. At the time when the system again comes to rest, the spring is stretched, so there is spring potential energy stored in the system, but no kinetic energy because the system is again at rest. E_1 has increased. Initially the energy E_2 of the blocks-spring-Earth system includes only gravitational potential energy because the system is at rest and the spring is unstretched. After the system moves and again comes to rest, there is still zero kinetic energy. As block B is lowered and the spring stretches, the gravitational potential energy of the system decreases and there is non-zero spring energy. However, the total energy of the system must decrease because friction exerted on block A by the rough table dissipates some of the system's mechanical energy into thermal energy. E_2 decreases from when the blocks are held at rest to when they come to rest again.

(C)	Incorrect. Initially the energy E_1 of the blocks-spring system is zero. The spring is not stretched, and the blocks are not moving so there is no spring potential energy, or kinetic energy. Since Earth is not part of the system there is no gravitational potential energy. The system is released and comes to rest again. At the time when the system again comes to rest, the spring is stretched, so there is spring potential energy stored in the system, but no kinetic energy because the system is again at rest. E_1 has increased. Initially the energy E_2 of the blocks-spring-Earth system includes only gravitational potential energy because the system is at rest and the spring is unstretched. After the system moves and again comes to rest, there is still zero kinetic energy. As block B is lowered and the spring stretches, the gravitational potential energy of the system decreases and there is non-zero spring energy. However, the total energy of the system must decrease because friction exerted on block A by the rough table dissipates some of the system's mechanical energy into thermal energy. E_2 decreases from when the blocks are held at rest to when they come to rest again.
(D)	Incorrect. Initially the energy E_1 of the blocks-spring system is zero. The spring is not stretched, and the blocks are not moving so there is no spring potential energy, or kinetic energy. Since Earth is not part of the system there is no gravitational potential energy. The system is released and comes to rest again. At the time when the system again comes to rest, the spring is stretched, so there is spring potential energy stored in the system, but no kinetic energy because the system is again at rest. E_1 has increased. Initially the energy E_2 of the blocks-spring-Earth system includes only gravitational potential energy because the system is at rest and the spring is unstretched. After the system moves and again comes to rest, there is still zero kinetic energy. As block B is lowered and the spring stretches, the gravitational potential energy of the system decreases and there is non-zero spring energy. However, the total energy of the system must decrease because friction exerted on block A by the rough table dissipates some of the system's mechanical energy into thermal energy. E_2 decreases from when the blocks are held at rest to when they come to rest again.

Question 21

Science Practice	**Learning Objective**	**Topic**
6.4	3.A.3.1	3.8

(A)	Incorrect. In case 2, since the cart is moving through the bottom of the dip, the cart is accelerating directly upward at the bottom. This means that the net force must be upward, and so $F_N > mg$. In case 1, since the cart is over the top of the hill, the cart is accelerating toward the center of the circle, which is directly downward. Since the acceleration is downward, the net force is downward, which means that $F_N > mg$. In case 3, the normal force could be greater than or less than the weight of the cart, depending on the speed of the cart.
(B)	**Correct.** In case 2, since the cart is moving through the bottom of the dip, the cart is accelerating directly upward at the bottom. This means that the net force must be upward, and so $F_N > mg$. In case 1, since the cart is over the top of the hill, the cart is accelerating toward the center of the circle, which is directly downward. Since the acceleration is downward, the net force is downward, which means that $F_N > mg$. In case 3, the normal force could be greater than or less than the weight of the cart, depending on the speed of the cart.
(C)	Incorrect. In case 2, since the cart is moving through the bottom of the dip, the cart is accelerating directly upward at the bottom. This means that the net force must be upward, and so $F_N > mg$. In case 1, since the cart is over the top of the hill, the cart is accelerating toward the center of the circle, which is directly downward. Since the acceleration is downward, the net force is downward, which means that $F_N > mg$. In case 3, the normal force could be greater than or less than the weight of the cart, depending on the speed of the cart.
(D)	Incorrect. In case 2, since the cart is moving through the bottom of the dip, the cart is accelerating directly upward at the bottom. This means that the net force must be upward, and so $F_N > mg$. In case 1, since the cart is over the top of the hill, the cart is accelerating toward the center of the circle, which is directly downward. Since the acceleration is downward, the net force is downward, which means that $F_N > mg$. In case 3, the normal force could be greater than or less than the weight of the cart, depending on the speed of the cart.

Question 22

<table>
<tr><th colspan="2">Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td colspan="2">6.4</td><td>3.A.4.1</td><td>2.5</td></tr>
<tr><td>(A)</td><td colspan="3">Incorrect. Newton’s third law states that the mutual forces exerted between any two objects are equal in magnitude and opposite in direction. The two objects cannot exert forces of different magnitude on each other.</td></tr>
<tr><td>(B)</td><td colspan="3">Incorrect. Newton’s third law states that the mutual forces exerted between any two objects are equal in magnitude and opposite in direction. The two objects cannot exert forces of different magnitude on each other.</td></tr>
<tr><td>(C)</td><td colspan="3">Incorrect. Newton’s third law states that the mutual forces exerted between any two objects are equal in magnitude and opposite in direction. The two objects cannot exert forces of different magnitude on each other.</td></tr>
<tr><td>(D)</td><td colspan="3">Correct. Newton’s third law states that the mutual forces exerted between any two objects are equal in magnitude and opposite in direction. The two objects cannot exert forces of different magnitude on each other.</td></tr>
</table>

Question 23

Science Practice	**Learning Objective**	**Topic**
2.2	4.C.1.1 5.B.3.2	4.3

(A)	Incorrect. The gravitational potential energy of the three – sphere system is equal to sum of the gravitational potential energies of each pair of spheres. $U_G = -\frac{Gm_1m_2}{r}$ $U_G = -\frac{G(2m)(m)}{r} - \frac{G(2m)(m)}{r} - \frac{G(m)(m)}{r}$ $U_G = -\frac{G(2m^2)}{r} - \frac{G(2m^2)}{r} - \frac{G(m^2)}{r}$ $U_G = -\frac{5Gm^2}{r}$
(B)	Incorrect. The gravitational potential energy of the three – sphere system is equal to sum of the gravitational potential energies of each pair of spheres. $U_G = -\frac{Gm_1m_2}{r}$ $U_G = -\frac{G(2m)(m)}{r} - \frac{G(2m)(m)}{r} - \frac{G(m)(m)}{r}$ $U_G = -\frac{G(2m^2)}{r} - \frac{G(2m^2)}{r} - \frac{G(m^2)}{r}$ $U_G = -\frac{5Gm^2}{r}$
(C)	Incorrect. The gravitational potential energy of the three – sphere system is equal to sum of the gravitational potential energies of each pair of spheres. $U_G = -\frac{Gm_1m_2}{r}$ $U_G = -\frac{G(2m)(m)}{r} - \frac{G(2m)(m)}{r} - \frac{G(m)(m)}{r}$ $U_G = -\frac{G(2m^2)}{r} - \frac{G(2m^2)}{r} - \frac{G(m^2)}{r}$ $U_G = -\frac{5Gm^2}{r}$
(D)	**Correct.** The gravitational potential energy of the three – sphere system is equal to sum of the gravitational potential energies of each pair of spheres. $U_G = -\frac{Gm_1m_2}{r}$ $U_G = -\frac{G(2m)(m)}{r} - \frac{G(2m)(m)}{r} - \frac{G(m)(m)}{r}$ $U_G = -\frac{G(2m^2)}{r} - \frac{G(2m^2)}{r} - \frac{G(m^2)}{r}$ $U_G = -\frac{5Gm^2}{r}$

Question 24

Science Practice	**Learning Objective**	**Topic**
7.2	3.F.3.1	7.2

(A)	Incorrect. The angular impulse on sphere B with respect to P is equal to the change in the angular momentum of sphere B from before the collision to after the collision. Before the collision sphere B is at rest, and all the angular momentum of sphere A is given to sphere B in the collision. The angular momentum of sphere A with respect to point P is equal to MvR, so the values for M, v and R need to be determined.
(B)	Incorrect. The angular impulse on sphere B with respect to P is equal to the change in the angular momentum of sphere B from before the collision to after the collision. Before the collision sphere B is at rest, and all the angular momentum of sphere A is given to sphere B in the collision. The angular momentum of sphere A with respect to point P is equal to MvR, so the values for M, v and R need to be determined.
(C)	Incorrect. The angular impulse on sphere B with respect to P is equal to the change in the angular momentum of sphere B from before the collision to after the collision. Before the collision sphere B is at rest, and all the angular momentum of sphere A is given to sphere B in the collision. The angular momentum of sphere A with respect to point P is equal to MvR, so the values for M, v and R need to be determined.
(D)	**Correct.** The angular impulse on sphere B with respect to P is equal to the change in the angular momentum of sphere B from before the collision to after the collision. Before the collision sphere B is at rest, and all the angular momentum of sphere A is given to sphere B in the collision. The angular momentum of sphere A with respect to point P is equal to MvR, so the values for M, v and R need to be determined.

Question 25

Science Practice	**Learning Objective**	**Topic**
1.4	5.B.3.3	6.2

(A)	**Correct.** Taking the gravitational potential energy of the block-spring-Earth system as zero at the initial position of the block, the initial mechanical energy of the system is zero. In figure 2, the block is 0.2 m below the zero height, and so the system has gravitational potential energy of $U_g = mgh = (1.0\text{kg})\left(10\frac{\text{m}}{\text{s}^2}\right)(-0.2\text{m}) = -2\text{J}$. Because the spring is now stretched, the elastic potential energy of the spring-block-Earth system is equal to $U_s = \frac{1}{2}kx^2 = \frac{1}{2}\left(50\frac{\text{N}}{\text{m}}\right)(-0.2\text{m})^2 = 1\text{J}$. The total change in energy is then $\Delta E = E_f - E_i$ $\Delta E = (1\text{J} - 2\text{J}) - 0 = -1\text{J}$.
(B)	Incorrect. Taking the gravitational potential energy of the block-spring-Earth system as zero at the initial position of the block, the initial mechanical energy of the system is zero. In figure 2, the block is 0.2 m below the zero height, and so the system has gravitational potential energy of $U_g = mgh = (1.0\text{kg})\left(10\frac{\text{m}}{\text{s}^2}\right)(-0.2\text{m}) = -2\text{J}$. Because the spring is now stretched, the elastic potential energy of the spring-block-Earth system is equal to $U_s = \frac{1}{2}kx^2 = \frac{1}{2}\left(50\frac{\text{N}}{\text{m}}\right)(-0.2\text{m})^2 = 1\text{J}$. The total change in energy is then $\Delta E = E_f - E_i$ $\Delta E = (1\text{J} - 2\text{J}) - 0 = -1\text{J}$.
(C)	Incorrect. Taking the gravitational potential energy of the block-spring-Earth system as zero at the initial position of the block, the initial mechanical energy of the system is zero. In figure 2, the block is 0.2 m below the zero height, and so the system has gravitational potential energy of $U_g = mgh = (1.0\text{kg})\left(10\frac{\text{m}}{\text{s}^2}\right)(-0.2\text{m}) = -2\text{J}$. Because the spring is now stretched, the elastic potential energy of the spring-block-Earth system is equal to $U_s = \frac{1}{2}kx^2 = \frac{1}{2}\left(50\frac{\text{N}}{\text{m}}\right)(-0.2\text{m})^2 = 1\text{J}$. The total change in energy is then $\Delta E = E_f - E_i$ $\Delta E = (1\text{J} - 2\text{J}) - 0 = -1\text{J}$.
(D)	Incorrect. Taking the gravitational potential energy of the block-spring-Earth system as zero at the initial position of the block, the initial mechanical energy of the system is zero. In figure 2, the block is 0.2 m below the zero height, and so the system has gravitational potential energy of $U_g = mgh = (1.0\text{kg})\left(10\frac{\text{m}}{\text{s}^2}\right)(-0.2\text{m}) = -2\text{J}$. Because the spring is now stretched, the elastic potential energy of the spring-block-Earth system is equal to $U_s = \frac{1}{2}kx^2 = \frac{1}{2}\left(50\frac{\text{N}}{\text{m}}\right)(-0.2\text{m})^2 = 1\text{J}$. The total change in energy is then $\Delta E = E_f - E_i$ $\Delta E = (1\text{J} - 2\text{J}) - 0 = -1\text{J}$.

Question 26

Science Practice	**Learning Objective**	**Topic**
2.2	3.B.1.3 3.B.2.1	2.6

(A)	Incorrect. Since all blocks are at rest, the net force acting on each block must be zero. The tension in the string supporting block C must be equal to the weight of block C. $T = m_c g$. The two horizontal forces exerted on block B must also sum to zero since block B remains at rest. The force exerted by block A on block B is exerted to the right and the force of tension exerted by the string to the left. Since block B remains at rest, the force exerted by A on block B must be equal to the tension in the string.
(B)	**Correct.** Since all blocks are at rest, the net force acting on each block must be zero. The tension in the string supporting block C must be equal to the weight of block C. $T = m_c g$. The two horizontal forces exerted on block B must also sum to zero since block B remains at rest. The force exerted by block A on block B is exerted to the right and the force of tension exerted by the string to the left. Since block B remains at rest, the force exerted by A on block B must be equal to the tension in the string.
(C)	Incorrect. Since all blocks are at rest, the net force acting on each block must be zero. The tension in the string supporting block C must be equal to the weight of block C. $T = m_c g$. The two horizontal forces exerted on block B must also sum to zero since block B remains at rest. The force exerted by block A on block B is exerted to the right and the force of tension exerted by the string to the left. Since block B remains at rest, the force exerted by A on block B must be equal to the tension in the string.
(D)	Incorrect. Since all blocks are at rest, the net force acting on each block must be zero. The tension in the string supporting block C must be equal to the weight of block C. $T = m_c g$. The two horizontal forces exerted on block B must also sum to zero since block B remains at rest. The force exerted by block A on block B is exerted to the right and the force of tension exerted by the string to the left. Since block B remains at rest, the force exerted by A on block B must be equal to the tension in the string.

Question 27

<table>
<tr><th>Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td>6.4</td><td>5.B.5.5</td><td>4.3</td></tr>
<tr><td>(A)</td><td colspan="2">Incorrect. The net work done on the box is equal to the change in kinetic energy of the box.
$W_{\text{net}} = \Delta K$
$W_{\text{net}} = K - K_0$
$W_{\text{net}} = \frac{1}{2}m(v^2 - v_0^2)$
Because kinetic energy is a scalar, it depends on the speed of the box, and is independent of the direction of the box's velocity.
Between 0 and t_1, the change in kinetic energy is zero because the initial and final speeds of the box are the same.
Between t_1 and t_2, the speed of the box is constant, and so the kinetic energy of the box remains constant, and there is no net work done on the box.
Between t_2 and t_3, the speed changes from v to zero, which means that the kinetic energy decreases. Therefore, negative work was done on the box during this time interval and $W_{net} < 0$.</td></tr>
<tr><td>(B)</td><td colspan="2">Incorrect. The net work done on the box is equal to the change in kinetic energy of the box.
$W_{\text{net}} = \Delta K$
$W_{\text{net}} = K - K_0$
$W_{\text{net}} = \frac{1}{2}m(v^2 - v_0^2)$
Because kinetic energy is a scalar, it depends on the speed of the box, and is independent of the direction of the box's velocity.
Between 0 and t_1, the change in kinetic energy is zero because the initial and final speeds of the box are the same.
Between t_1 and t_2, the speed of the box is constant, and so the kinetic energy of the box remains constant, and there is no net work done on the box.
Between t_2 and t_3, the speed changes from v to zero, which means that the kinetic energy decreases. Therefore, negative work was done on the box during this time interval and $W_{net} < 0$.</td></tr>
</table>

(C)	**Correct.** The net work done on the box is equal to the change in kinetic energy of the box. $W_{\text{net}} = \Delta K$ $W_{\text{net}} = K - K_0$ $W_{\text{net}} = \frac{1}{2}m(v^2 - v_0^2)$ Because kinetic energy is a scalar, it depends on the speed of the box, and is independent of the direction of the box's velocity. Between 0 and t_1, the change in kinetic energy is zero because the initial and final speeds of the box are the same. Between t_1 and t_2, the speed of the box is constant, and so the kinetic energy of the box remains constant, and there is no net work done on the box. Between t_2 and t_3, the speed changes from v to zero, which means that the kinetic energy decreases. Therefore, negative work was done on the box during this time interval and $W_{net} < 0$.
(D)	Incorrect. The net work done on the box is equal to the change in kinetic energy of the box. $W_{\text{net}} = \Delta K$ $W_{\text{net}} = K - K_0$ $W_{\text{net}} = \frac{1}{2}m(v^2 - v_0^2)$ Because kinetic energy is a scalar, it depends on the speed of the box, and is independent of the direction of the box's velocity. Between 0 and t_1, the change in kinetic energy is zero because the initial and final speeds of the box are the same. Between t_1 and t_2, the speed of the box is constant, and so the kinetic energy of the box remains constant, and there is no net work done on the box. Between t_2 and t_3, the speed changes from v to zero, which means that the kinetic energy decreases. Therefore, negative work was done on the box during this time interval and $W_{net} < 0$.

Question 28

Science Practice	**Learning Objective**	**Topic**
2.1	5.D.2.5	5.4

(A)	**Correct.** In all collisions, momentum is conserved. Because the masses and initial speeds of the carts is known, the final speed of the carts can be calculated using only conservation of momentum. Conservation of energy does not need to be applied to this collision.
(B)	Incorrect. In all collisions, momentum is conserved. Because the masses and initial speeds of the carts is known, the final speed of the carts can be calculated using only conservation of momentum. Conservation of energy does not need to be applied to this collision.
(C)	Incorrect. In all collisions, momentum is conserved. Because the masses and initial speeds of the carts is known, the final speed of the carts can be calculated using only conservation of momentum. Conservation of energy does not need to be applied to this collision.
(D)	Incorrect. In all collisions, momentum is conserved. Because the masses and initial speeds of the carts is known, the final speed of the carts can be calculated using only conservation of momentum. Conservation of energy does not need to be applied to this collision.

Question 29

Science Practice	**Learning Objective**	**Topic**
1.4	4.D.2.1	7.3
(A)	Incorrect. When a block is dropped onto the disk, it sticks to the disk, increasing the rotational inertia of the disk-block system, and decreasing the rotational speed of the disk-block system. The rotational inertia of the block-disk system is equal to $I_{disk} + mr^2$, where m is the mass of the block and r is the distance from the center of the disk to the location of the block. The larger the rotational inertia, the smaller the final rotational speed after the block is dropped. Block A is furthest from the center of the disk and will increase the rotational inertia of the system the most, and decrease the angular speed the most. Block C by contrast is closest to the center of the disk, will increase the rotational inertia the least and so will decrease the angular speed the least. The correct ordering of blocks corresponds to the relative change in angular speed and position of the blocks on the disk.	
(B)	Incorrect. When a block is dropped onto the disk, it sticks to the disk, increasing the rotational inertia of the disk-block system, and decreasing the rotational speed of the disk-block system. The rotational inertia of the block-disk system is equal to $I_{disk} + mr^2$, where m is the mass of the block and r is the distance from the center of the disk to the location of the block. The larger the rotational inertia, the smaller the final rotational speed after the block is dropped. Block A is furthest from the center of the disk and will increase the rotational inertia of the system the most, and decrease the angular speed the most. Block C by contrast is closest to the center of the disk, will increase the rotational inertia the least and so will decrease the angular speed the least. The correct ordering of blocks corresponds to the relative change in angular speed and position of the blocks on the disk.	

Question 29 (continued)

(C)	Incorrect. When a block is dropped onto the disk, it sticks to the disk, increasing the rotational inertia of the disk-block system, and decreasing the rotational speed of the disk-block system. The rotational inertia of the block-disk system is equal to $I_{disk} + mr^2$, where m is the mass of the block and r is the distance from the center of the disk to the location of the block. The larger the rotational inertia, the smaller the final rotational speed after the block is dropped. Block A is furthest from the center of the disk and will increase the rotational inertia of the system the most, and decrease the angular speed the most. Block C by contrast is closest to the center of the disk, will increase the rotational inertia the least and so will decrease the angular speed the least. The correct ordering of blocks corresponds to the relative change in angular speed and position of the blocks on the disk.
(D)	**Correct.** When a block is dropped onto the disk, it sticks to the disk, increasing the rotational inertia of the disk-block system, and decreasing the rotational speed of the disk-block system. The rotational inertia of the block-disk system is equal to $I_{disk} + mr^2$, where m is the mass of the block and r is the distance from the center of the disk to the location of the block. The larger the rotational inertia, the smaller the final rotational speed after the block is dropped. Block A is furthest from the center of the disk and will increase the rotational inertia of the system the most, and decrease the angular speed the most. Block C by contrast is closest to the center of the disk, will increase the rotational inertia the least and so will decrease the angular speed the least. The correct ordering of blocks corresponds to the relative change in angular speed and position of the blocks on the disk.

Question 30

<table>
<tr><th colspan="2">Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td colspan="2">1.4</td><td>4.D.2.2</td><td>7.3</td></tr>
<tr><td>(A)</td><td colspan="3">Incorrect. The angular momentum of the three block – disk system is constant from before the collisions start until after all three blocks are on the disk. Because there are no external torques on the system, and the angular momentum is constant, the final speed of the system is the same regardless of the order in which the blocks are dropped onto the disk.</td></tr>
<tr><td>(B)</td><td colspan="3">Correct. The angular momentum of the three block – disk system is constant from before the collisions start until after all three blocks are on the disk. Because there are no external torques on the system, and the angular momentum is constant, the final speed of the system is the same regardless of the order in which the blocks are dropped onto the disk.</td></tr>
<tr><td>(C)</td><td colspan="3">Incorrect. The angular momentum of the three block – disk system is constant from before the collisions start until after all three blocks are on the disk. Because there are no external torques on the system, and the angular momentum is constant, the final speed of the system is the same regardless of the order in which the blocks are dropped onto the disk.</td></tr>
<tr><td>(D)</td><td colspan="3">Incorrect. The angular momentum of the three block – disk system is constant from before the collisions start until after all three blocks are on the disk. Because there are no external torques on the system, and the angular momentum is constant, the final speed of the system is the same regardless of the order in which the blocks are dropped onto the disk.</td></tr>
</table>

Question 31

<table>
<tr><th colspan="2">Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td colspan="2">1.4</td><td>3.F.1.1</td><td>7.2</td></tr>
<tr><td>(A)</td><td colspan="3">Incorrect. Since the meterstick is positioned on the fulcrum at its center, if there were no other forces exerted on the meterstick, it would remain horizontal. The addition of the force F exerted two spaces to the left of the fulcrum, creates a torque equal to $\tau = (F)(2x) = 2Fx$ in the counterclockwise direction. In order for the meterstick to remain horizontal, there needs to be another force creating an equal magnitude torque in the clockwise direction. An upward force at either C or D would create a torque in the counterclockwise direction. Since the new force is to be twice as large, the force must be exerted at half the distance. An upward force exerted at point B would create a counterclockwise torque equal to $\tau = (2F)(x) = 2Fx$ and keep the meterstick in equilibrium.</td></tr>
<tr><td>(B)</td><td colspan="3">Correct. Since the meterstick is positioned on the fulcrum at its center, if there were no other forces exerted on the meterstick, it would remain horizontal. The addition of the force F exerted two spaces to the left of the fulcrum, creates a torque equal to $\tau = (F)(2x) = 2Fx$ in the counterclockwise direction. In order for the meterstick to remain horizontal, there needs to be another force creating an equal magnitude torque in the clockwise direction. An upward force at either C or D would create a torque in the counterclockwise direction. Since the new force is to be twice as large, the force must be exerted at half the distance. An upward force exerted at point B would create a counterclockwise torque equal to $\tau = (2F)(x) = 2Fx$ and keep the meterstick in equilibrium.</td></tr>
</table>

(C)	Incorrect. Since the meterstick is positioned on the fulcrum at its center, if there were no other forces exerted on the meterstick, it would remain horizontal. The addition of the force F exerted two spaces to the left of the fulcrum, creates a torque equal to $\tau = (F)(2x) = 2Fx$ in the counterclockwise direction. In order for the meterstick to remain horizontal, there needs to be another force creating an equal magnitude torque in the clockwise direction. An upward force at either C or D would create a torque in the counterclockwise direction. Since the new force is to be twice as large, the force must be exerted at half the distance. An upward force exerted at point B would create a counterclockwise torque equal to $\tau = (2F)(x) = 2Fx$ and keep the meterstick in equilibrium.
(D)	Incorrect. Since the meterstick is positioned on the fulcrum at its center, if there were no other forces exerted on the meterstick, it would remain horizontal. The addition of the force F exerted two spaces to the left of the fulcrum, creates a torque equal to $\tau = (F)(2x) = 2Fx$ in the counterclockwise direction. In order for the meterstick to remain horizontal, there needs to be another force creating an equal magnitude torque in the clockwise direction. An upward force at either C or D would create a torque in the counterclockwise direction. Since the new force is to be twice as large, the force must be exerted at half the distance. An upward force exerted at point B would create a counterclockwise torque equal to $\tau = (2F)(x) = 2Fx$ and keep the meterstick in equilibrium.

Question 32

Science Practice	**Learning Objective**	**Topic**
1.5	3.A.1.1 3.B.1.1	1.1

(A)	Incorrect. During the elastic collision with the ceiling, the horizontal velocity remains constant, and the graph must be a constant value. The vertical velocity changes direction, and the graph must change from positive to negative. The slope of the vertical velocity graph should be equal to the acceleration due to gravity. The slope will be constant, and at time t_1, the velocity switches direction.
(B)	**Correct.** During the elastic collision with the ceiling, the horizontal velocity remains constant, and the graph must be a constant value. The vertical velocity changes direction, and the graph must change from positive to negative. The slope of the vertical velocity graph should be equal to the acceleration due to gravity. The slope will be constant, and at time t_1, the velocity switches direction.
(C)	Incorrect. During the elastic collision with the ceiling, the horizontal velocity remains constant, and the graph must be a constant value. The vertical velocity changes direction, and the graph must change from positive to negative. The slope of the vertical velocity graph should be equal to the acceleration due to gravity. The slope will be constant, and at time t_1, the velocity switches direction.
(D)	Incorrect. During the elastic collision with the ceiling, the horizontal velocity remains constant, and the graph must be a constant value. The vertical velocity changes direction, and the graph must change from positive to negative. The slope of the vertical velocity graph should be equal to the acceleration due to gravity. The slope will be constant, and at time t_1, the velocity switches direction.

Question 33

Science Practice	**Learning Objective**	**Topic**
2.2	3.C.1.2	3.3

(A)	Incorrect. A satellite moves in a circular orbit because the gravitational force exerted on the satellite by the planet causes a centripetal acceleration. Using this relationship, the velocity of the satellite in terms of its distance from the planet can be derived: $\frac{GM_Em_s}{R^2}=\frac{m_sv^2}{R}$ $\frac{GM_E}{R}=v^2$. $v=\sqrt{\frac{GM_E}{R}}$. The orbital speed of each satellite is proportional to the square root of $\frac{1}{R}$, so if R is nine times larger, $v_B=v_A\sqrt{\frac{1}{9}}$. $v_B=\frac{v_A}{3}$
(B)	**Correct.** A satellite moves in a circular orbit because the gravitational force exerted on the satellite by the planet causes a centripetal acceleration. Using this relationship, the velocity of the satellite in terms of its distance from the planet can be derived: $\frac{GM_Em_s}{R^2}=\frac{m_sv^2}{R}$ $\frac{GM_E}{R}=v^2$. $v=\sqrt{\frac{GM_E}{R}}$. The orbital speed of each satellite is proportional to the square root of $\frac{1}{R}$, so if R is nine times larger, $v_B=v_A\sqrt{\frac{1}{9}}$. $v_B=\frac{v_A}{3}$
(C)	Incorrect. A satellite moves in a circular orbit because the gravitational force exerted on the satellite by the planet causes a centripetal acceleration. Using this relationship, the velocity of the satellite in terms of its distance from the planet can be derived: $\frac{GM_Em_s}{R^2}=\frac{m_sv^2}{R}$ $\frac{GM_E}{R}=v^2$. $v=\sqrt{\frac{GM_E}{R}}$. The orbital speed of each satellite is proportional to the square root of $\frac{1}{R}$, so if R is nine times larger, $v_B=v_A\sqrt{\frac{1}{9}}$. $v_B=\frac{v_A}{3}$
(D)	Incorrect. A satellite moves in a circular orbit because the gravitational force exerted on the satellite by the planet causes a centripetal acceleration. Using this relationship, the velocity of the satellite in terms of its distance from the planet can be derived: $\frac{GM_Em_s}{R^2}=\frac{m_sv^2}{R}$ $\frac{GM_E}{R}=v^2$. $v=\sqrt{\frac{GM_E}{R}}$. The orbital speed of each satellite is proportional to the square root of $\frac{1}{R}$, so if R is nine times larger, $v_B=v_A\sqrt{\frac{1}{9}}$. $v_B=\frac{v_A}{3}$

Question 34

Science Practice	**Learning Objective**	**Topic**
7.2	4.A.1.1 5.D.1.1 5.D.2.1	1.2

(A)	**Correct.** During each collision, the net external force on the two-cart system is equal to zero, meaning that the change in momentum of the center of mass is equal to zero. Because the change in momentum of the center of mass is equal to zero, the speed of the center of mass does not change during the collision.
(B)	Incorrect. During each collision, the net external force on the two-cart system is equal to zero, meaning that the change in momentum of the center of mass is equal to zero. Because the change in momentum of the center of mass is equal to zero, the speed of the center of mass does not change during the collision.
(C)	Incorrect. During each collision, the net external force on the two-cart system is equal to zero, meaning that the change in momentum of the center of mass is equal to zero. Because the change in momentum of the center of mass is equal to zero, the speed of the center of mass does not change during the collision.
(D)	Incorrect. During each collision, the net external force on the two-cart system is equal to zero, meaning that the change in momentum of the center of mass is equal to zero. Because the change in momentum of the center of mass is equal to zero, the speed of the center of mass does not change during the collision.

Question 35

Science Practice	Learning Objective	Topic
1.2 1.4 6.4	4.A.1.1	1.2

(A)	Incorrect. Initially, the two astronaut-container system is at rest relative to the space station, and the initial momentum of the system is equal to zero. Just after astronaut X throws the container towards astronaut Y to the right, the two astronaut-system must move to the left so that the total momentum of the two astronauts-container system is zero. Once astronaut Y catches the container, the astronauts-container system again comes to rest, keeping the momentum of the system equal to zero.
(B)	Incorrect. Initially, the two astronaut-container system is at rest relative to the space station, and the initial momentum of the system is equal to zero. Just after astronaut X throws the container towards astronaut Y to the right, the two astronaut-system must move to the left so that the total momentum of the two astronauts-container system is zero. Once astronaut Y catches the container, the astronauts-container system again comes to rest, keeping the momentum of the system equal to zero.
(C)	Incorrect. Initially, the two astronaut-container system is at rest relative to the space station, and the initial momentum of the system is equal to zero. Just after astronaut X throws the container towards astronaut Y to the right, the two astronaut-system must move to the left so that the total momentum of the two astronauts-container system is zero. Once astronaut Y catches the container, the astronauts-container system again comes to rest, keeping the momentum of the system equal to zero.
(D)	**Correct.** Initially, the two astronaut-container system is at rest relative to the space station, and the initial momentum of the system is equal to zero. Just after astronaut X throws the container towards astronaut Y to the right, the two astronaut-system must move to the left so that the total momentum of the two astronauts-container system is zero. Once astronaut Y catches the container, the astronauts-container system again comes to rest, keeping the momentum of the system equal to zero.

Question 36

Science Practice	**Learning Objective**	**Topic**
2.2 6.4	4.C.2.1 5.B.5.5	4.2

(A)	**Correct.** The force exerted by the spring as a function of the length of the spring looks to be linear, and a best-fit line can be drawn to represent the trend of the data. The area between the best-fit line and the horizontal axis between $x = 0.2$ m and $x = 0.3$ m is equal to the work done on the spring by the block while compressing the spring. As no other forces act on the block-spring system, the spring will do the same amount of work on the block. The block starts from rest, so this work is equal to the final kinetic energy of the block. $\text{Area} = W$ $W = \Delta K_{\text{block}}$ $\frac{1}{2}(\text{base} \times \text{height}) = \Delta K_{\text{block}}$ $\frac{1}{2}\left((0.1\text{m}) \times (60\text{N})\right) = \Delta K_{\text{block}}$ $3\text{J} = \Delta K_{\text{block}}$
(B)	Incorrect. The force exerted by the spring as a function of the length of the spring looks to be linear, and a best-fit line can be drawn to represent the trend of the data. The area between the best-fit line and the horizontal axis between $x = 0.2$ m and $x = 0.3$ m is equal to the work done on the spring by the block while compressing the spring. As no other forces act on the block-spring system, the spring will do the same amount of work on the block. The block starts from rest, so this work is equal to the final kinetic energy of the block. $\text{Area} = W$ $W = \Delta K_{\text{block}}$ $\frac{1}{2}(\text{base} \times \text{height}) = \Delta K_{\text{block}}$ $\frac{1}{2}\left((0.1\text{m}) \times (60\text{N})\right) = \Delta K_{\text{block}}$ $3\text{J} = \Delta K_{\text{block}}$

Question 36 (continued)

(C)	Incorrect. The force exerted by the spring as a function of the length of the spring looks to be linear, and a best-fit line can be drawn to represent the trend of the data. The area between the best-fit line and the horizontal axis between $x - 0.2\ \text{m}$ and $x = 0.3\ \text{m}$ is equal to the work done on the spring by the block while compressing the spring. As no other forces act on the block-spring system, the spring will do the same amount of work on the block. The block starts from rest, so this work is equal to the final kinetic energy of the block. $\text{Area} = W$ $W = \Delta K_{\text{block}}$ $\frac{1}{2}(\text{base} \times \text{height}) = \Delta K_{\text{block}}$ $\frac{1}{2}\left((0.1\text{m}) \times (60\text{N})\right) = \Delta K_{\text{block}}$ $3\text{J} = \Delta K_{\text{block}}$
(D)	Incorrect. The force exerted by the spring as a function of the length of the spring looks to be linear, and a best-fit line can be drawn to represent the trend of the data. The area between the best-fit line and the horizontal axis between $x = 0.2\ \text{m}$ and $x = 0.3\ \text{m}$ is equal to the work done on the spring by the block while compressing the spring. As no other forces act on the block-spring system, the spring will do the same amount of work on the block. The block starts from rest, so this work is equal to the final kinetic energy of the block. $\text{Area} = W$ $W = \Delta K_{\text{block}}$ $\frac{1}{2}(\text{base} \times \text{height}) = \Delta K_{\text{block}}$ $\frac{1}{2}\left((0.1\text{m}) \times (60\text{N})\right) = \Delta K_{\text{block}}$ $3\text{J} = \Delta K_{\text{block}}$

Question 37

<table>
<tr><th colspan="2">Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td colspan="2">1.4</td><td>3.B.2.1</td><td>2.6</td></tr>
<tr><td>(A)</td><td colspan="3">Incorrect. The slope of the vertical velocity as a function of time is negative, which means that the acceleration is negative, and the vertical component of the net force must also be negative. In this free body diagram, the sum of the vertical components is zero.</td></tr>
<tr><td>(B)</td><td colspan="3">Incorrect. The horizontal velocity is constant, and the horizontal acceleration is zero. Because the horizontal acceleration is zero, the horizontal component of the net force must be equal to zero. In this free body diagram, the sum of the horizontal components is nonzero. The slope of the vertical velocity as a function of time is negative, which means that the acceleration is negative, and the vertical component of the net force must be negative. In this free body diagram, the sum of the vertical components is zero.</td></tr>
<tr><td>(C)</td><td colspan="3">Incorrect. The slope of the vertical velocity as a function of time is negative, which means that the acceleration is negative, and the vertical component of the net force must be negative. In this free body diagram, the sum of the vertical components is zero.</td></tr>
<tr><td>(D)</td><td colspan="3">Correct. The horizontal velocity is constant, which means that the horizontal acceleration is zero. Because the horizontal acceleration is zero, the horizontal component of the net force must be equal to zero. The slope of the vertical velocity as a function of time is negative, which means that the acceleration is negative and the vertical component of the net force must be negative. In this free body diagram, the sum of the horizontal components is zero, and the sum of the vertical components is negative.</td></tr>
</table>

Question 38

Science Practice	**Learning Objective**	**Topic**
1.4	3.B.2.1	2.6

(A)	Incorrect. As block A passes point P, the net force on the block A – block B system increases because there is no longer a frictional force exerted on block A from the surface. Because the net force on the system increases, the acceleration of the system must also increase. Looking at block B only, there are only two horizontal forces, the force of tension and the frictional force. Since the frictional force remains constant on block B, but the acceleration of block B increases, the force of tension exerted on block B must also increase.
(B)	**Correct.** As block A passes point P, the net force on the block A – block B system increases because there is no longer a frictional force exerted on block A from the surface. Because the net force on the system increases, the acceleration of the system must also increase. Looking at block B only, there are only two horizontal forces, the force of tension and the frictional force. Since the frictional force remains constant on block B, but the acceleration of block B increases, the force of tension exerted on block B must also increase.
(C)	Incorrect. As block A passes point P, the net force on the block A – block B system increases because there is no longer a frictional force exerted on block A from the surface. Because the net force on the system increases, the acceleration of the system must also increase. Looking at block B only, there are only two horizontal forces, the force of tension and the frictional force. Since the frictional force remains constant on block B, but the acceleration of block B increases, the force of tension exerted on block B must also increase.
(D)	Incorrect. As block A passes point P, the net force on the block A – block B system increases because there is no longer a frictional force exerted on block A from the surface. Because the net force on the system increases, the acceleration of the system must also increase. Looking at block B only, there are only two horizontal forces, the force of tension and the frictional force. Since the frictional force remains constant on block B, but the acceleration of block B increases, the force of tension exerted on block B must also increase.

Question 39

<table>
<tr><th>Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td>6.4</td><td>4.C.2.1</td><td>4.2</td></tr>
<tr><td>(A)</td><td colspan="2">Incorrect. The change in kinetic energy of the box is equal to the work done by the external force. In this situation, the net external force is equal in both the first and second section, and the distance traveled through each section is equal. Therefore, equal work is done on the box and the change in the kinetic energy is also equal.</td></tr>
<tr><td>(B)</td><td colspan="2">Correct. The change in kinetic energy of the box is equal to the work done by the external force. In this situation, the net external force is equal in both the first and second section, and the distance traveled through each section is equal. Therefore, equal work is done on the box and the change in the kinetic energy is also equal.</td></tr>
<tr><td>(C)</td><td colspan="2">Incorrect. The change in kinetic energy of the box is equal to the work done by the external force. In this situation, the net external force is equal in both the first and second section, and the distance traveled through each section is equal. Therefore, equal work is done on the box and the change in the kinetic energy is also equal.</td></tr>
<tr><td>(D)</td><td colspan="2">Incorrect. The change in kinetic energy of the box is equal to the work done by the external force. In this situation, the net external force is equal in both the first and second section, and the distance traveled through each section is equal. Therefore, equal work is done on the box and the change in the kinetic energy is also equal.</td></tr>
</table>

Question 40

<table>
<tr><th colspan="2">Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td colspan="2">6.4</td><td>5.B.4.1</td><td>4.3</td></tr>
<tr><td>(A)</td><td colspan="3">Incorrect. Although both blocks do travel the same distance, the change in gravitational potential energy for the block 1-Earth system does not equal the change in gravitational potential energy for the block 2-Earth system.</td></tr>
<tr><td>(B)</td><td colspan="3">Incorrect. Although both blocks do gain the same amount of kinetic energy, the change in gravitational potential energy for the block 1-Earth system does not equal the change in gravitational potential energy for the block 2-Earth system.</td></tr>
<tr><td>**(C)**</td><td colspan="3">**Correct.** Initially, the system consisting of the two blocks and the earth is at rest and can be said to have some gravitational potential energy. The potential energy lost by the block 2- earth system has to be greater than the potential energy gained by the block 1 – earth system because the height change of block 2 is greater than the height change of block 1, even though they travel the same distance. The difference in the change of gravitation potential energy for each block is converted into kinetic energy in the system.</td></tr>
<tr><td>(D)</td><td colspan="3">Incorrect. Although the change in gravitational potential energy for the block 1-Earth system is less than the change in gravitational potential energy for the block 2-Earth system, the tension exerted on block 1 by the string is not less than the tension exerted on block 2 by the string.</td></tr>
</table>

Question 41

Science Practice	**Learning Objective**	**Topic**
6.4	4.A.1.1	1.2

(A)	Incorrect. When the ball is in the launcher, it travels with the launcher and has the same horizontal speed as the block and launcher. There is no net horizontal force on either the ball or the launcher-block system, so the horizontal speed of both the ball and launcher-block does not change. As the ball rises and reaches the maximum height, both the ball and launcher-block continue forward at the same speed, so the ball is still directly over the launcher.
(B)	**Correct.** When the ball is in the launcher, it travels with the launcher and has the same horizontal speed as the block and launcher. There is no net horizontal force on either the ball or the launcher-block system, so the horizontal speed of both the ball and launcher-block does not change. As the ball rises and reaches the maximum height, both the ball and launcher-block continue forward at the same speed, so the ball is still directly over the launcher.
(C)	Incorrect. When the ball is in the launcher, it travels with the launcher and has the same horizontal speed as the block and launcher. There is no net horizontal force on either the ball or the launcher-block system, so the horizontal speed of both the ball and launcher-block does not change. As the ball rises and reaches the maximum height, both the ball and launcher-block continue forward at the same speed, so the ball is still directly over the launcher.
(D)	Incorrect. When the ball is in the launcher, it travels with the launcher and has the same horizontal speed as the block and launcher. There is no net horizontal force on either the ball or the launcher-block system, so the horizontal speed of both the ball and launcher-block does not change. As the ball rises and reaches the maximum height, both the ball and launcher-block continue forward at the same speed, so the ball is still directly over the launcher.

Question 42

Science Practice	**Learning Objective**	**Topic**
4.2	4.D.3.2	7.3

(A)	Incorrect. The wheel is initially at rest, meaning that its initial angular momentum is zero. The force exerted on the wheel multiplied by the distance between the application of the force and the center of the wheel will give the torque exerted on the wheel. The torque exerted on the wheel multiplied by the time the force is exerted for is equal to the angular impulse or change in angular momentum of the wheel. For final angular momentum to be calculated, the student needs to measure the radius of the wheel.
(B)	**Correct.** The wheel is initially at rest, meaning that its initial angular momentum is zero. The force exerted on the wheel multiplied by the distance between the application of the force and the center of the wheel will give the torque exerted on the wheel. The torque exerted on the wheel multiplied by the time the force is exerted for is equal to the angular impulse or change in angular momentum of the wheel. For final angular momentum to be calculated, the student needs to measure the radius of the wheel.
(C)	Incorrect. The wheel is initially at rest, meaning that its initial angular momentum is zero. The force exerted on the wheel multiplied by the distance between the application of the force and the center of the wheel will give the torque exerted on the wheel. The torque exerted on the wheel multiplied by the time the force is exerted for is equal to the angular impulse or change in angular momentum of the wheel. For final angular momentum to be calculated, the student needs to measure the radius of the wheel.
(D)	Incorrect. The wheel is initially at rest, meaning that its initial angular momentum is zero. The force exerted on the wheel multiplied by the distance between the application of the force and the center of the wheel will give the torque exerted on the wheel. The torque exerted on the wheel multiplied by the time the force is exerted for is equal to the angular impulse or change in angular momentum of the wheel. For final angular momentum to be calculated, the student needs to measure the radius of the wheel.

Question 43

Science Practice	**Learning Objective**	**Topic**
6.4	3.A.3.1	3.8
(A)	Incorrect. The planets all have the same density, so the mass of each planet is related to the radius of the planet cubed. $\rho = \frac{M}{V}$ $M = \rho V$ $M = \rho\left(\frac{4}{3}\pi R^3\right)$ The force of gravity between each sphere can be determined $F_g = \frac{Gm_1m_2}{r^2}$ $F_{g_A} = \frac{G\left(\frac{4}{3}\pi R^3\right)\left(\frac{4}{3}\pi R^3\right)}{R^2} \propto \frac{16}{9}R^4$ $F_{g_B} = \frac{G\left(\frac{4}{3}\pi(2R)^3\right)\left(\frac{4}{3}\pi(2R)^3\right)}{(2R)^2} \propto \frac{64}{9}R^4$ $F_{g_C} = \frac{G\left(\frac{4}{3}\pi(3R)^3\right)\left(\frac{4}{3}\pi(R)^3\right)}{(4R)^2} \propto \frac{27}{9}R^4$ $B > C > A$	
(B)	Incorrect. The planets all have the same density, so the mass of each planet is related to the radius of the planet cubed. $\rho = \frac{M}{V}$ $M = \rho V$ $M = \rho\left(\frac{4}{3}\pi R^3\right)$ The force of gravity between each sphere can be determined $F_g = \frac{Gm_1m_2}{r^2}$ $F_{g_A} = \frac{G\left(\frac{4}{3}\pi R^3\right)\left(\frac{4}{3}\pi R^3\right)}{R^2} \propto \frac{16}{9}R^4$ $F_{g_B} = \frac{G\left(\frac{4}{3}\pi(2R)^3\right)\left(\frac{4}{3}\pi(2R)^3\right)}{(2R)^2} \propto \frac{64}{9}R^4$ $F_{g_C} = \frac{G\left(\frac{4}{3}\pi(3R)^3\right)\left(\frac{4}{3}\pi(R)^3\right)}{(4R)^2} \propto \frac{27}{9}R^4$ $B > C > A$	

Question 43 (continued)

(C)	**Correct.** The planets all have the same density, so the mass of each planet is related to the radius of the planet cubed. $\rho = \frac{M}{V}$ $M = \rho V$ $M = \rho\left(\frac{4}{3}\pi R^3\right)$ The force of gravity between each sphere can be determined $F_g = \frac{Gm_1m_2}{r^2}$ $F_{g_A} = \frac{G\left(\frac{4}{3}\pi R^3\right)\left(\frac{4}{3}\pi R^3\right)}{R^2} \propto \frac{16}{9}R^4$ $F_{g_B} = \frac{G\left(\frac{4}{3}\pi (2R)^3\right)\left(\frac{4}{3}\pi (2R)^3\right)}{(2R)^2} \propto \frac{64}{9}R^4$ $F_{g_C} = \frac{G\left(\frac{4}{3}\pi (3R)^3\right)\left(\frac{4}{3}\pi (R)^3\right)}{(4R)^2} \propto \frac{27}{9}R^4$ $B > C > A$
(D)	Incorrect. The planets all have the same density, so the mass of each planet is related to the radius of the planet cubed. $\rho = \frac{M}{V}$ $M = \rho V$ $M = \rho\left(\frac{4}{3}\pi R^3\right)$ The force of gravity between each sphere can be determined $F_g = \frac{Gm_1m_2}{r^2}$ $F_{g_A} = \frac{G\left(\frac{4}{3}\pi R^3\right)\left(\frac{4}{3}\pi R^3\right)}{R^2} \propto \frac{16}{9}R^4$ $F_{g_B} = \frac{G\left(\frac{4}{3}\pi (2R)^3\right)\left(\frac{4}{3}\pi (2R)^3\right)}{(2R)^2} \propto \frac{64}{9}R^4$ $F_{g_C} = \frac{G\left(\frac{4}{3}\pi (3R)^3\right)\left(\frac{4}{3}\pi (R)^3\right)}{(4R)^2} \propto \frac{27}{9}R^4$ $B > C > A$

Question 44

Science Practice	**Learning Objective**	**Topic**
7.2	2.B.1.1	2.2

(A)

Correct. The frictional force between the board and the box is proportional to the normal force exerted on the box by the board.

$$F_f = \mu F_N$$

The board is horizontal and the box does not accelerate vertically, so the normal force is equal to the weight of the box.

$$F_{N,Earth} = F_{g,Earth} = \frac{GM_E m}{{R_E}^2}$$

A planet that has twice the radius and one-third the mass of earth will exert a gravitational force on the box equal to:

$$F_{g,new} = \frac{G\left(\frac{1}{3}M_E\right)m}{(2R_E)^2} = \frac{1}{12}\frac{GM_E m}{{R_E}^2}$$

Since the weight of the box on the new planet is $\frac{1}{12}$ of the weight of the box on Earth, the frictional force exerted by the board on the box on the new planet is $\frac{1}{12}$ of the frictional force exerted by the board on the box on Earth.

(B)

Incorrect. The frictional force between the board and the box is proportional to the normal force exerted on the box by the board.

$$F_f = \mu F_N$$

The board is horizontal and the box does not accelerate vertically, so the normal force is equal to the weight of the box.

$$F_{N,Earth} = F_{g,Earth} = \frac{GM_E m}{{R_E}^2}$$

A planet that has twice the radius and one-third the mass of earth will exert a gravitational force on the box equal to:

$$F_{g,new} = \frac{G\left(\frac{1}{3}M_E\right)m}{(2R_E)^2} = \frac{1}{12}\frac{GM_E m}{{R_E}^2}$$

Since the weight of the box on the new planet is $\frac{1}{12}$ of the weight of the box on Earth, the frictional force exerted by the board on the box on the new planet is $\frac{1}{12}$ of the frictional force exerted by the board on the box on Earth.

(C)	Incorrect. The frictional force between the board and the box is proportional to the normal force exerted on the box by the board. $$F_f = \mu F_N$$ The board is horizontal and the box does not accelerate vertically, so the normal force is equal to the weight of the box. $$F_{N,Earth} = F_{g,Earth} = \frac{GM_E m}{{R_E}^2}$$ A planet that has twice the radius and one-third the mass of earth will exert a gravitational force on the box equal to: $$F_{g,new} = \frac{G\left(\frac{1}{3}M_E\right)m}{(2R_E)^2} = \frac{1}{12}\frac{GM_E m}{{R_E}^2}$$ Since the weight of the box on the new planet is $\frac{1}{12}$ of the weight of the box on Earth, the frictional force exerted by the board on the box on the new planet is $\frac{1}{12}$ of the frictional force exerted by the board on the box on Earth.
(D)	Incorrect. The frictional force between the board and the box is proportional to the normal force exerted on the box by the board. $$F_f = \mu F_N$$ The board is horizontal and the box does not accelerate vertically, so the normal force is equal to the weight of the box. $$F_{N,Earth} = F_{g,Earth} = \frac{GM_E m}{{R_E}^2}$$ A planet that has twice the radius and one-third the mass of earth will exert a gravitational force on the box equal to: $$F_{g,new} = \frac{G\left(\frac{1}{3}M_E\right)m}{(2R_E)^2} = \frac{1}{12}\frac{GM_E m}{{R_E}^2}$$ Since the weight of the box on the new planet is $\frac{1}{12}$ of the weight of the box on Earth, the frictional force exerted by the board on the box on the new planet is $\frac{1}{12}$ of the frictional force exerted by the board on the box on Earth.

Question 45

Science Practice	**Learning Objective**	**Topic**
1.4	4.B.1.1	5.2
(A)	Incorrect. The slope of the graph of force exerted on an object as a function of time does not give information about the final momentum of the object.	
(B)	Incorrect. The area between the graph of force as a function of time and the horizontal axis is equal to the change in momentum of the object. The area under the curve between 2 and 5 seconds is greater than the area between zero and 2 seconds, so the net change in momentum is negative. Although the maximum positive force is twice the maximum negative force, the total change in momentum is negative because the smaller negative force was exerted for more time.	
(C)	**Correct.** The area between the graph of force as a function of time and the horizontal axis is equal to the change in momentum of the object. The area under the curve between 2 and 5 seconds is greater than the area between zero and 2 seconds, so the net change in momentum is negative.	
(D)	Incorrect. The area between the graph of force as a function of time and the horizontal axis is equal to the change in momentum of the object. The area under the curve between 2 and 5 seconds is greater than the area between zero and 2 seconds, so the net change in momentum is negative.	

Question 131

Science Practice	**Learning Objective**	**Topic**
1.5	3.A.1.1	7.1
(A)	Incorrect. The angular speed of the object is proportional to the angular momentum, since the angular momentum decreases and then increases in magnitude, the angular speed is not constant.	
(B)	**Correct.** The slope of the angular momentum as a function of time graph represents the net torque exerted on the object. The net torque is constant and is proportional to the angular acceleration of the object which is also constant.	
(C)	Incorrect. The angular momentum of the object is proportional to the angular speed of the object, which means a graph of the angular speed as a function of time would have the same shape. Since the object is rotating, the angular position cannot be constant.	
(D)	**Correct.** The slope of the angular momentum as a function of time graph represents the net torque exerted on the object. The slope is constant and so the net torque exerted on the object is also constant.	

Question 132

Science Practice	**Learning Objective**	**Topic**
5.1 5.3	5.D.1.2	5.4

(A)	Incorrect. During the collision, even though there is a spring-loaded launcher that exerts a force on cart 1, that launcher is inside the two-cart system, and so does not change the momentum of the system. All four answer choices keep the momentum of the system constant from before the collision to after the collision. $p_i = p_f$ $(m)(1.0\text{m/s}) = (m)\left(v_{1_f}\right) + (m)\left(v_{2_f}\right)$. However, there was initially energy stored in the spring launcher, that after the collision has been turned into kinetic energy in the system. Because of this, the final kinetic energy should be greater than the initial kinetic energy. This is true with the final speeds in choices C and D
(B)	Incorrect. During the collision, even though there is a spring-loaded launcher that exerts a force on cart 1, that launcher is inside the two-cart system, and so does not change the momentum of the system. All four answer choices keep the momentum of the system constant from before the collision to after the collision. $p_i = p_f$ $(m)(1.0\text{m/s}) = (m)\left(v_{1_f}\right) + (m)\left(v_{2_f}\right)$. However, there was initially energy stored in the spring launcher, that after the collision has been turned into kinetic energy in the system. Because of this, the final kinetic energy should be greater than the initial kinetic energy. This is true with the final speeds in choices C and D

Question 132 (continued)

(C)	**Correct.** During the collision, even though there is a spring-loaded launcher that exerts a force on cart 1, that launcher is inside the two-cart system, and so does not change the momentum of the system. All four answer choices keep the momentum of the system constant from before the collision to after the collision. $p_i = p_f$ $(m)(1.0\text{m/s}) = (m)\left(v_{1_f}\right) + (m)\left(v_{2_f}\right)$. However, there was initially energy stored in the spring launcher, that after the collision has been turned into kinetic energy in the system. Because of this, the final kinetic energy should be greater than the initial kinetic energy. This is true with the final speeds in choices C and D
(D)	**Correct.** During the collision, even though there is a spring-loaded launcher that exerts a force on cart 1, that launcher is inside the two-cart system, and so does not change the momentum of the system. All four answer choices keep the momentum of the system constant from before the collision to after the collision. $p_i = p_f$ $(m)(1.0\text{m/s}) = (m)\left(v_{1_f}\right) + (m)\left(v_{2_f}\right)$. However, there was initially energy stored in the spring launcher, that after the collision has been turned into kinetic energy in the system. Because of this, the final kinetic energy should be greater than the initial kinetic energy. This is true with the final speeds in choices C and D

Question 133

Science Practice	**Learning Objective**	**Topic**
1.4 6.4 7.2	3.A.3.1 3.A.3.3 3.A.4.2 3.A.4.3	2.5

(A)	**Correct.** The total force exerted on the block by the incline is the vector sum of the normal force and the frictional force, since these two forces are both applied by the incline. The block is at rest, and so the net force on the block must be zero. The magnitude of the downwards force of gravity exerted on the block by earth is equal to mg. Therefore, the magnitude of the total upwards force exerted on the block by the incline must also be equal to mg.
(B)	Incorrect. The normal force will be equal in magnitude to the component of the gravitational force that is perpendicular to the ramp but will be smaller than the gravitational force exerted by Earth on the block.
(C)	Incorrect. The force of friction will be equal in magnitude to the component of the gravitational force that is parallel to the ramp but will be smaller than the gravitational force exerted by Earth on the block.
(D)	**Correct.** By definition, the force exerted by Earth on the block is equal to mg. Newton's third law states that if the force of gravity exerted by Earth on the block is equal to mg, then the force of gravity exerted by the block on Earth is also equal to mg.

Question 134

Science Practice	**Learning Objective**	**Topic**
1.4	3.E.1.2	4.2

(A)	Incorrect. There is a net force acting on Earth from the incline and the block which changes the momentum of Earth as the block moves down the incline.
(B)	**Correct.** As the block slides down the incline, the force of friction exerted on the block by the incline dissipates mechanical energy as thermal energy from the block-Earth system.
(C)	**Correct.** The block speeds up as it moves down the incline, which means that the momentum of the block must be increasing as it moves down the incline.
(D)	Incorrect. As the block slides down the incline, the force of friction acts on the box – Earth system dissipating energy and reducing the mechanical energy of the block – Earth system.

Question 135

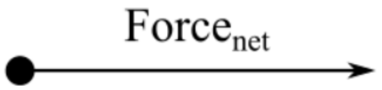
Science Practice	**Learning Objective**	**Topic**
6.4	3.F.2.1	7.2

(A)	Incorrect. The net torque exerted by the force is equal to the rotational inertia of the rod times the angular acceleration of the rod. So for this rod – force combination, the angular acceleration can be found to be: $\tau = Fr = I\alpha$ $(2F)L = \left(\frac{1}{3}ML^2\right)\alpha_A$ $\alpha_A = \frac{6F}{ML}$
(B)	Incorrect. The net torque exerted by the force is equal to the rotational inertia of the rod times the angular acceleration of the rod. So for this rod – force combination, the angular acceleration can be found to be: $\tau = Fr = I\alpha$ $(F)(2L) = \left(\frac{1}{3}M(2L)^2\right)\alpha_B$ $\alpha_B = \frac{3F}{2ML}$
(C)	**Correct.** The net torque exerted by the force is equal to the rotational inertia of the rod times the angular acceleration of the rod. So for this rod – force combination, the angular acceleration can be found to be: $\tau = Fr = I\alpha$ $(2F)(2L) = \left(\frac{1}{3}M(2L)^2\right)\alpha_C$ $\alpha_C = \frac{3F}{ML}$
(D)	**Correct.** The net torque exerted by the force is equal to the rotational inertia of the rod times the angular acceleration of the rod. So for this rod – force combination, the angular acceleration can be found to be: $\tau = Fr = I\alpha$ $(2F)L\cos 60^\circ = \left(\frac{1}{3}ML^2\right)\alpha_D$ $\alpha_D = \frac{3F}{ML}$

Question 1: Short Answer — 7 points

(a) For an arrow that points horizontally to the right. **1 point**

Example response:



Total for part (a) **1 point**

(b) For a correct claim that the motion sensor was started when the block was at point B (equilibrium) **1 point**

For a correct justification of why the block is not at point A **1 point**

OR

For a correct justification of why the block is at point B

For a correct justification of why the block is moving to the left **1 point**

Example response for part (b)

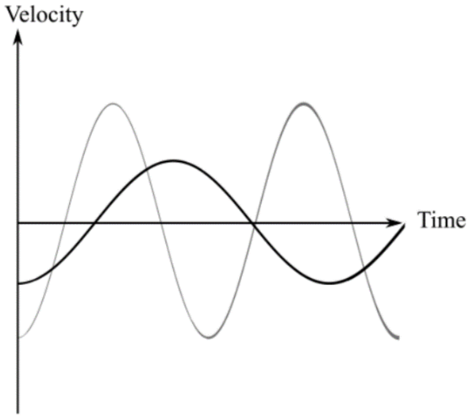
At time zero the block has a maximum speed, which means that it is traveling through the equilibrium position, which is position B. Since the velocity is negative, and to the right was defined as positive, the block must be moving to the left through position B.

Total for part (b) **3 points**

(c)	For a sine or cosine graph	**1 point**
	For a graph that has a smaller maximum velocity	**1 point**
	For a sinusoidal graph with a longer period	**1 point**

Scoring Note: The starting point of this graph is not required to be correct to earn these points. Any phase shift is acceptable for this graph.

Example response for part (c)



Total for part (c) **3 points**

Total for question 1 **7 points**

Question 2: Experimental Design 12 points

(a)	**(i)(ii)**	For indicating valid measured quantities **Scoring note:** This point is not earned if the procedure in part (iii) includes measured quantities or measurement equipment that is not listed in parts (i) and (ii).	**1 point**
		For a list of equipment and a plausible way to measure the quantities stated in (a)(i)	**1 point**
	(iii)	For a practical procedure consistent with the quantities indicated in (a)(i)	**1 point**
		For a plausible procedure that could be used to experimentally determine frictional torque	**1 point**
		For including a valid method to reduce experimental uncertainty	**1 point**

Example methods:

Method 1: Start the platform rotating and let it rotate freely. Use a feasible method for measuring the angular velocity at two different times.

Method 2: Apply a known external force tangential to the rim of the initially motionless platform. Measure the change in angular velocity as in method 1. Also measure the radius of the platform (or some other valid measurement of lever arm).

Method 3: Measure the torque needed to maintain the platform at a constant angular velocity. Determine if the torque is indeed constant by measuring the angular speed at two different times and seeing if they are the same within experimental uncertainty.

Method 4: With the platform freely rotating, measure angular displacement over some time interval.

Total for part (a) 5 points

(b)	For a valid expression involving the necessary angular quantity consistent with the procedure in part (a)	**1 point**
	For explicitly or implicitly relating the calculated quantity to angular acceleration	**1 point**
	For correctly combining the above two concepts in a way that would yield the frictional torque	**1 point**

Total for part (b) 3 points

(c)	For correctly relating the procedure in parts (a) and (b) to the assumption of dependence or independence of frictional torque on angular speed	**1 point**
	For connecting the analysis to the dependence of frictional torque on angular speed	**1 point**
	Total for part (c)	**2 points**
(d)	For a modification that has any additional trial at a different angular speed **OR** correctly and explicitly stating that no modification is necessary	**1 point**
	For indicating how analysis of the initial or modified experiment could plausibly determine whether frictional torque is independent of angular speed	**1 point**
	Total for part (d)	**2 points**
	Total for question 2	**12 points**

Question 3: Qualitative/Quantitative Translation **12 points**

(a)	For indicating (explicitly or implicitly) that intersecting the vertical axis corresponds to zero stiffness	**1 point**
	For correctly indicating that no measurement of stiffness could be zero	**1 point**
	Example: The vertical axis is where $S = 0$, indicating a substance puts up no resistance to getting stirred. But even at room temperature the oil has *some* stiffness. Hence, the lowest measured stiffness is positive, not zero, and the graph reflects this.	
	Total for part (a)	**2 points**
(b)	For a correct equation: $E_{\text{max}} = MgD$ **OR** $E_{\text{max}} = -MgD$	**1 point**
	For stating that the maximum energy that can be lost is equal to the initial energy of the system	**1 point**
	For stating that the initial energy of the system is the initial gravitational potential energy **Example:** The maximum energy that can be lost is equal to the initial energy, which is all gravitational potential energy: MgD.	**1 point**
	Alternate solution for the last 2 points	
	For a statement or the application of mechanical energy as the sum of kinetic and potential energies	**1 point**
	For combining the change in the gravitational potential energy with a small change in kinetic energy as the ball falls to make a valid argument for E_{max}.	**1 point**
	Example: In a very stiff oil that the ball can barely fall through, it gains essentially no kinetic energy. In this case the overall change in mechanical energy, $\Delta K + \Delta U$, is approximately equal to ΔU because ΔK is essentially zero. So, $E_{\text{max}} = \lvert\Delta U\rvert = MgD$.	
	Total for part (b)	**3 points**

(c) For each of the following, up to a maximum of 2 points

1 point for each valid, independent statement that the equation does not match the graph (maximum of 2 points). **1 point**

1 point for a statement that demonstrates that E_{lost} cannot increase indefinitely. **1 point**

Example statements (1 point each, any two could be combined for 2 points):

The equation indicates that E_{lost} increases indefinitely with S, but the graph has an upper limit for E_{lost} .

The equation represents a parabola (or is concave-up), which does not match the graph.

It doesn't make physical sense that E_{lost} could be more than the available potential energy MgD .

Total for part (c) 2 points

(d) Correct answer: "Not plausible"

Note: The explanation can earn the first point if the incorrect selection is made.

For a statement or implication that the equation indicates that t increases as S decreases **1 point**

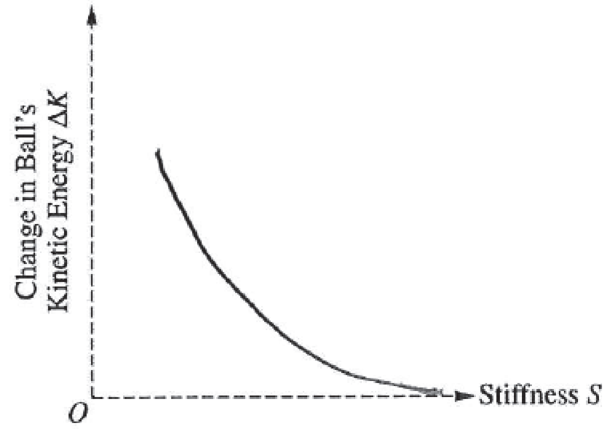
For a statement or implication that t should be larger as S increases **1 point**

Note: If only one of the above statements is written explicitly, and "Not plausible" is selected, the second point is earned by implication.

Example 1 (2 points): "Not plausible". According to the equation, a less stiff oil makes the sphere take more time to reach the bottom.
Example 2 (2 points): "Not plausible". A greater stiffness means that the ball should take a longer time to fall through the oil.
Example 3 (1 point): "Plausible". The equation says that bigger S means bigger time, which agrees with the idea that a thicker oil resists the ball's motion more.

Total for part (d) 2 points

(e) **1 point**



For drawing a concave-upward curve that approaches the horizontal at higher S

For having the maximum value of ΔK at the lowest graphed value of S, which can be $S = 0$ or a positive value **1 point**

Note: This point is not earned if the graph indicates that ΔK approaches infinity as S approaches zero.

For high values of S, the graph approaches and does not cross the horizontal axis **1 point**

Note: This point is earned if the graph touches the horizontal axis without crossing it.

Total for part (e) **3 points**

Total for question 3 **12 points**

Question 4: Paragraph-Length Response 7 points

(a)	**Correct answer:** 2 θ_{embed} 3 θ_{pass} 1 θ_{bounce}	
(b)	For using conservation of momentum **Note:** This point is earned for an indication of how momentum conservation applies to the situation.	**1 point**
	For correctly stating or implying that in all three cases the magnitude of the change in the horizontal momentum of the arrow during the collision equals magnitude of the momentum gained by the pumpkin	**1 point**
	For a valid argument explaining why the Bounce arrow must transfer the most momentum	**1 point**
	For stating that the Pass arrow ends up faster than the Embedded arrow or does not transfer as much momentum to the pumpkin immediately after collision	**1 point**
	For indicating (regardless of conclusion about whether the Pass or Embedded arrow ends up going faster after the collision) that the arrow that slowed more during the collision transfers more momentum to the pumpkin	**1 point**
	For an explicit or implicit correct justification, in terms of energy conservation, that the angle reached by the pumpkin is related to the speed of the pumpkin just after the collision	**1 point**
	For a logical, relevant, and internally consistent response that addresses the required argument or question asked, and follows the guidelines described in the published requirements for the paragraph-length response	**1 point**
	Example: *The Bounce arrow is the only one that reverses direction, so has momentum to the left after the collision. By conservation of momentum the pumpkin must then have a greater momentum to the right than the arrow had before the collision. After the Embedded arrow hits, the arrow and pumpkin together have the same momentum as the arrow did just before the collision. The Pass arrow still has some momentum to the right after hitting the pumpkin so by conservation of momentum the pumpkin has less momentum to the right than the arrow did before the collision. By conservation of energy, the maximum angle that the pumpkin reaches depends on the speed of the pumpkin (higher speed means higher angle), so the Bounce arrow pumpkin has the highest angle and the Pass arrow pumpkin has the lowest angle.*	
	Total for part (b)	**7 points**
	Total for question 4	**7 points**

Question 5: Short Answer — 7 points

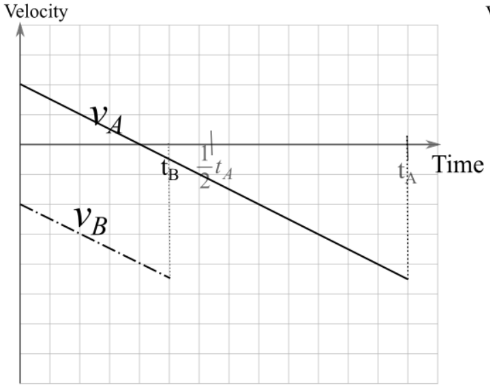
(a) For a graph that shows that the initial velocity of rock A is positive, and the initial velocity of rock B is the negative value of the initial velocity of rock A. **1 point**

For a graph that contains two parallel lines with the same negative slope **1 point**

For a graph of the velocity of rock A that only crosses the horizontal axis before $\frac{1}{2}t_A$ **1 point**

For a graph of the velocity of rock B where the velocity of rock B at t_B is the same as the velocity of rock A at t_A **1 point**

Example response for part (a):



Total for part (a) 4 points

(b) For correctly determining the time rock A takes to move upwards and return to its original position. **1 point**

$$v = v_0 + at$$

$$-v_0 = v_0 - gt_{\text{return}}$$

$$-2v_0 = -gt_1$$

$$t_{\text{return}} = \frac{2v_0}{g}$$

For implicitly or explicitly recognizing that the time for both rocks to move downwards from the top of the cliff to the ground is the same. **1 point**

$$t_{\text{ground}} = t_B$$

For a correct equation for t_A in terms of t_B **1 point**

$$t_A = t_{\text{return}} + t_{\text{ground}}$$

$$t_A = \frac{2v_0}{g} + t_B$$

Total for part (b) 3 points

Total for question 5 7 points

AP Physics 1 - 2022 Practice Exam 1 Scoring Worksheet

Section I: Multiple Choice

__________ × .8000 = __________

Number Correct (out of 50) | Weighted Section I Score (Do not round)

Section II: Free Response

Question 1 __________ (out of 7) × 0.8888 = __________ (Do not round)

Question 2 __________ (out of 12) × 0.8888 = __________ (Do not round)

Question 3 __________ (out of 12) × 0.8888 = __________ (Do not round)

Question 4 __________ (out of 7) × 0.8888 = __________ (Do not round)

Question 5 __________ (out of 7) × 0.8888 = __________ (Do not round)

Sum = __________ Weighted Section II Score (Do not round)

Composite Score

__________ + __________ = __________

Weighted Section I Score | Weighted Section II Score | Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics 1

Composite Score Range	AP Score
61-80	5
48-60	4
37-47	3
24-36	2
0-23	1

When an AP Exam is administered, psychometric analysis determines the score ranges corresponding with each AP Exam score (5, 4, 3, 2, and 1) based on a composite score scale that combines and weights the exam parts. Due to minor variations in exam difficulty, the number of points corresponding with each AP Exam score can vary on different exams. Because this practice exam was never administered, AP has developed these estimated score ranges that teachers can use to approximate AP Exam scores. We caution that these ranges, and the resulting AP Exam scores, are only estimates, and student performance on this practice exam does not necessarily predict performance on a different exam.

Multiple-Choice Questions

Question	Science Practice	Learning Objective	Topic	Key
1	6.4	3.A.1.1 4.A.2.1	1.2	D
2	1.4	3.A.1.1 3.B.2.1 4.B.2.1	5.2	B
3	1.4	3.A.1.1	1.1	C
4	1.4	4.C.1.1	4.2	C
5	7.2	5.B.5.4	4.3	A
6	5.1	3.A.1.1 3.A.1.3 3.B.3.3	1.1	D
7	5.1	3.A.1.1 3.A.1.3	1.1	B
8	5.1	3.B.3.3	6.1	D
9	2.2	3.A.3.1 3.B.1.3	2.5	D
10	2.2	5.D.2.5	5.4	A
11	6.4	5.B.5.5	4.3	D
12	5.1	4.B.1.2	5.2	C
13	2.2	4.D.3.1	7.3	C
14	1.4	5.B.5.3	4.3	B
15	6.4	5.D.3.1	5.4	B
16	6.4	2.B.1.1 3.B.1.1 3.B.2.1	2.6	A
17	5.1	4.B.2.2	5.2	B
18	1.4	3.E.1.3 3.E.1.4 4.C.2.1	4.2	B
19	7.2	3.A.4.2	2.5	A
20	6.4	4.C.2.1	4.2	A
21	6.4	3.A.3.1	3.8	B
22	6.4	3.A.4.1	2.5	D
23	2.2	4.C.1.1 5.B.3.2	4.3	D
24	7.2	3.F.3.1	7.2	D
25	1.4	5.B.3.3	6.2	A
26	2.2	3.B.1.3 3.B.2.1	2.6	B
27	6.4	5.B.5.5	4.3	C
28	2.1	5.D.2.5	5.4	A
29	1.4	4.D.2.1	7.3	D
30	1.4	4.D.2.2	7.3	B

Question	Science Practice	Learning Objective	Topic	Key
31	1.4	4.D.2.2	7.2	B
32	1.5	3.A.1.1 3.B.1.1	1.1	B
33	2.2	3.C.1.2	3.3	B
34	7.2	4.A.1.1 5.D.1.1 5.D.2.1	1.2	A
35	1.2, 1.4, 6.4	4.A.1.1	1.2	D
36	2.2, 6.4	4.C.2.1 5.B.5.5	4.2	A
37	1.4	3.B.2.1	2.6	D
38	1.4	3.B.2.1	2.6	B
39	6.4	4.C.2.1	4.2	B
40	6.4	5.B.4.1	4.3	C
41	6.4	4.A.1.1	1.2	B
42	4.2	4.D.3.2	7.3	B
43	6.4	3.A.3.1	3.8	C
44	7.2	2.B.1.1	2.2	A
45	1.4	4.B.1.1	5.2	C

Question	Science Practice	Learning Objective	Topic	Key
131	1.5	3.A.1.1	7.1	B, D
132	5.1, 5.3	5.D.1.2	5.4	C, D
133	1.4, 6.4, 7.2	3.A.3.1 3.A.3.3 3.A.4.2 3.A.4.3	2.5	A, D
134	1.4	3.E.1.2	4.2	B, C
135	6.4	3.F.2.1	7.2	C, D

Free-Response Questions

<table>
<tr><th>Question</th><th>Science Practice</th><th>Learning Objective</th><th>Topic</th></tr>
<tr><td>1</td><td>1.1|6.4|6.4|7.2|1.4|1.4|7.2</td><td>3.A.3.2|4.A.2.1|4.A.2.1|3.B.3.1|5.B.2.1|5.B.2.1|3.B.3.1</td><td>2.5|1.1|1.1|6.1|6.2|6.2|6.1</td></tr>
<tr><td>2</td><td>4.2|4.2|4.2|4.2|4.2|5.1|5.1|5.1|4.2|5.1|4.2|4.2</td><td>3.F.2.2|4.D.3.2|3.F.3.3|3.A.1.2|3.F.3.3|3.A.1.3|3.F.2.2|3.F.3.3|3.F.2.2|3.F.3.3|3.F.2.2|3.F.3.3</td><td>7.2|7.3|7.2|7.1|7.2|7.1|7.2|7.2|7.2|7.2|7.2|7.2</td></tr>
<tr><td>3</td><td>6.4|6.1|6.4|6.4|2.2|6.4|7.2|7.2|7.2|6.4|1.4|1.5</td><td>3.A.3.1|3.C.4.1|4.C.1.2|4.C.2.1|4.C.1.1|4.C.1.2|5.B.4.1|3.B.1.1|5.B.5.4|4.C.1.2|4.C.1.1|5.B.1.2</td><td>2.5|2.3|4.2|4.2|4.2|4.2|4.3|2.6|4.3|4.2|4.2|4.3</td></tr>
<tr><td>4</td><td>2.2|6.4|6.4|6.4|1.5|6.4|2.1</td><td>5.D.1.5|5.D.2.1|5.B.3.1|5.D.2.1|3.A.1.1|5.D.2.3|5.D.2.5</td><td>5.4|5.4|4.3|5.4|1.1|5.4|5.4</td></tr>
<tr><td>5</td><td>1.5|1.5|1.5|2.2|2.2|2.2|6.4</td><td>3.A.1.1|3.A.1.1|3.A.1.1|4.A.2.3|4.A.2.3|4.A.2.3|4.A.2.1</td><td>1.1|1.1|1.1|1.2|1.2|1.2|1.2</td></tr>
</table>