Week 11

AP Physics 1

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

AP Physics 1 Name: ______________ Score: ______

1. What is the kinetic energy of a 2 kg ball moving at 3 $\frac{\text{m}}{\text{s}}$, in joules?

   ______________ J

2. A rope pulls a sled 5 m with 20 N at 60° ($\cos 60° = 0.5$). How much work is done, in joules?

   ______________ J

3. Lift a 2 kg book to a 1.5 m shelf ($g = 9.8\ \frac{\text{N}}{\text{kg}}$). How much gravitational PE is stored, in joules?

   ______________ J

4. A ball is dropped from rest at 5 m ($g = 10\ \frac{\text{m}}{\text{s}^2}$, no air resistance). What is its speed at the bottom, in $\frac{\text{m}}{\text{s}}$?

   ______________ m/s

5. A motor does 600 J of work in 3 s. What is its power, in watts?

   ______________ W

6. If a car doubles its speed, its kinetic energy becomes:

   ☐ twice as large

   ☐ four times as large

   ☐ the same

   ☐ half as large

7. A force acts at 90° to an object's motion. How much work does it do?

   ☐ the maximum possible

   ☐ half the force times distance

   ☐ zero

   ☐ a negative amount

8. Gravitational potential energy mgh increases when you increase which of these?

   ☐ the mass m

   ☐ the height h

   ☐ the gravitational field strength g

   ☐ the object's colour

   Tick every correct option.

9. Mechanical energy is the sum of kinetic energy and ______ energy.

____

10. What is the SI unit of power?

- ☐ joule
- ☐ newton
- ☐ watt
- ☐ pascal

AP Physics 1

1. **9 J**

   $E_k = \frac{1}{2}mv^2 = \frac{1}{2}(2)(9) = 9$ J.

2. **50 J**

   $W = Fd\cos\theta = 20 \times 5 \times 0.5 = 50$ J.

3. **29.4 J**

   $E_p = mgh = 2 \times 9.8 \times 1.5 = 29.4$ J.

4. **10 m/s**

   $mgh = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{2gh} = \sqrt{2 \times 10 \times 5} = 10\ \frac{\text{m}}{\text{s}}$.

5. **200 W**

   $P = W/t = 600/3 = 200$ W.

6. **four times as large**

   $E_k \propto v^2$, so doubling v gives $2^2 = 4$ times the kinetic energy.

7. **zero**

   $\cos 90° = 0$, so $W = Fd\cos 90° = 0$. A perpendicular force does no work.

8. **the mass m; the height h; the gravitational field strength g**

   $E_p = mgh$ grows with mass, height and g. Colour is irrelevant.

9. **potential**

   Mechanical energy $= E_k + E_p$ — kinetic plus **potential**.

10. **watt**

    Power is measured in **watts**, where 1 W $= 1\ \frac{\text{J}}{\text{s}}$.

AP PHYSICS 1 • EXERCISE SHEET

3.1 Translational Kinetic Energy

Name: ____________ Class: ________ Date: __________ **Total: 11 marks**

KEY WORDS energy 能量 • kinetic energy 动能 • work 功 • work-energy theorem 动能定理 • joules 焦耳

Objective

Build the skills to answer exam questions on **translational kinetic energy**.

You must be able to:

- define **kinetic energy** 动能 $KE = \frac{1}{2}mv^2$
- explain that kinetic energy is a **scalar** that depends on the **square** of the speed
- state the **work-energy theorem** 动能定理: the net work equals the change in kinetic energy
- calculate the change in kinetic energy from a change in speed

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Kinetic energy

$KE = \frac{1}{2}mv^2$, a scalar measured in joules. Because it depends on v^2, **doubling** the speed gives **four times** the kinetic energy.

■ The work-energy theorem

$W_{net} = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$. Positive net work speeds an object up; negative net work slows it down.

■ Example

A 2.0 kg cart speeds from 3.0 to 5.0 m s^{-1}:

$$\Delta KE = \tfrac{1}{2}(2.0)(5.0^2 - 3.0^2) = \tfrac{1}{2}(2.0)(16) = 16\text{ J}.$$

2 Practice

2.1 Find the kinetic energy of a 0.50 kg ball moving at 6.0 m s^{-1}. [2]

2.2 State how the kinetic energy changes if the speed triples. [1]

2.3 A 1000 kg car slows from 20 m s^{-1} to rest. Find the net work done on it. [2]

2.4 State the work-energy theorem in words. [1]

3 Exam-style questions

3.1 The kinetic energy of an object depends on its speed as [1]

- **A** $KE \propto v$
- **B** $KE \propto v^2$
- **C** $KE \propto 1/v$
- **D** $KE \propto \sqrt{v}$

3.2 A net work of 40 J is done on a 2.0 kg object starting from rest. Its final speed is [1]

- **A** 40 m s^{-1}
- **B** 20 m s^{-1}
- **C** 6.3 m s^{-1}
- **D** 4.5 m s^{-1}

3.3 A 0.20 kg hockey puck is pushed from rest and gains 9.0 J of kinetic energy.

(a) State its final kinetic energy. [1]

(b) Find its final speed. [2]

Solutions

2.1 $KE = \frac{1}{2}(0.50)(6.0)^2 = 9.0$ J.

2.2 it becomes **nine times** as large (3^2).

2.3 $W_{net} = \Delta KE = 0 - \frac{1}{2}(1000)(20)^2 = -2.0 \times 10^5$ J.

2.4 The net work done on an object equals its change in kinetic energy.

3.1 **B**.

3.2 **C** — $\frac{1}{2}(2.0)v^2 = 40 \Rightarrow v = \sqrt{40} = 6.3$ m s^{-1}.

3.3 (a) 9.0 J. (b) $\frac{1}{2}(0.20)v^2 = 9.0 \Rightarrow v = \sqrt{90} = 9.5$ m s^{-1}.

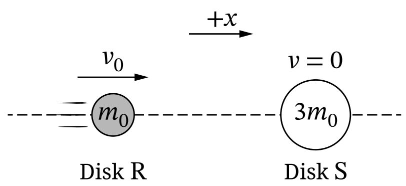
Question 2: Version J

2. Two small disks, R and S, are on a straight, horizontal track.

At time $t = 0$, Disk R of mass m_0 is located at position $x = 0$. Disk R is initially moving with speed v_0 in the $+x$-direction. Disk S of mass $3m_0$ is initially at rest, as shown in the top view in Figure 1. Frictional forces are negligible.

At $t = t_1$, the disks collide. Immediately after the collision, Disk R moves with speed $\frac{1}{2}v_0$ in the $-x$-direction.

Figure 1



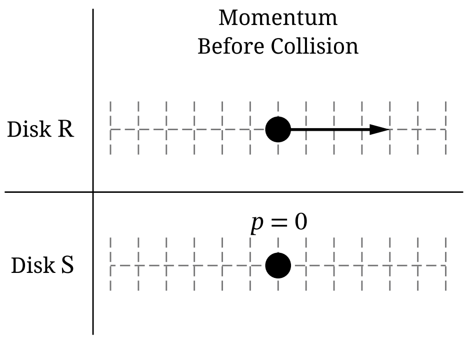
Top View

Note: Figure not drawn to scale.

Part A

The momentum-vector diagram in Figure 2 represents the momentums of Disk R and Disk S before the collision.

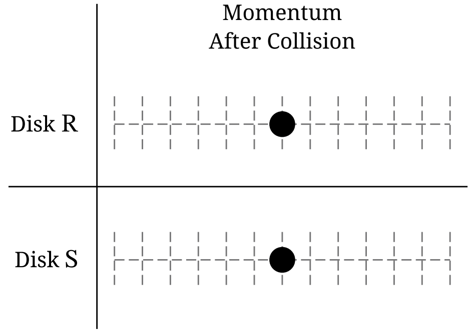
Figure 2



Draw arrows on Figure 3 to represent the momentum vectors of Disk R and Disk S after the collision.

- Each arrow must start on, and point away from, each dot.
- If the momentum of either disk is zero, write "$p = 0$" next to the dot.
- Draw the length of each arrow to represent the magnitude of each momentum, consistent with the scale used in Figure 2.

Figure 3



Part B

Starting with conservation of linear momentum, **derive** an expression for the kinetic energy of Disk S immediately after the collision. Express your final answer in terms of m_0, v_0, and physical constants, as appropriate. Begin your derivation by writing the fundamental physics principle or an equation from the reference information.

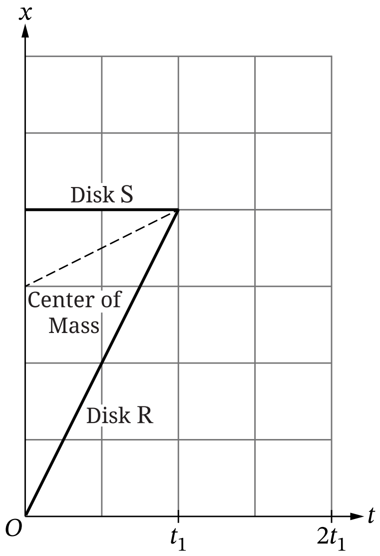
Part C

The graph shown in Figure 4 represents the positions x as functions of time t from $t = 0$ until $t = t_1$ for each of the following:

- Disk R
- Disk S
- The center of mass of the two-disk system

On the graph shown in Figure 4, **draw** three lines that represent the positions x of Disk R, Disk S, and the center of mass of the two-disk system as functions of t from $t = t_1$ to $t = 2t_1$. Distinctly **label** each line.

Figure 4



Part D

During the collision, the magnitudes of the changes in momentum of Disk R and Disk S are $|\Delta p_R|$ and $|\Delta p_S|$, respectively.

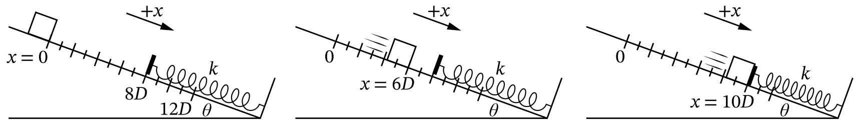
Indicate whether $|\Delta p_R|$ is greater than, less than, or equal to $|\Delta p_S|$ by writing one of the following.

- $|\Delta p_R| > |\Delta p_S|$
- $|\Delta p_R| < |\Delta p_S|$
- $|\Delta p_R| = |\Delta p_S|$

Briefly **justify** your response by referencing a fundamental physics principle.

Question 2: Version J

2. A block of mass M is released from rest at position $x = 0$ near the top of a ramp. The ramp makes an angle of θ with the horizontal. The block slides down the ramp with negligible friction. At $x = 8D$ the block makes contact with an uncompressed spring with spring constant k. The spring is then compressed and the block momentarily comes to rest at $x = 12D$. Figure 1 shows the instants when the block is at $x = 0$, $x = 6D$, and $x = 10D$, respectively.



A. Figure 4 shows an energy bar chart that represents the kinetic energy K of the block, the gravitational potential energy U_g of the block-spring-Earth system, and the spring potential energy U_s of the block-spring-Earth system at the instant that the block is at $x = 10D$. The gravitational potential energy U_g of the block-spring-Earth system is defined to be zero when the block momentarily comes to rest at $x = 12D$.

Draw shaded bars that represent K, U_g, and U_s to complete the energy bar charts in Figure 2 and Figure 3 for when the block is released from rest at $x = 0$ and for when the block is at $x = 6D$, respectively.

- Shaded bars should start at the dashed line that represents zero energy.
- Represent any energy that is equal to zero with a distinct line on the zero-energy line.
- The relative heights of each shaded bar should reflect the magnitude of the respective energy consistent with the scale used in Figure 4.

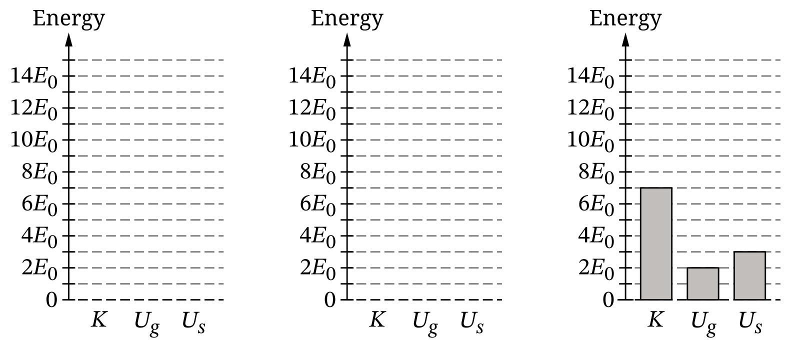
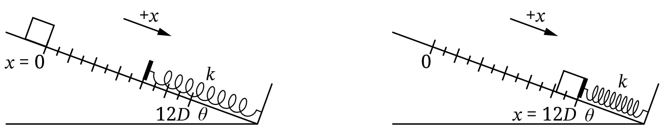


Figure 2 Figure 3 Figure 4

B. Figure 5 shows the block at $x = 0$ when the block is released from rest and the block at $x = 12D$ when the block momentarily comes to rest against the compressed spring.

Figure 5



Starting with conservation of energy, **derive** an equation for the spring constant k. Express your answer in terms of M, θ, D, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. Figure 6 shows a graph of the energy of the system as a function of the position of the block from $x = 8D$ to $x = 12D$. The spring potential energy U_s of the block-spring-Earth system is shown on the graph.

On the axes shown in Figure 6, do the following.

i. **Sketch** and **label** a line or curve that represents the total mechanical energy E for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

ii. **Sketch** and **label** a line or curve that represents the gravitational potential energy U_g for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

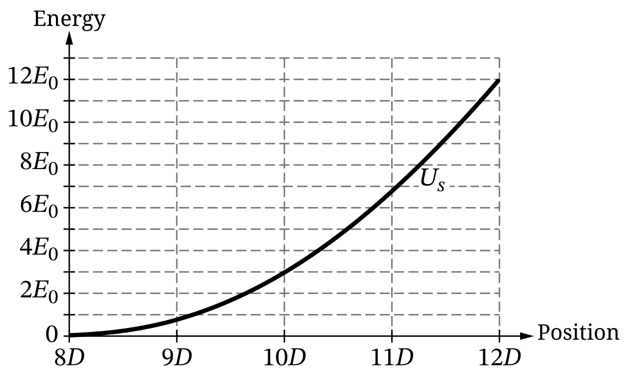


Figure 6

D. **Indicate** whether the speed v_{9D} of the block at $x = 9D$ is greater than, less than, or equal to the speed v_{8D} of the block at $x = 8D$.

______ $v_{9D} > v_{8D}$

______ $v_{9D} < v_{8D}$

______ $v_{9D} = v_{8D}$

Justify how your response is consistent with the energy lines or curves you drew in Figure 6 in part C.

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

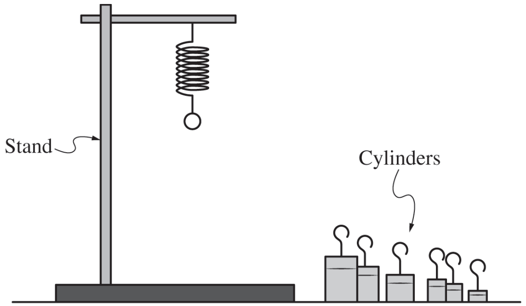


Figure 1

2. (12 points, suggested time 25 minutes)

A student hangs a spring of unknown spring constant k vertically by attaching one end to a stand, as shown in Figure 1. The other end of the spring has a small loop from which small cylinders can be hung. In addition to the spring, the student has access only to a variety of cylinders of unknown masses, a stopwatch, and a digital scale.

(a) Design an experimental procedure the student could use to determine the spring constant k of the spring.

In the following table, list the quantities that would be measured using only the provided equipment in your experiment. Define a symbol to represent each quantity.

In the space below the table, **describe** the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table. If needed, you may include a simple diagram of the setup with your procedure.

GO ON TO THE NEXT PAGE.

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

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement
		Stopwatch
		Digital scale
Procedure (and diagram, if needed)		

(b)

i. **Indicate** the quantities that could be plotted to produce a linear graph whose slope can be used to determine the spring constant k of the spring.

Vertical axis:____________________ Horizontal axis:_____________________

ii. Briefly **describe** how the slope of the graph would be analyzed to determine the spring constant k of the spring.

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

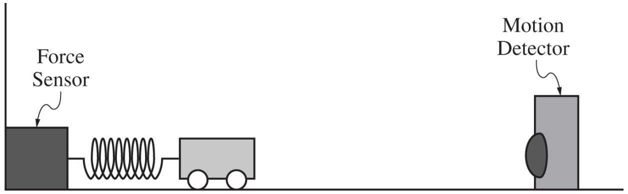
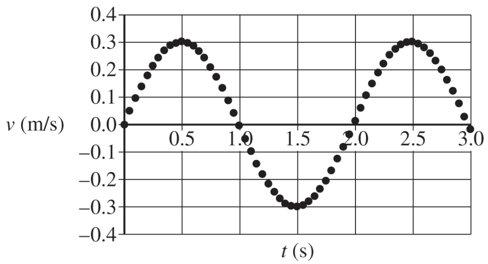
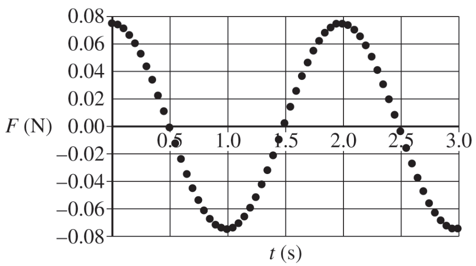


Figure 2

In a different experiment, the student attaches one end of a spring to a force sensor that is attached to a wall. The other end of the spring is attached to a cart with mass $m = 0.25$ kg. The student places a motion detector to the right of the cart, as shown in Figure 2, and pulls the cart to the right a small distance so that the spring is stretched. The student releases the cart from rest, and the cart-spring system oscillates.

The following graphs show the velocity v of the cart and the force F exerted on the cart by the spring as functions of time t.





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

(c)

i. Using the data in the velocity-time graph, **calculate** the change in kinetic energy of the cart from $t = 0.5$ s to $t = 2.0$ s. Show your steps and substitutions.

ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5$ s to $t = 2.5$ s. Briefly **explain** how you arrived at your estimation.

iii. Do the data from the velocity-time graph confirm your estimation from part (c)(ii) ? Briefly **explain**.

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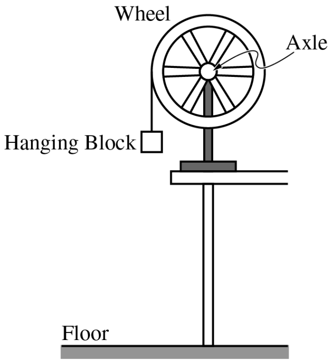
Begin your response to **QUESTION 3** on this page.



. (12 points, suggested time 25 minutes)

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

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

(a) Design an experimental procedure that the students could use to compare the increase in the block's translational kinetic energy with the decrease in the gravitational potential energy of the block-Earth system as the block falls.

In the table, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

In the space to the right of the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.

If needed, you may include a simple diagram of the setup with your procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement	Procedure (and diagram, if needed)

(b) Explain how the students could determine the kinetic energy of the block immediately before it reaches the floor using the quantities you indicated in the table in part (a).

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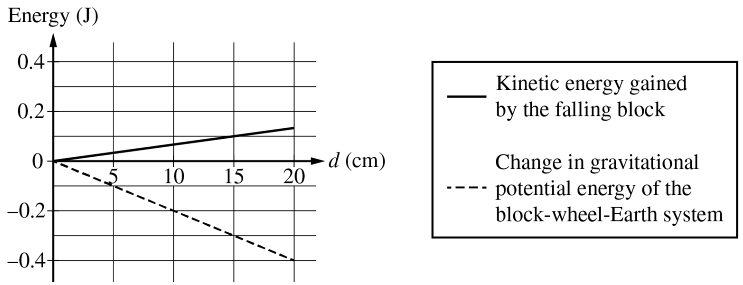
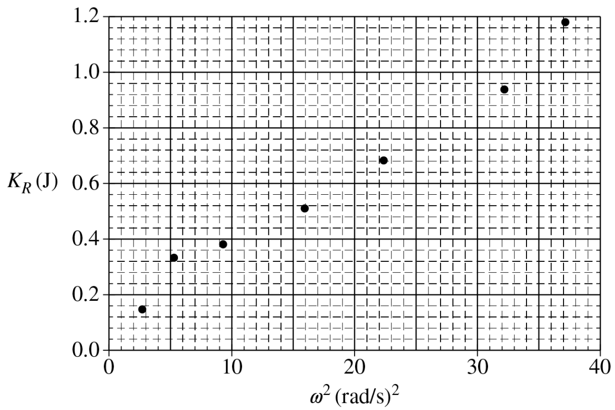


(c) The graph above represents both the change in the gravitational potential energy of the block-wheel-Earth system and the translational kinetic energy gained by the block as functions of the block's falling distance d. On the graph, draw a line or curve to represent the rotational kinetic energy of the wheel as a function of the block's falling distance d.

(d) The students also measure the angular velocity ω of the wheel as the block falls and determine the rotational kinetic energy K_R of the wheel. The students then make a graph of K_R as a function of ω^2, as shown.



i. On the above graph, draw a straight line that best represents the data.

ii. Using the line you drew for part (d)(i), calculate an experimental value for the rotational inertia of the wheel.

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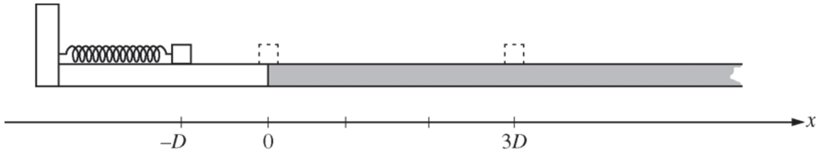


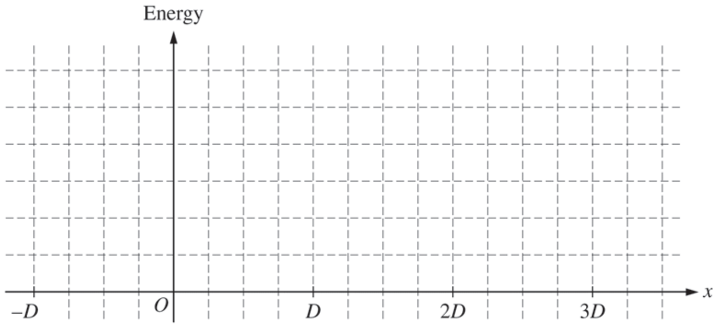
3. (12 points, suggested time 25 minutes)

A block is initially at position $x = 0$ and in contact with an uncompressed spring of negligible mass. The block is pushed back along a frictionless surface from position $x = 0$ to $x = -D$, as shown above, compressing the spring by an amount $\Delta x = D$. The block is then released. At $x = 0$ the block enters a rough part of the track and eventually comes to rest at position $x = 3D$. The coefficient of kinetic friction between the block and the rough track is μ.

(a) On the axes below, sketch and label graphs of the following two quantities as a function of the position of the block between $x = -D$ and $x = 3D$. You do not need to calculate values for the vertical axis, but the same vertical scale should be used for both quantities.

i. The kinetic energy K of the block

ii. The potential energy U of the block-spring system



The spring is now compressed twice as much, to $\Delta x = 2D$. A student is asked to predict whether the final position of the block will be twice as far at $x = 6D$. The student reasons that since the spring will be compressed twice as much as before, the block will have more energy when it leaves the spring, so it will slide farther along the track before stopping at position $x = 6D$.

(b)
  i. Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.
  ii. Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

(c) Use quantitative reasoning, including equations as needed, to develop an expression for the new final position of the block. Express your answer in terms of D.

(d) Explain how any correct aspects of the student's reasoning identified in part (b) are expressed by your mathematical relationships in part (c). Explain how your relationships in part (c) correct any incorrect aspects of the student's reasoning identified in part (b). Refer to the relationships you wrote in part (c), not just the final answer you obtained by manipulating those relationships.

AP PHYSICS 1 • EXERCISE SHEET

3.2 Work

Name: ____________ Class: ________ Date: __________ **Total: 11 marks**

KEY WORDS work 功 • angle 角度 • energy 能量 • joules 焦耳

Objective

Build the skills to answer exam questions on **work**.

You must be able to:

- define **work** 功 as $W = Fd\cos\theta$
- explain how the **angle** 角度 between force and displacement makes work positive, negative, or zero
- calculate the work done by a constant force
- find the work done by a variable force from the **area** under a force-position graph

1 Worked examples

Study these first. Each one shows the method for a question type used later.

The work formula

$W = Fd\cos\theta$, where θ is the angle between the force and the displacement. Work is a scalar, measured in joules.

The sign of work

- $\theta < 90°$ → **positive** work (energy added)
- $\theta = 90°$ → **zero** work (e.g. the normal force on a box sliding along a flat floor)
- $\theta > 90°$ → **negative** work (e.g. friction opposing motion)

Variable force

The work done by a changing force is the **area under the force-versus-position graph**.

2 Practice

2.1 A 30 N force pushes a box 4.0 m in the direction of the force. Find the work done.[1]

2.2 State the work done by the normal force on a box sliding along a flat floor, and why. [2]

2.3 A 50 N force drags a crate 10 m at 37° above the horizontal ($\cos 37° \approx 0.80$). Find the work done. [2]

2.4 A force-position graph is a rectangle 10 N tall and 3.0 m wide. Find the work done. [1]

3 Exam-style questions

3.1 The work done by a force is zero when the angle between the force and the displacement is [1]

- **A** 0°
- **B** 45°
- **C** 90°
- **D** 180°

3.2 Friction acting on a sliding object does [1]

- **A** positive work
- **B** negative work
- **C** zero work
- **D** undefined work

3.3 A child pulls a sled with a 40 N force at 30° above the horizontal for 20 m ($\cos 30° \approx 0.87$).

(a) Find the work done by the pull. [2]

(b) Explain why the vertical component of the pull does no work here. [1]

Solutions

2.1 $W = Fd = 30 \times 4.0 = 120$ J.

2.2 zero — the normal force is perpendicular to the motion ($\theta = 90°$, $\cos 90° = 0$).

2.3 $W = 50 \times 10 \times 0.80 = 400$ J.

2.4 area $= 10 \times 3.0 = 30$ J.

3.1 **C**.

3.2 **B**.

3.3 (a) $W = 40 \times 20 \times \cos 30° = 800 \times 0.87 = 696$ J. (b) the sled moves horizontally, so the vertical component is perpendicular to the displacement and does no work.

3.3 Potential Energy

Name: ____________ Class: ________ Date: __________ **Total: 11 marks**

KEY WORDS potential energy 势能 • gravitational potential energy 重力势能 • elastic potential energy 弹性势能 • conservative force 保守力 • energy 能量

Objective

Build the skills to answer exam questions on **potential energy**.

You must be able to:

- define **potential energy 势能** as energy stored in the configuration of a system
- calculate **gravitational potential energy 重力势能** with $\Delta U_g = mg\,\Delta h$
- calculate **elastic potential energy 弹性势能** with $U_s = \frac{1}{2}kx^2$
- relate a **conservative force 保守力** to the change in potential energy
- interpret a **potential energy versus position** graph

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Gravitational potential energy

$\Delta U_g = mg\,\Delta h$. Lifting a 2.0 kg book 3.0 m (take $g = 10$ m s^{-2}): $\Delta U_g = 2.0 \times 10 \times 3.0 = 60$ J.

■ Elastic potential energy

$U_s = \frac{1}{2}kx^2$. A spring with $k = 200$ N m^{-1} compressed 0.10 m: $U_s = \frac{1}{2}(200)(0.10)^2 = 1.0$ J.

■ Reading a potential-energy graph

A **minimum** of U is a point of **stable equilibrium**; the object oscillates about it. The steeper the curve, the larger the force ($F = -$slope).

2 Practice

2.1 Find the gravitational potential energy gained by lifting a 5.0 kg box 2.0 m (take $g = 10\ \mathrm{m\ s^{-2}}$). [2]

2.2 A spring of constant 300 N $\mathrm{m^{-1}}$ is compressed 0.20 m. Find the elastic potential energy stored. [2]

2.3 State what a minimum on a potential-energy versus position graph tells you about the object there. [1]

3 Exam-style questions

3.1 The elastic potential energy stored in a spring is [1]

- **A** kx
- **B** $\frac{1}{2}kx$
- **C** $\frac{1}{2}kx^2$
- **D** kx^2

3.2 Doubling the compression of a spring changes its stored potential energy by a factor of [1]

- **A** 2
- **B** 4
- **C** $\frac{1}{2}$
- **D** no change

3.3 A 0.30 kg ball is raised 1.5 m and then released from rest (take $g = 10\ \mathrm{m\ s^{-2}}$).

(a) Find the gravitational potential energy at the top. [2]

(b) Using energy conservation, find its speed just before it lands. [2]

Solutions

2.1 $\Delta U_g = mg\,\Delta h = 5.0 \times 10 \times 2.0 = 100$ J.

2.2 $U_s = \frac{1}{2}(300)(0.20)^2 = 6.0$ J.

2.3 it is a point of stable equilibrium (the object tends to stay or oscillate about it).

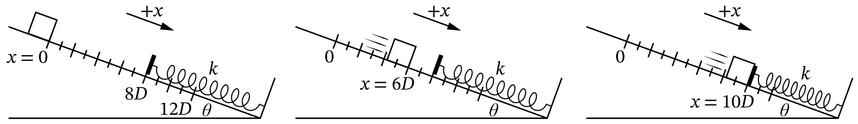
3.1 **C**.

3.2 **B** — $U_s \propto x^2$.

3.3 (a) $U_g = 0.30 \times 10 \times 1.5 = 4.5$ J. (b) $\frac{1}{2}mv^2 = U_g \Rightarrow v = \sqrt{2g\,\Delta h} = \sqrt{30} = 5.5$ m s^{-1}.

Question 2: Version J

2. A block of mass M is released from rest at position $x = 0$ near the top of a ramp. The ramp makes an angle of θ with the horizontal. The block slides down the ramp with negligible friction. At $x = 8D$ the block makes contact with an uncompressed spring with spring constant k. The spring is then compressed and the block momentarily comes to rest at $x = 12D$. Figure 1 shows the instants when the block is at $x = 0$, $x = 6D$, and $x = 10D$, respectively.



A. Figure 4 shows an energy bar chart that represents the kinetic energy K of the block, the gravitational potential energy U_g of the block-spring-Earth system, and the spring potential energy U_s of the block-spring-Earth system at the instant that the block is at $x = 10D$. The gravitational potential energy U_g of the block-spring-Earth system is defined to be zero when the block momentarily comes to rest at $x = 12D$.

Draw shaded bars that represent K, U_g, and U_s to complete the energy bar charts in Figure 2 and Figure 3 for when the block is released from rest at $x = 0$ and for when the block is at $x = 6D$, respectively.

- Shaded bars should start at the dashed line that represents zero energy.
- Represent any energy that is equal to zero with a distinct line on the zero-energy line.
- The relative heights of each shaded bar should reflect the magnitude of the respective energy consistent with the scale used in Figure 4.

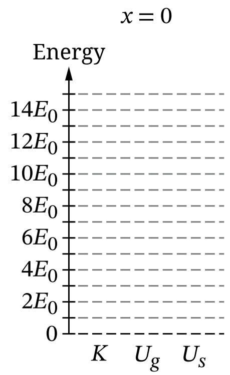


Figure 2

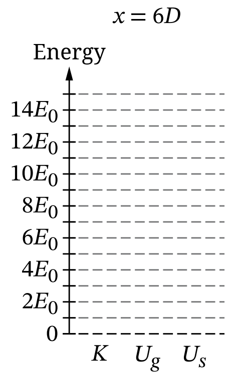


Figure 3

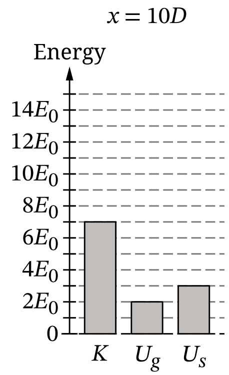
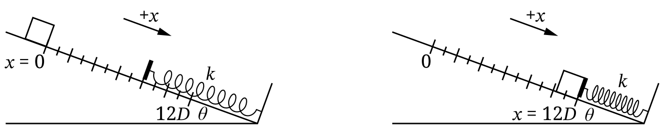


Figure 4

B. Figure 5 shows the block at $x = 0$ when the block is released from rest and the block at $x = 12D$ when the block momentarily comes to rest against the compressed spring.

Figure 5



Starting with conservation of energy, **derive** an equation for the spring constant k. Express your answer in terms of M, θ, D, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. Figure 6 shows a graph of the energy of the system as a function of the position of the block from $x = 8D$ to $x = 12D$. The spring potential energy U_s of the block-spring-Earth system is shown on the graph.

On the axes shown in Figure 6, do the following.

i. **Sketch** and **label** a line or curve that represents the total mechanical energy E for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

ii. **Sketch** and **label** a line or curve that represents the gravitational potential energy U_g for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

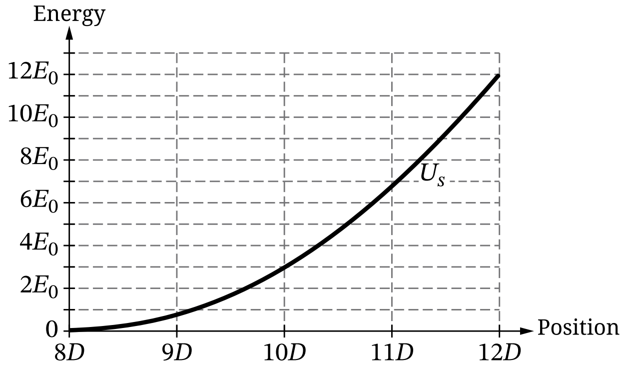


Figure 6

D. Indicate whether the speed v_{9D} of the block at $x = 9D$ is greater than, less than, or equal to the speed v_{8D} of the block at $x = 8D$.

______ $v_{9D} > v_{8D}$

______ $v_{9D} < v_{8D}$

______ $v_{9D} = v_{8D}$

Justify how your response is consistent with the energy lines or curves you drew in Figure 6 in part C.

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

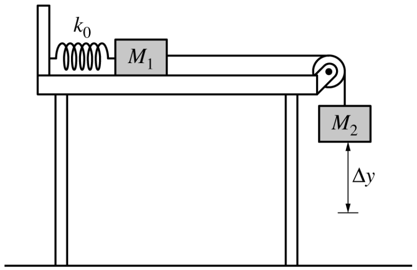
PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

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



. (7 points, suggested time 13 minutes)

Two blocks are connected by a string that passes over a pulley, as shown above. Block 1 is on a horizontal surface and is attached to a spring that is at its unstretched length. Frictional forces are negligible in the pulley's axle and between the block and the surface. Block 2 is released from rest and moves downward before momentarily coming to rest.

k_0 is the spring constant of the spring.
M_1 is the mass of block 1.
M_2 is the mass of block 2.
Δy is the distance block 2 moves before momentarily coming to rest.

GO ON TO THE NEXT PAGE.

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

(a)

i. Block 2 starts from rest and speeds up, then it slows down and momentarily comes to rest at a position below its initial position. In terms of only the forces directly exerted on block 2, explain why block 2 initially speeds up and explain why it slows down to a momentary stop.

ii. Derive an expression for the distance Δy that block 2 travels before momentarily coming to rest. Express your answer in terms of k_0, M_1, M_2, and physical constants, as appropriate.

(b) Indicate whether the total mechanical energy of the blocks-spring-Earth system changes as block 2 moves downward.

___ Changes ___ Does not change

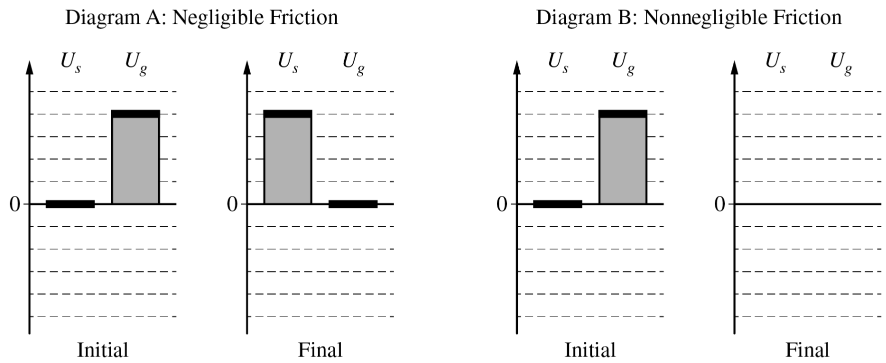
Briefly explain your reasoning.

GO ON TO THE NEXT PAGE.

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

Consider the system that includes the spring, Earth, both blocks, and the string, but not the surface. Let the initial state be when the blocks are at rest just before they start moving, and let the final state be when the blocks first come momentarily to rest. Diagram A at left below is a bar chart that represents the energies in the scenario where there is negligible friction between block 1 and the surface.

The shaded-in bars in the energy bar charts represent the potential energy of the spring and the gravitational potential energy of the blocks-Earth system, U_s and U_g, respectively, in the initial and final states. Positive energy values are above the zero-point line ("0") and negative energy values are below the zero-point line.



(c) Complete diagram B (at right above) for the scenario in which friction is nonnegligible. The energies for the initial state are already provided. Shade in the energies in the final state using the same scale as in diagram A.

- Shaded regions should start at the solid line representing the zero-point line.
- Represent any energy that is equal to zero with a distinct line on the zero-point line.

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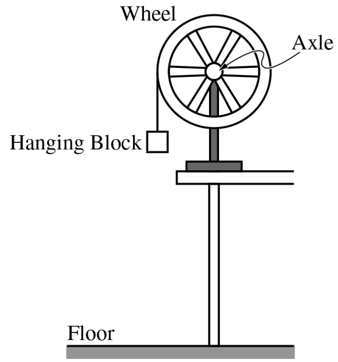
Begin your response to **QUESTION 3** on this page.



. (12 points, suggested time 25 minutes)

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

GO ON TO THE NEXT PAGE.

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

(a) Design an experimental procedure that the students could use to compare the increase in the block's translational kinetic energy with the decrease in the gravitational potential energy of the block-Earth system as the block falls.

In the table, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

In the space to the right of the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.

If needed, you may include a simple diagram of the setup with your procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement	Procedure (and diagram, if needed)

(b) Explain how the students could determine the kinetic energy of the block immediately before it reaches the floor using the quantities you indicated in the table in part (a).

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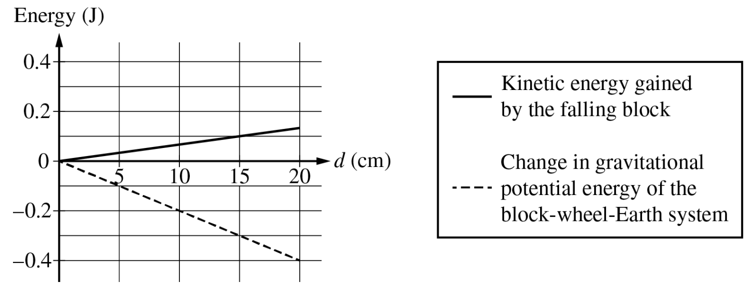
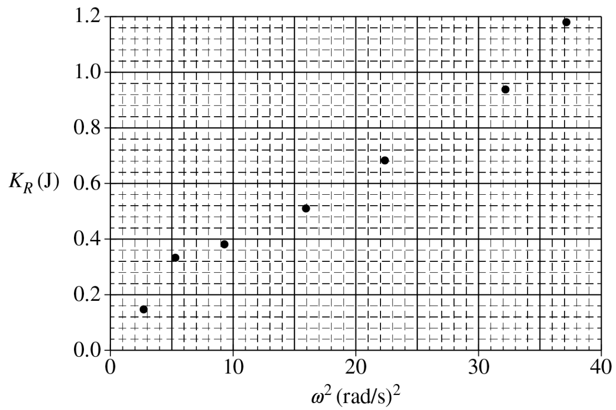
Continue your response to **QUESTION 3** on this page.



(c) The graph above represents both the change in the gravitational potential energy of the block-wheel-Earth system and the translational kinetic energy gained by the block as functions of the block's falling distance d. On the graph, draw a line or curve to represent the rotational kinetic energy of the wheel as a function of the block's falling distance d.

(d) The students also measure the angular velocity ω of the wheel as the block falls and determine the rotational kinetic energy K_R of the wheel. The students then make a graph of K_R as a function of ω^2, as shown.



i. On the above graph, draw a straight line that best represents the data.

ii. Using the line you drew for part (d)(i), calculate an experimental value for the rotational inertia of the wheel.

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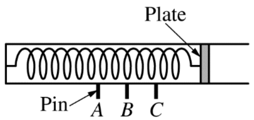


Figure 1. Uncompressed spring

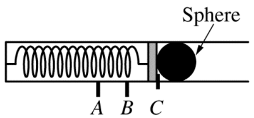


Figure 2. Compressed spring

3. (12 points, suggested time 25 minutes)

A projectile launcher consists of a spring with an attached plate, as shown in Figure 1. When the spring is compressed, the plate can be held in place by a pin at any of three positions *A*, *B*, or *C*. For example, Figure 2 shows a steel sphere placed against the plate, which is held in place by a pin at position *C*. The sphere is launched upon release of the pin.

A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a) The student plans to test the hypothesis by launching the sphere <u>using the launcher</u>.

i. State a basic physics principle or law the student could use in designing an experiment to test the hypothesis.

ii. Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory.

(b) Design an experimental procedure to test the hypothesis <u>in which the student uses the launcher to launch the sphere</u>. Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities and associated symbols that would be measured in your experiment. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

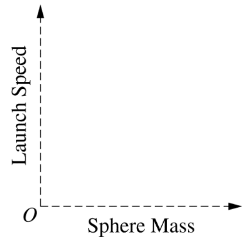
Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

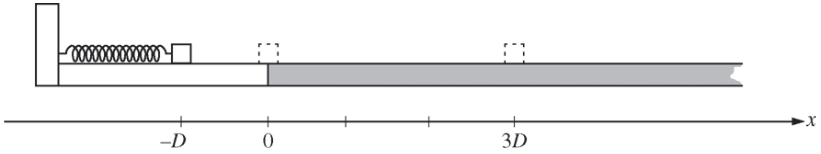
(b) Continued

Describe the overall procedure to be used to test the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

(c) Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances.

(d) Another student uses the launcher to consecutively launch several spheres that have the same diameter but different masses, one after another. Each sphere is launched from position A. Consider each sphere's launch speed, which is the speed of the sphere at the instant it loses contact with the plate. On the axes below, sketch a graph of launch speed as a function of sphere mass.





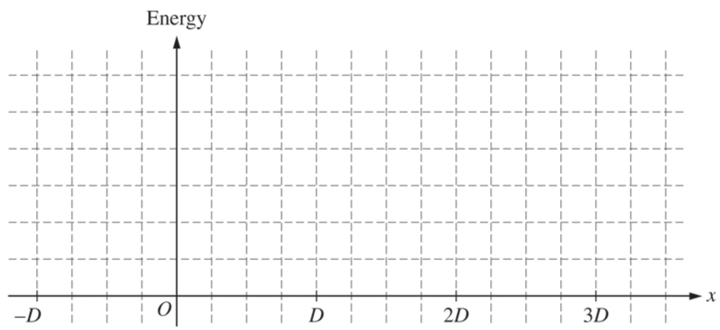
3. (12 points, suggested time 25 minutes)

A block is initially at position $x = 0$ and in contact with an uncompressed spring of negligible mass. The block is pushed back along a frictionless surface from position $x = 0$ to $x = -D$, as shown above, compressing the spring by an amount $\Delta x = D$. The block is then released. At $x = 0$ the block enters a rough part of the track and eventually comes to rest at position $x = 3D$. The coefficient of kinetic friction between the block and the rough track is μ.

(a) On the axes below, sketch and label graphs of the following two quantities as a function of the position of the block between $x = -D$ and $x = 3D$. You do not need to calculate values for the vertical axis, but the same vertical scale should be used for both quantities.

i. The kinetic energy K of the block

ii. The potential energy U of the block-spring system



Name: AP Physics 1: **2015**

The spring is now compressed twice as much, to $\Delta x = 2D$. A student is asked to predict whether the final position of the block will be twice as far at $x = 6D$. The student reasons that since the spring will be compressed twice as much as before, the block will have more energy when it leaves the spring, so it will slide farther along the track before stopping at position $x = 6D$.

(b)
i. Which aspects of the student's reasoning, if any, are correct? Explain how you arrived at your answer.
ii. Which aspects of the student's reasoning, if any, are incorrect? Explain how you arrived at your answer.

(c) Use quantitative reasoning, including equations as needed, to develop an expression for the new final position of the block. Express your answer in terms of D.

(d) Explain how any correct aspects of the student's reasoning identified in part (b) are expressed by your mathematical relationships in part (c). Explain how your relationships in part (c) correct any incorrect aspects of the student's reasoning identified in part (b). Refer to the relationships you wrote in part (c), not just the final answer you obtained by manipulating those relationships.

3.4 Conservation of Energy

Name: ____________ Class: ________ Date: __________ **Total: 10 marks**

KEY WORDS thermal energy 热能 • conservative forces 保守力 • conserved 守恒 • nonconservative forces 非保守力 • energy 能量

Objective

Build the skills to answer exam questions on **conservation of energy**.

You must be able to:

- state the **law of conservation of energy 能量守恒定律** for an isolated system
- distinguish **conservative forces 保守力** from **nonconservative forces 非保守力** such as friction
- apply **conservation of mechanical energy** when no nonconservative force does work
- account for energy transferred to **thermal energy 热能** when friction acts

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Mechanical energy is conserved without friction

With only conservative forces, $KE_i + PE_i = KE_f + PE_f$. A pendulum trades potential for kinetic energy and back.

■ With friction, track the heat

$KE_i + PE_i = KE_f + PE_f + E_{thermal}$. Friction converts mechanical energy into thermal energy — the total is still conserved.

■ Example

A 1.0 kg ball is dropped 5.0 m (take $g = 10$ m s^{-2}). All the PE becomes KE: $v = \sqrt{2gh} = \sqrt{2(10)(5.0)} = 10$ m s^{-1}.

2 Practice

2.1 A 2.0 kg cart starts from rest at the top of a 3.0 m high frictionless ramp (take $g = 10$ m s^{-2}). Find its speed at the bottom. [2]

2.2 State the main energy change when friction acts on a moving block. [1]

2.3 A pendulum bob swings down through a height of 0.20 m. Find its speed at the lowest point (take $g = 10$ m s^{-2}). [2]

3 Exam-style questions

3.1 As a skier descends a frictionless slope, her gravitational potential energy is [1]

- **A** increased
- **B** converted to kinetic energy
- **C** unchanged
- **D** converted to thermal energy

3.2 When friction acts on a moving object, its mechanical energy is [1]

- **A** created
- **B** exactly conserved
- **C** partly converted to thermal energy
- **D** destroyed

3.3 A 0.50 kg ball is dropped from 8.0 m and hits the ground at 10 m s^{-1} (take $g =$ 10 m s^{-2}).

(a) Find the initial gravitational potential energy. [1]

(b) Find the kinetic energy on landing. [1]

(c) Find the energy converted to thermal and other forms. [1]

Solutions

2.1 $\frac{1}{2}mv^2 = mgh \Rightarrow v = \sqrt{2gh} = \sqrt{2(10)(3.0)} = 7.7$ m s^{-1}.

2.2 mechanical energy is converted to thermal energy (heat).

2.3 $v = \sqrt{2gh} = \sqrt{2(10)(0.20)} = 2.0$ m s^{-1}.

3.1 B.

3.2 C.

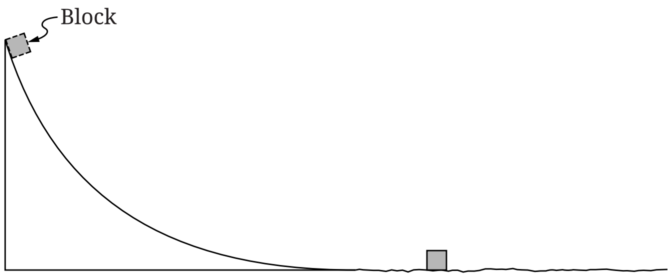
3.3 (a) $U_g = mgh = 0.50 \times 10 \times 8.0 = 40$ J. (b) $KE = \frac{1}{2}(0.50)(10)^2 = 25$ J. (c) $40 - 25 = 15$ J lost to thermal/other forms.

Question 3: Version J

The following information applies to parts A and B.

3. A group of students are investigating friction using the following procedure. The students release a block of unknown mass near the top of a curved ramp. The block slides down the ramp. The block then transitions to a horizontal surface, as shown in Figure 1. Frictional forces are negligible between the block and the curved ramp, but there is friction between the block and the horizontal surface.

Figure 1



The students are asked to perform an experiment in which a single quantity is varied in order to collect data that could be graphed to determine the value μ_k of the coefficient of kinetic friction between the block and the horizontal surface. The students have access to only a meterstick.

Part A

i. **Indicate** quantities that could be measured by the students that would allow them to determine μ_k using a linear graph.

ii. Briefly **describe** a method to reduce experimental uncertainty for the measured quantities.

Part B

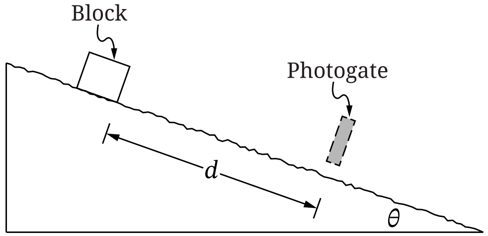
i. **Indicate** what quantities the students could graph on the horizontal and vertical axes to create a linear graph that can be used to determine μ_k. Clearly state which quantity will be graphed on each axis.

ii. Briefly **describe** the relationship between μ_k and a feature of the graph from part B (i). Your answer may include an equation that relates μ_k and the chosen feature of the graph.

The following information applies to parts C and D.

In a different experiment, the students release a block from rest on a rough ramp. The block is released a distance d from a photogate. The ramp is inclined at an angle θ above the horizontal, as shown in Figure 2. The block slides down the ramp and passes through the photogate, which is positioned near the bottom of the ramp. The photogate determines the speed v of the block as it passes through the photogate. The unknown coefficient of kinetic friction between the block and the ramp is μ_k.

Figure 2



The experiment is repeated several times with different release distances d for the same block. Table 1 shows the measured values of d and v.

Table 1

d (m)	v (m/s)
0.20	0.29
0.30	0.38
0.40	0.41
0.50	0.49
0.60	0.52

The students correctly determine that the relationship between d and v is given by

$$v^2 = [2g(\sin\theta - \mu_k \cos\theta)]d,$$

where $\theta = 30^\circ$. The students want to determine μ_k. The students create a graph with d plotted on the horizontal axis.

Part C

i. **Label** the vertical axis of Figure 3 with a measured or calculated quantity. Include units, as appropriate. The graphed quantities should yield a linear graph that can be used to determine μ_k.

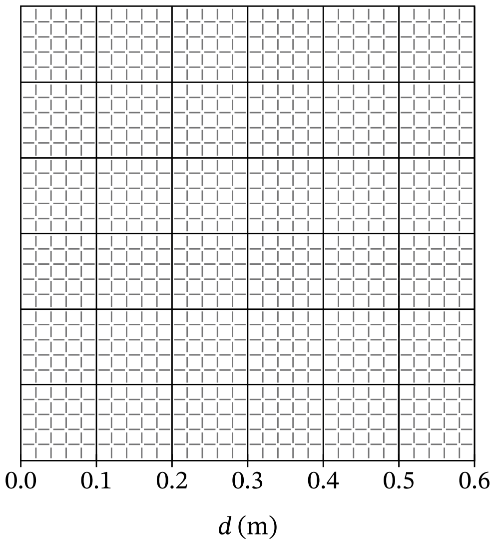
ii. On the grid provided in Figure 3, create a graph that can be used to determine μ_k.

- Clearly **label** the vertical axis with a numerical scale.
- **Plot** the corresponding data points on the grid.
- Table 2 is provided in your booklet for scratch work and will not be scored.

Figure 3

Quantity (units, if appropriate)

__________ __________



iii. **Draw** a best-fit line for the data plotted in part C (ii).

Part D

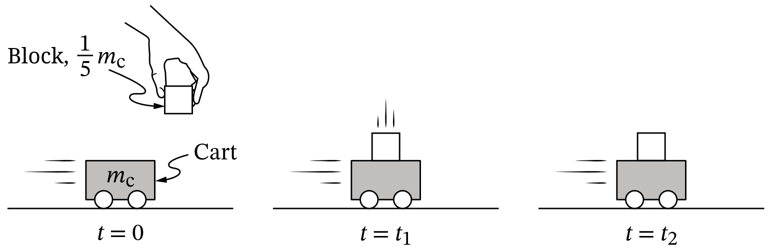
Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for μ_k.

Question 1: Version J

1. A student has a cart of mass m_c and a block of mass $\frac{1}{5}m_c$, as shown in Figure 1.

- At time $t = 0$, the cart is moving to the right across a horizontal surface with constant speed v_c, and the student releases the block from rest.
- At $t = t_1$, the block collides with and sticks to the top of the cart. The block does not slide on the cart.
- At $t = t_2$, the block-cart system continues to move to the right with constant speed v_f.

Figure 1



A.

i. On the axes shown in Figure 2, **sketch** a graph of the magnitude p_x of the x-component of the momentum of the block-cart system as a function of time t from $t = 0$ until $t > t_2$.

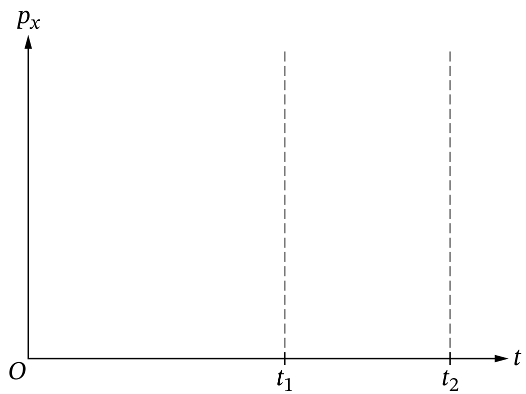


Figure 2

ii. **Derive** an expression for the speed v_f of the block-cart system after time $t = t_2$ in terms of m_c, v_c, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

iii. **Derive** an expression for the change in the kinetic energy ΔK in the block-cart system from $t = 0$ to $t = t_2$ in terms of m_c, v_c, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

B. Consider the case where a new block is dropped and collides with the top of the cart. The new block slides along the cart during the collision but does not slide off the cart. The time interval from when the new block collides with the cart and moves together with the cart is Δt. During Δt there is a frictional force between the new block and the cart.

Indicate whether the x-component of the momentum of the new block-cart system increases, decreases, or remains constant during Δt.

______ Increases

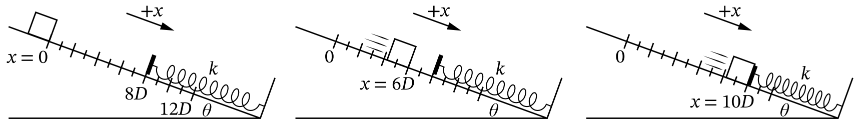
______ Decreases

______ Remains constant

Justify your response.

Question 2: Version J

2. A block of mass M is released from rest at position $x = 0$ near the top of a ramp. The ramp makes an angle of θ with the horizontal. The block slides down the ramp with negligible friction. At $x = 8D$ the block makes contact with an uncompressed spring with spring constant k. The spring is then compressed and the block momentarily comes to rest at $x = 12D$. Figure 1 shows the instants when the block is at $x = 0$, $x = 6D$, and $x = 10D$, respectively.



A. Figure 4 shows an energy bar chart that represents the kinetic energy K of the block, the gravitational potential energy U_g of the block-spring-Earth system, and the spring potential energy U_s of the block-spring-Earth system at the instant that the block is at $x = 10D$. The gravitational potential energy U_g of the block-spring-Earth system is defined to be zero when the block momentarily comes to rest at $x = 12D$.

Draw shaded bars that represent K, U_g, and U_s to complete the energy bar charts in Figure 2 and Figure 3 for when the block is released from rest at $x = 0$ and for when the block is at $x = 6D$, respectively.

- Shaded bars should start at the dashed line that represents zero energy.
- Represent any energy that is equal to zero with a distinct line on the zero-energy line.
- The relative heights of each shaded bar should reflect the magnitude of the respective energy consistent with the scale used in Figure 4.

$x = 0$

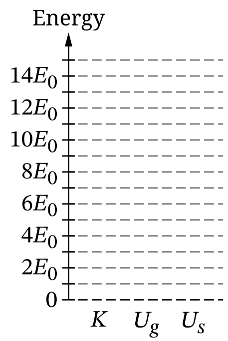


Figure 2

$x = 6D$

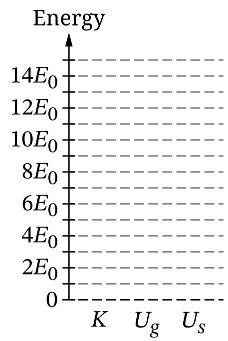


Figure 3

$x = 10D$

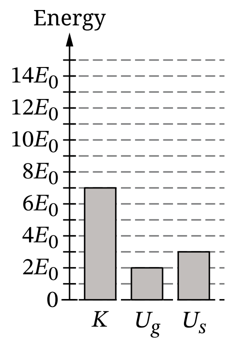
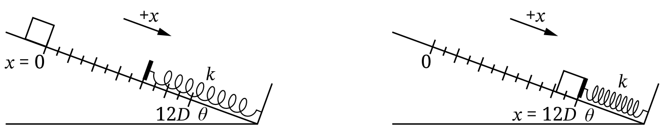


Figure 4

B. Figure 5 shows the block at $x = 0$ when the block is released from rest and the block at $x = 12D$ when the block momentarily comes to rest against the compressed spring.

Figure 5



Starting with conservation of energy, **derive** an equation for the spring constant k. Express your answer in terms of M, θ, D, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. Figure 6 shows a graph of the energy of the system as a function of the position of the block from $x = 8D$ to $x = 12D$. The spring potential energy U_s of the block-spring-Earth system is shown on the graph.

On the axes shown in Figure 6, do the following.

i. **Sketch** and **label** a line or curve that represents the total mechanical energy E for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

ii. **Sketch** and **label** a line or curve that represents the gravitational potential energy U_g for the block-spring-Earth system as a function of the position of the block from $x = 8D$ to $x = 12D$.

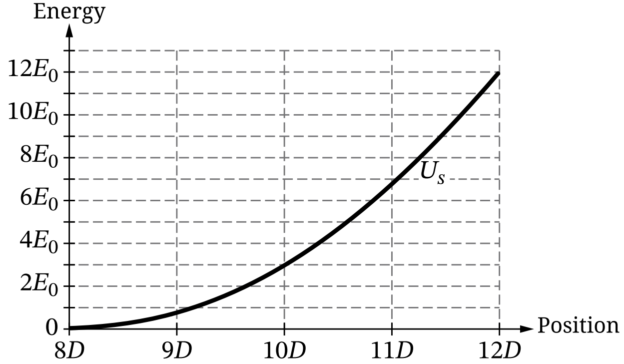


Figure 6

D. **Indicate** whether the speed v_{9D} of the block at $x = 9D$ is greater than, less than, or equal to the speed v_{8D} of the block at $x = 8D$.

______ $v_{9D} > v_{8D}$

______ $v_{9D} < v_{8D}$

______ $v_{9D} = v_{8D}$

Justify how your response is consistent with the energy lines or curves you drew in Figure 6 in part C.

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

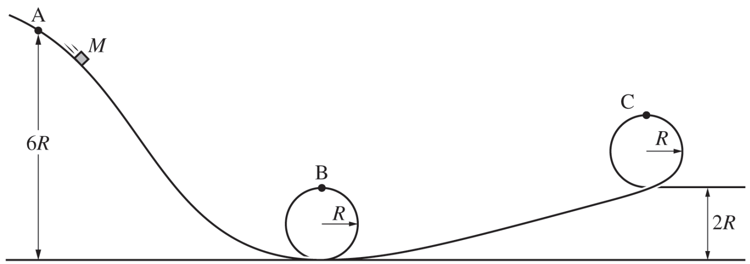
PHYSICS 1

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)

A block of mass M is released from rest at Point A, a height $6R$ above the horizontal. After being released, the block slides down a track, as shown. When released from Point A, the block does not lose contact with the track at any point. Points B and C are located at the highest points of their respective circular loops, both of radius R. All frictional forces are negligible.

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

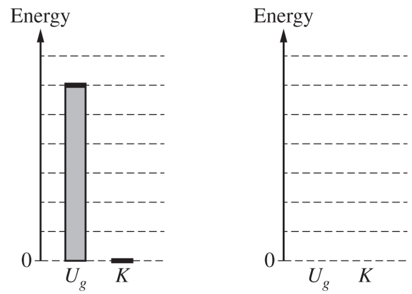

Diagram A Diagram B

Diagram A shows an energy bar chart that represents the gravitational potential energy U_g of the block-Earth system and the kinetic energy K of the block at Point A, when the block is released from rest at height $6R$.

(a) **Draw** shaded regions in Diagram B that represent the gravitational potential energy U_g and kinetic energy K of the block-Earth system when the block is located at Point B, a height $2R$ above the horizontal.

- Shaded regions should start at the dashed line that represents zero energy.
- Represent any energy that is equal to zero with a distinct line on the zero-energy line.
- The relative height of each shaded region should reflect the magnitude of the respective energy consistent with the scale shown in Diagram A.

(b) Starting with conservation of energy, **derive** an expression for the speed of the block at Point B. Express your answer in terms of R and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

GO ON TO THE NEXT PAGE.

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

(c)

i. On the following dot that represents the block, **draw** and **label** the forces (not components) that are exerted on the block at the instant the block slides through Point C. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.

ii. A student claims that $4R$ is the minimum height of Point A, such that the block can slide through Point C without losing contact with the track after the block is released from rest. Briefly **explain** why this claim is incorrect.

GO ON TO THE NEXT PAGE.

PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

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

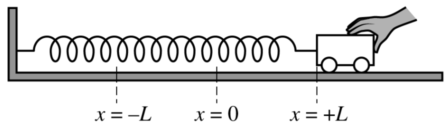

Figure 1

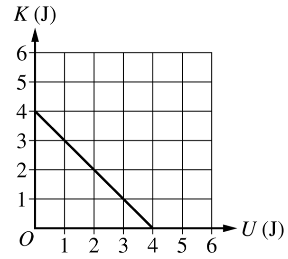

Figure 2

. (7 points, suggested time 13 minutes)

A cart on a horizontal surface is attached to a spring. The other end of the spring is attached to a wall. The cart is initially held at rest, as shown in Figure 1. When the cart is released, the system consisting of the cart and spring oscillates between the positions $x = +L$ and $x = -L$. Figure 2 shows the kinetic energy of the cart-spring system as a function of the system's potential energy. Frictional forces are negligible.

(a) On the graph of kinetic energy K versus potential energy U shown in Figure 2, the values for the x-intercept and y-intercept are the same. Briefly explain why this is true, using physics principles.

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

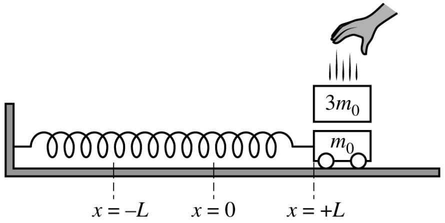


Figure 3

When the cart is at $+L$ and momentarily at rest, a block is dropped onto the cart, as shown in Figure 3. The block sticks to the cart, and the block-cart-spring system continues to oscillate between $-L$ and $+L$. The masses of the cart and the block are m_0 and $3m_0$, respectively.

(b) The frequency of oscillation before the block is dropped onto the cart is f_1. The frequency of oscillation after the block is dropped onto the cart is f_2. Calculate the numerical value of the ratio $\dfrac{f_2}{f_1}$.

GO ON TO THE NEXT PAGE.

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

(c) The dashed line in Figure 4 shows the kinetic energy K versus potential energy U of the block-cart-spring system after the block is dropped onto the cart. This graph is identical to the graph shown in Figure 2 for the cart-spring system before the block is dropped onto the cart.

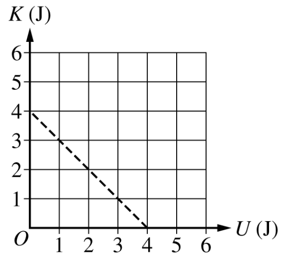


Figure 4

i. Briefly explain why the two graphs must be the same, using physics principles.

ii. After the block is dropped onto the cart, consider a system that consists only of the cart and the spring. On Figure 4, sketch a solid line that shows the kinetic energy of the system that consists of the cart and the spring but not the block after the block is dropped onto the cart.

GO ON TO THE NEXT PAGE.

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

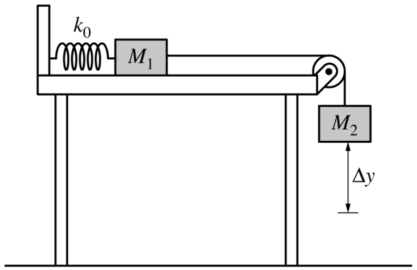
PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

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



. (7 points, suggested time 13 minutes)

Two blocks are connected by a string that passes over a pulley, as shown above. Block 1 is on a horizontal surface and is attached to a spring that is at its unstretched length. Frictional forces are negligible in the pulley's axle and between the block and the surface. Block 2 is released from rest and moves downward before momentarily coming to rest.

k_0 is the spring constant of the spring.
M_1 is the mass of block 1.
M_2 is the mass of block 2.
Δy is the distance block 2 moves before momentarily coming to rest.

GO ON TO THE NEXT PAGE.

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

(a)

i. Block 2 starts from rest and speeds up, then it slows down and momentarily comes to rest at a position below its initial position. In terms of only the forces directly exerted on block 2, explain why block 2 initially speeds up and explain why it slows down to a momentary stop.

ii. Derive an expression for the distance Δy that block 2 travels before momentarily coming to rest. Express your answer in terms of k_0, M_1, M_2, and physical constants, as appropriate.

(b) Indicate whether the total mechanical energy of the blocks-spring-Earth system changes as block 2 moves downward.

___ Changes ___ Does not change

Briefly explain your reasoning.

GO ON TO THE NEXT PAGE.

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

Consider the system that includes the spring, Earth, both blocks, and the string, but not the surface. Let the initial state be when the blocks are at rest just before they start moving, and let the final state be when the blocks first come momentarily to rest. Diagram A at left below is a bar chart that represents the energies in the scenario where there is negligible friction between block 1 and the surface.

The shaded-in bars in the energy bar charts represent the potential energy of the spring and the gravitational potential energy of the blocks-Earth system, U_s and U_g, respectively, in the initial and final states. Positive energy values are above the zero-point line ("0") and negative energy values are below the zero-point line.

Diagram A: Negligible Friction

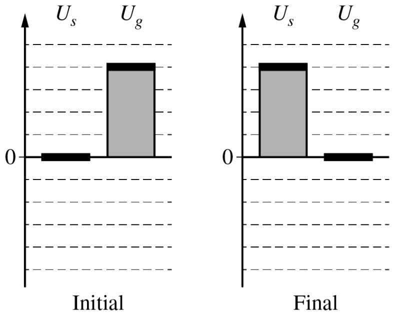
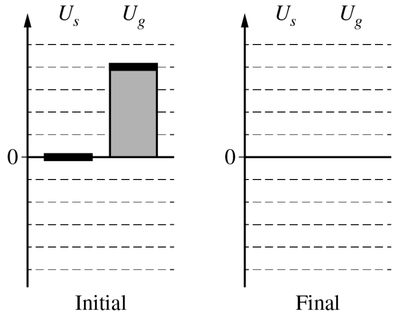


Diagram B: Nonnegligible Friction



(c) Complete diagram B (at right above) for the scenario in which friction is nonnegligible. The energies for the initial state are already provided. Shade in the energies in the final state using the same scale as in diagram A.

- Shaded regions should start at the solid line representing the zero-point line.
- Represent any energy that is equal to zero with a distinct line on the zero-point line.

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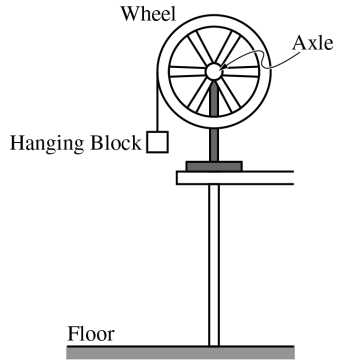
Begin your response to **QUESTION 3** on this page.



. (12 points, suggested time 25 minutes)

A wheel is mounted on a horizontal axle. A light string is attached to the wheel's rim and wrapped around it several times, and a small block is attached to the free end of the string, as shown in the figure. When the block is released from rest and begins to fall, the wheel begins to rotate with negligible friction.

Two students are discussing how different forms of energy change as the block falls. One student says that the kinetic energy of the block increases as it falls. The second student says that this is because gravitational potential energy is converted to kinetic energy. The students decide to test whether the decrease in gravitational potential energy is equal to the increase in the block's kinetic energy from when the block starts moving to immediately before it reaches the floor.

GO ON TO THE NEXT PAGE.

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

(a) Design an experimental procedure that the students could use to compare the increase in the block's translational kinetic energy with the decrease in the gravitational potential energy of the block-Earth system as the block falls.

In the table, list the quantities that would be measured in your experiment. Define a symbol to represent each quantity and list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

In the space to the right of the table, describe the overall procedure. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table.

If needed, you may include a simple diagram of the setup with your procedure.

Quantity to Be Measured	Symbol for Quantity	Equipment for Measurement	Procedure (and diagram, if needed)

(b) Explain how the students could determine the kinetic energy of the block immediately before it reaches the floor using the quantities you indicated in the table in part (a).

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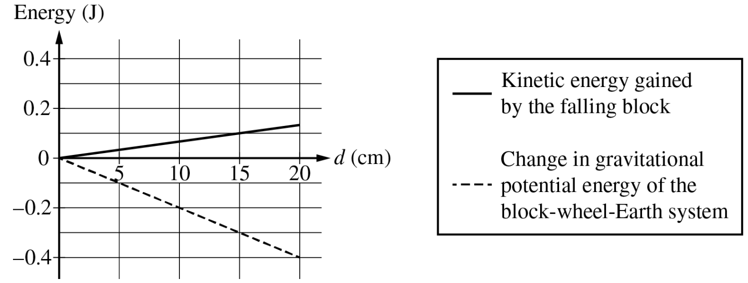
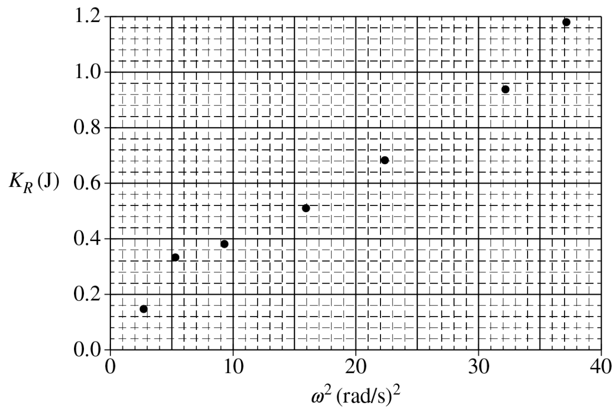
Continue your response to **QUESTION 3** on this page.



(c) The graph above represents both the change in the gravitational potential energy of the block-wheel-Earth system and the translational kinetic energy gained by the block as functions of the block's falling distance d. On the graph, draw a line or curve to represent the rotational kinetic energy of the wheel as a function of the block's falling distance d.

(d) The students also measure the angular velocity ω of the wheel as the block falls and determine the rotational kinetic energy K_R of the wheel. The students then make a graph of K_R as a function of ω^2, as shown.



i. On the above graph, draw a straight line that best represents the data.

ii. Using the line you drew for part (d)(i), calculate an experimental value for the rotational inertia of the wheel.

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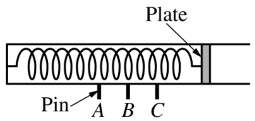


Figure 1. Uncompressed spring

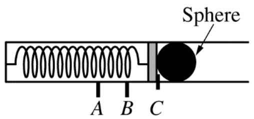


Figure 2. Compressed spring

3. (12 points, suggested time 25 minutes)

A projectile launcher consists of a spring with an attached plate, as shown in Figure 1. When the spring is compressed, the plate can be held in place by a pin at any of three positions *A*, *B*, or *C*. For example, Figure 2 shows a steel sphere placed against the plate, which is held in place by a pin at position *C*. The sphere is launched upon release of the pin.

A student hypothesizes that the spring constant of the spring inside the launcher has the same value for different compression distances.

(a) The student plans to test the hypothesis by launching the sphere <u>using the launcher</u>.

i. State a basic physics principle or law the student could use in designing an experiment to test the hypothesis.

ii. Using the principle or law stated in part (a)(i), determine an expression for the spring constant in terms of quantities that can be obtained from measurements made with equipment usually found in a school physics laboratory.

(b) Design an experimental procedure to test the hypothesis <u>in which the student uses the launcher to launch the sphere</u>. Assume equipment usually found in a school physics laboratory is available.

In the table below, list the quantities and associated symbols that would be measured in your experiment. Also list the equipment that would be used to measure each quantity. You do not need to fill in every row. If you need additional rows, you may add them to the space just below the table.

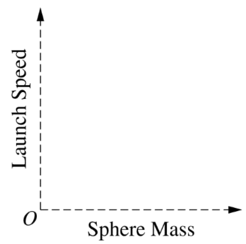
Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

(b) Continued

Describe the overall procedure to be used to test the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances, referring to the table. Provide enough detail so that another student could replicate the experiment, including any steps necessary to reduce experimental uncertainty. As needed, use the symbols defined in the table and/or include a simple diagram of the setup.

(c) Describe how the experimental data could be analyzed to confirm or disconfirm the hypothesis that the spring constant of the spring inside the launcher has the same value for different compression distances.

(d) Another student uses the launcher to consecutively launch several spheres that have the same diameter but different masses, one after another. Each sphere is launched from position A. Consider each sphere's launch speed, which is the speed of the sphere at the instant it loses contact with the plate. On the axes below, sketch a graph of launch speed as a function of sphere mass.



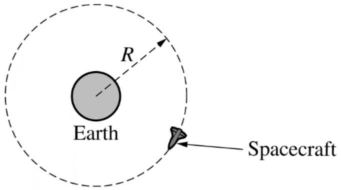
PHYSICS 1

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.

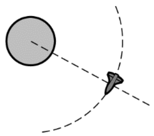


Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

A spacecraft of mass m is in a clockwise circular orbit of radius R around Earth, as shown in the figure above. The mass of Earth is M_E.

(a) In the figure below, draw and label the forces (not components) that act on the spacecraft. Each force must be represented by a distinct arrow starting on, and pointing away from, the spacecraft.



Note: Figure not drawn to scale.

(b)

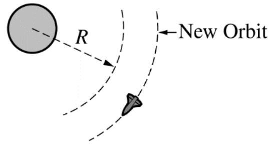
i. Derive an equation for the orbital period T of the spacecraft in terms of m, M_E, R, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (a) to assist in your solution, use the space below. Do NOT add anything to the figure in part (a).

ii. A second spacecraft of mass $2m$ is placed in a circular orbit with the same radius R. Is the orbital period of the second spacecraft greater than, less than, or equal to the orbital period of the first spacecraft?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.

(c) The first spacecraft is moved into a new circular orbit that has a radius greater than R, as shown in the figure below.

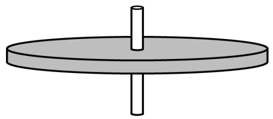


Note: Figure not drawn to scale.

Is the speed of the spacecraft in the new orbit greater than, less than, or equal to the original speed?

____ Greater than ____ Less than ____ Equal to

Briefly explain your reasoning.



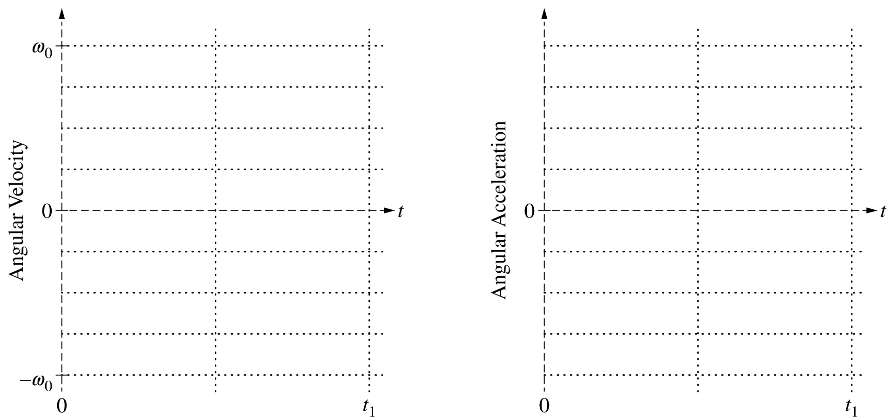
3. (12 points, suggested time 25 minutes)

The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

(a) At time $t = 0$ the disk has an initial counterclockwise (positive) angular velocity ω_0. The disk later comes to rest at time $t = t_1$.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

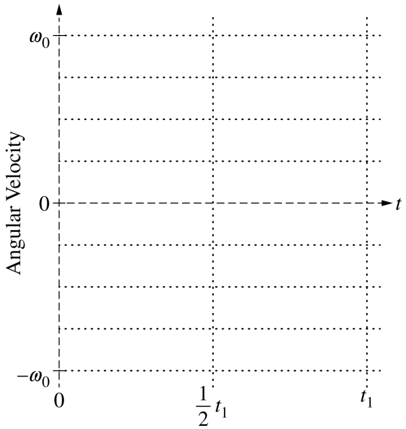


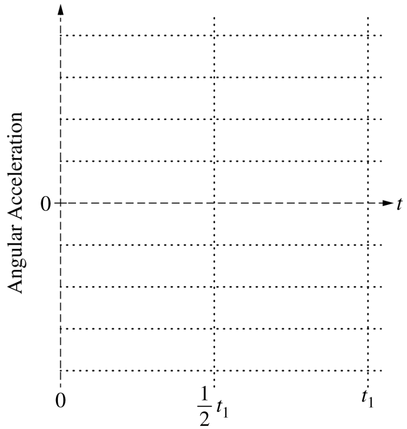
(b) The magnitude of the frictional torque exerted on the disk is τ_0. Derive an equation for the rotational inertia I of the disk in terms of τ_0, ω_0, t_1, and physical constants, as appropriate.

(c) In another experiment, the disk again has an initial positive angular velocity ω_0 at time $t = 0$. At time $t = \frac{1}{2}t_1$, the student starts dripping oil on the contact surface between the axle and the disk to reduce the friction. As time passes, more and more oil reaches that contact surface, reducing the friction even further.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from $t = 0$ to $t = t_1$, which is the time at which the disk came to rest in part (a).

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time from $t = 0$ to $t = t_1$.





(d) The student is trying to mathematically model the magnitude τ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2}t_1$. The student writes down the following two equations, each of which includes a positive constant $(C_1 \text{ or } C_2)$ with appropriate units.

(1) $\tau = C_1\left(t - \frac{1}{2}t_1\right)$ (for $t > \frac{1}{2}t_1$)

(2) $\tau = \dfrac{C_2}{\left(t + \frac{1}{2}t_1\right)}$ (for $t > \frac{1}{2}t_1$)

Which equation better mathematically models this experiment?

____ Equation (1) ____ Equation (2)

Briefly explain why the equation you selected is plausible and why the other equation is not plausible.

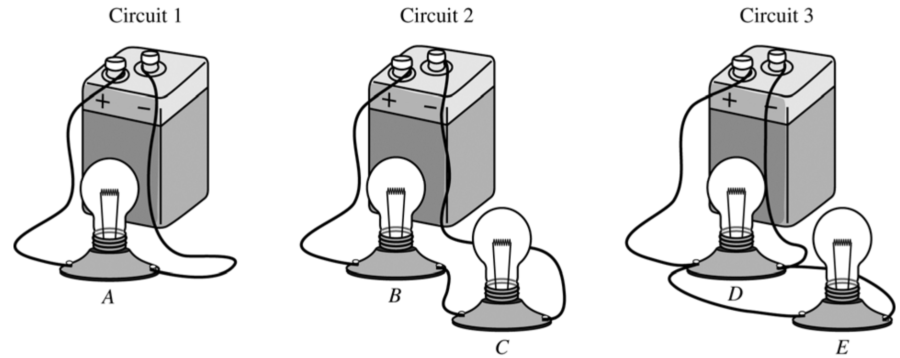
PHYSICS 1

Section II

5 Questions

Time—90 minutes

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)

In the three circuits shown above, the batteries are all identical, and the lightbulbs are all identical. In circuit 1 a single lightbulb is connected to the battery. In circuits 2 and 3, two lightbulbs are connected to the battery in different ways, as shown. The lightbulbs are labeled *A*–*E*.

(a) Rank the magnitudes of the potential differences across lightbulbs *A*, *B*, *C*, *D*, and *E* from largest to smallest. If any lightbulbs have the same potential difference across them, state that explicitly.

Ranking:

Briefly explain how you determined your ranking.

(b) The batteries all start with an identical amount of usable energy and are all connected to the lightbulbs in the circuits at the same time.

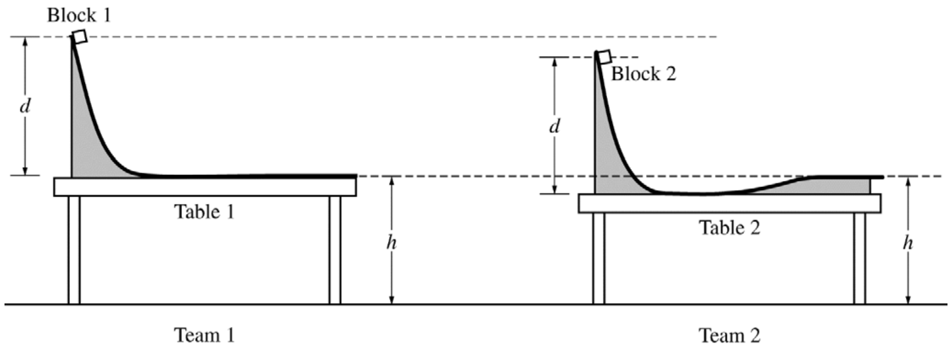
In which circuit will the battery run out of usable energy first?

____ Circuit 1 ____ Circuit 2 ____ Circuit 3

In which circuit will the battery run out of usable energy last?

____ Circuit 1 ____ Circuit 2 ____ Circuit 3

In a clear, coherent paragraph-length response that may also contain equations and drawings, explain your reasoning.



4. (7 points, suggested time 13 minutes)

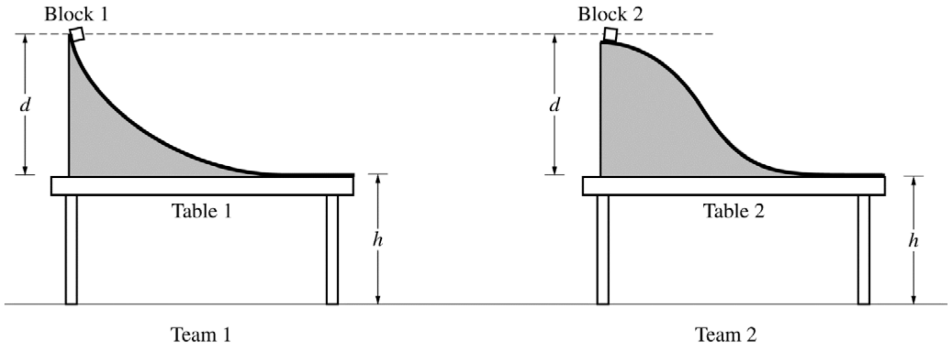
A physics class is asked to design a low-friction slide that will launch a block horizontally from the top of a lab table. Teams 1 and 2 assemble the slides shown above and use identical blocks 1 and 2, respectively. Both slides start at the same height d above the tabletop. However, team 2's table is lower than team 1's table. To compensate for the lower table, team 2 constructs the right end of the slide to rise above the tabletop so that the block leaves the slide horizontally at the same height h above the floor as does team 1's block (see figure above).

(a) Both blocks are released from rest at the top of their respective slides. Do block 1 and block 2 land the same distance from their respective tables?

____ Yes ____ No

Justify your answer.

In another experiment, teams 1 and 2 use tables and low-friction slides with the same height. However, the two slides have different shapes, as shown below.



(b) Both blocks are released from rest at the top of their respective slides at the same time.

i. Which block, if either, lands farther from its respective table?

____ Block 1 ____ Block 2 ____ The two blocks land the same distance from their respective tables.

Briefly explain your reasoning without manipulating equations.

ii. Which block, if either, hits the floor first?

____ Block 1 ____ Block 2 ____ The two blocks hit the floor at the same time.

Briefly explain your reasoning without manipulating equations.

3.5 Power

Name: ____________ Class: ________ Date: __________ **Total: 9 marks**

KEY WORDS power 功率 • watt 瓦特 • average power 平均功率 • energy 能量 • work 功

Objective

Build the skills to answer exam questions on **power**.

You must be able to:

- define **power** 功率 as $P = \dfrac{W}{\Delta t}$
- calculate **average power** 平均功率 from work done over a time interval
- relate **instantaneous power** to force and velocity, $P = Fv$
- use the SI unit **watt** 瓦特 and convert between energy and power

1 Worked examples

Study these first. Each one shows the method for a question type used later.

Power is the rate of energy transfer

$P = \dfrac{W}{\Delta t}$, measured in watts (1 W = 1 J s^{-1}). A motor that does 600 J of work in 3.0 s delivers $P = 200$ W.

Power from force and speed

For a force acting at speed v, $P = Fv$. A car engine providing 50 N of drive at 4.0 m s^{-1}: $P = 200$ W.

Energy from power

$W = P\,\Delta t$. A 100 W bulb left on for 60 s uses 6000 J.

2 Practice

2.1 A crane does 9000 J of work in 6.0 s. Find its power. [1]

2.2 A car engine pushes with 800 N at a steady 20 m s^{-1}. Find the power delivered. [2]

2.3 A 60 W device runs for 120 s. Find the energy it uses. [1]

3 Exam-style questions

3.1 One watt is equal to [1]

- **A** 1 J
- **B** 1 J s^{-1}
- **C** 1 N
- **D** 1 J s

3.2 A motor lifts a 200 N weight at a constant 0.50 m s^{-1}. Its power output is [1]

- **A** 100 W
- **B** 200 W
- **C** 400 W
- **D** zero

3.3 A 500 kg lift rises 20 m at constant speed in 10 s (take $g = 10$ m s^{-2}).

(a) Find the work done against gravity. [2]

(b) Find the power output of the motor. [1]

Solutions

2.1 $P = \dfrac{W}{\Delta t} = \dfrac{9000}{6.0} = 1500$ W.

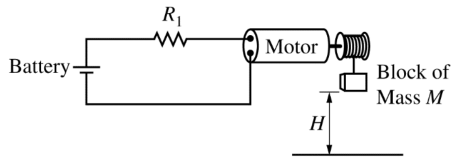
2.2 $P = Fv = 800 \times 20 = 16\,000$ W.

2.3 $W = P\,\Delta t = 60 \times 120 = 7200$ J.

3.1 **B**.

3.2 **A** — $P = Fv = 200 \times 0.50 = 100$ W.

3.3 (a) $W = mgh = 500 \times 10 \times 20 = 1.0 \times 10^5$ J. (b) $P = \dfrac{1.0 \times 10^5}{10} = 1.0 \times 10^4$ W.



4. (7 points, suggested time 13 minutes)

A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass M at constant speed from the ground to a height H above the ground in a time interval Δt. The motor has constant resistance and is connected in series with a resistor of resistance R_1 and a battery.

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

(a) Determine an expression for the mechanical power in terms of M, H, Δt, and physical constants, as appropriate.

(b) Without M or H being changed, the time interval Δt can be decreased by adding one resistor of resistance R_2, where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance R_2 be added to the circuit to decrease Δt ?

___ In parallel with the battery ___ In parallel with R_1 ___ In parallel with the motor ___ In series with the battery, R_1, and the motor

In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease Δt.

2. (12 points, suggested time 25 minutes)

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas A and lengths ℓ. Each student applies a potential difference ΔV across the ends of a dough cylinder and determines the resistance R of the cylinder. The results of their experiments are shown in the table below.

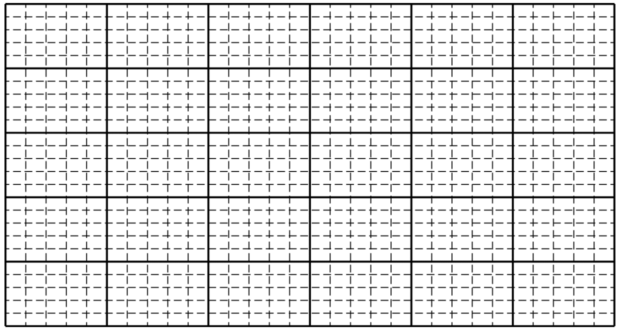
Dough Cylinder	A (m^2)	ℓ (m)	ΔV (V)	R (Ω)		
1	0.00049	0.030	1.02	23.6		
2	0.00049	0.050	2.34	31.5		
3	0.00053	0.080	3.58	61.2		
4	0.00057	0.150	6.21	105		

(a) The students want to determine the resistivity of the dough cylinders.

i. Indicate below which quantities could be graphed to determine a value for the resistivity of the dough cylinders. You may use the remaining columns in the table above, as needed, to record any quantities (including units) that are not already in the table.

Vertical Axis: ________________________ Horizontal Axis: ________________________

ii. On the grid below, plot the appropriate quantities to determine the resistivity of the dough cylinders. Clearly scale and label all axes, including units as appropriate.



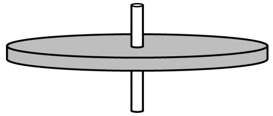
iii. Use the above graph to estimate a value for the resistivity of the dough cylinders.

(b) Another group of students perform the experiment described in part (a) but shape the dough into long rectangular shapes instead of cylinders. Will this change affect the value of the resistivity determined by the second group of students?

____ Yes ____ No

Briefly justify your reasoning.

(c) Describe an experimental procedure to determine whether or not the resistivity of the dough cylinders depends on the temperature of the dough. Give enough detail so that another student could replicate the experiment. As needed, include a diagram of the experimental setup. Assume equipment usually found in a school physics laboratory is available.



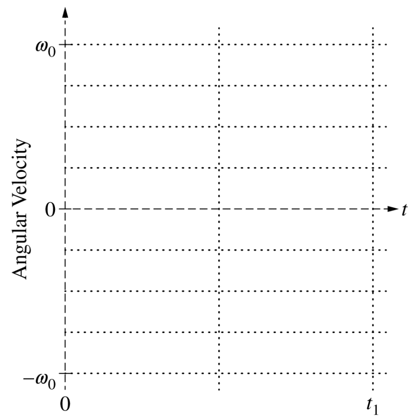
3. (12 points, suggested time 25 minutes)

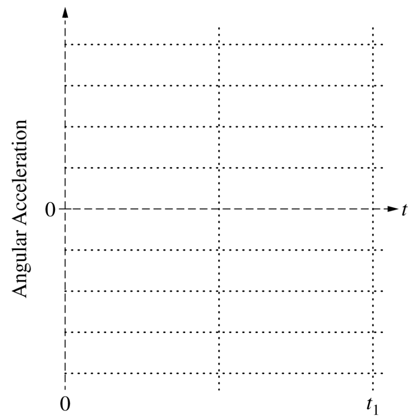
The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

(a) At time $t = 0$ the disk has an initial counterclockwise (positive) angular velocity ω_0. The disk later comes to rest at time $t = t_1$.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.



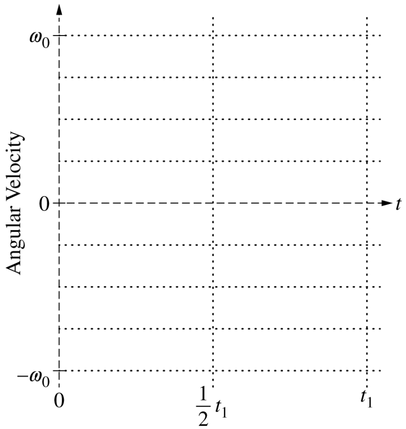


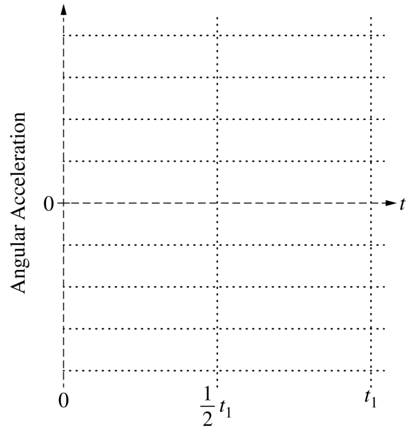
(b) The magnitude of the frictional torque exerted on the disk is τ_0. Derive an equation for the rotational inertia I of the disk in terms of τ_0, ω_0, t_1, and physical constants, as appropriate.

(c) In another experiment, the disk again has an initial positive angular velocity ω_0 at time $t = 0$. At time $t = \frac{1}{2}t_1$, the student starts dripping oil on the contact surface between the axle and the disk to reduce the friction. As time passes, more and more oil reaches that contact surface, reducing the friction even further.

i. On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from $t = 0$ to $t = t_1$, which is the time at which the disk came to rest in part (a).

ii. On the grid at right below, sketch the disk's angular acceleration as a function of time from $t = 0$ to $t = t_1$.





(d) The student is trying to mathematically model the magnitude τ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2}t_1$. The student writes down the following two equations, each of which includes a positive constant (C_1 or C_2) with appropriate units.

(1) $\tau = C_1\left(t - \frac{1}{2}t_1\right)$ (for $t > \frac{1}{2}t_1$)

(2) $\tau = \dfrac{C_2}{\left(t + \frac{1}{2}t_1\right)}$ (for $t > \frac{1}{2}t_1$)

Which equation better mathematically models this experiment?

____ Equation (1) ____ Equation (2)

Briefly explain why the equation you selected is plausible and why the other equation is not plausible.

PHYSICS 1

Section II

5 Questions

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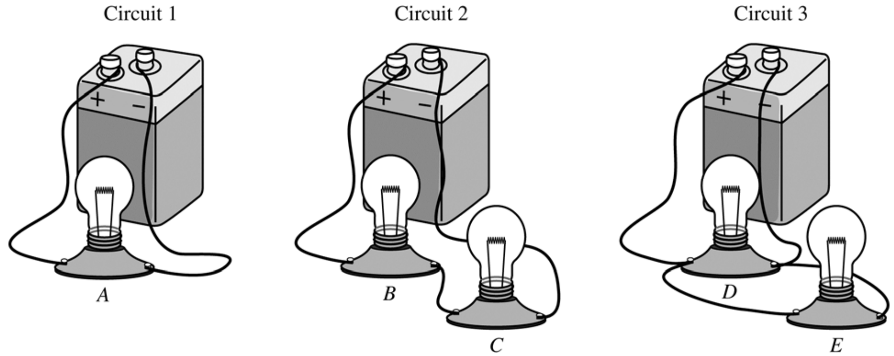

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