Week 5

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. A 2 kg mass is at $x = 0$ and a 6 kg mass at $x = 8$ m. Where is the centre of mass, in metres?

   ____________ m

2. What is the SI unit of force?

   ☐ joule

   ☐ newton

   ☐ watt

   ☐ pascal

3. You push a wall with a force of 50 N. With what force does the wall push back on you?

   ☐ 0 N — walls do not push

   ☐ 25 N

   ☐ 50 N

   ☐ 100 N

4. An object has zero net force acting on it. What must be true of its motion?

   ☐ It must be at rest

   ☐ It must be speeding up

   ☐ It has constant velocity (possibly zero)

   ☐ It must be turning

5. A net force of 12 N acts on a 3 kg trolley. What is its acceleration, in $\frac{\text{m}}{\text{s}^2}$?

   ____________ m/s^2

6. What is the weight of a 5 kg bag on Earth, where $g = 9.8\ \frac{\text{N}}{\text{kg}}$? Answer in N.

   ____________ N

7. Which friction acts on an object that is being pushed but has **not** started to move?

   ☐ kinetic friction

   ☐ static friction

   ☐ no friction at all

   ☐ both, equally

8. A spring with $k = 200\ \frac{\text{N}}{\text{m}}$ is stretched by 0.10 m. What is the spring force, in N?

________________ N

9. A ball whirls on a string in a horizontal circle. The string suddenly snaps. Which way does the ball fly?

   ☐ straight outward, away from the centre

   ☐ straight toward the centre

   ☐ along the tangent, in a straight line

   ☐ it stops immediately

10. The two forces of an action–reaction pair act on the same object.

    ☐ True ☐ False

AP Physics 1

1. **6 m**

   $x_{\text{cm}} = \dfrac{2(0)+6(8)}{2+6} = \dfrac{48}{8} = 6$ m — closer to the heavier mass.

2. **newton**

   Force is measured in **newtons** (N). Joules measure energy, watts power, pascals pressure.

3. 50 **N**

   By the third law the reaction is equal in size: the wall pushes back with 50 N.

4. **It has constant velocity (possibly zero)**

   Zero net force ⇒ zero acceleration ⇒ constant velocity. Rest is the special case where that velocity is zero.

5. **4 m/s^2**

   $a = F_{\text{net}}/m = 12/3 = 4\ \frac{\text{m}}{\text{s}^2}$.

6. **49 N**

   $W = mg = 5 \times 9.8 = 49$ N.

7. **static friction**

   Before sliding, **static** friction acts and grows to match the push, up to $\mu_s N$.

8. **20 N**

   $F = kx = 200 \times 0.10 = 20$ N.

9. **along the tangent, in a straight line**

   With no inward force, inertia carries the ball in a straight line — along the **tangent** where the string broke.

10. **False**

    They act on **different** objects — one on A, one on B. That is why they do not cancel.

AP PHYSICS 1 • EXERCISE SHEET

2.1 Systems and Center of Mass

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

KEY WORDS system 系统 • force 力 • centre of mass 质心 • internal 内力 • external forces 外力

Objective

Build the skills to answer exam questions on **systems and centre of mass**.

You must be able to:

- define a **system 系统** and distinguish **internal 内力** and **external forces 外力**
- define the **centre of mass 质心** as the mass-weighted average position
- explain that a system's centre of mass accelerates only under the **net external force**
- calculate the centre of mass of a set of point masses

1 Worked examples

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

■ Centre of mass of point masses

$$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}.$$

Masses 2.0 kg at $x = 0$ and 3.0 kg at $x = 5.0$ m: $x_{cm} = \dfrac{2.0(0) + 3.0(5.0)}{5.0} = 3.0$ m.

■ Internal vs external forces

Forces **between** parts of the system are **internal** and cancel in third-law pairs; only **external** forces (from outside the system) change the motion of the centre of mass.

■ Motion of the centre of mass

When a firework explodes, its fragments fly apart under **internal** forces, but the centre of mass keeps following the original projectile path — the only external force is gravity.

2 Practice

2.1 Masses 1.0 kg at $x = 0$ and 4.0 kg at $x = 10$ m. Find the centre of mass. [2]

2.2 Two blocks are joined by a string and pulled along. Taking the **system to be both blocks**, state whether the string tension is an internal or external force. [1]

2.3 Two equal masses sit at $x = 2.0$ m and $x = 8.0$ m. State the centre of mass without calculating, and justify. [2]

3 Exam-style questions

3.1 The acceleration of a system's centre of mass depends only on [1]

- **A** the internal forces
- **B** the net external force
- **C** the largest mass
- **D** the total kinetic energy

3.2 Three 2.0 kg masses lie at $x = 0$, 3.0 m and 6.0 m. The centre of mass is at [1]

- **A** 2.0 m
- **B** 3.0 m
- **C** 4.5 m
- **D** 6.0 m

3.3 A 60 kg skater and a 40 kg skater stand 5.0 m apart on frictionless ice and pull on a rope between them.

(a) Find the centre of mass, measured from the 60 kg skater. [2]

(b) State where they meet, and explain why. [1]

Solutions

2.1 $x_{cm} = \dfrac{1.0(0) + 4.0(10)}{5.0} = 8.0$ m.

2.2 internal (it acts between two parts of the system).

2.3 midpoint, $x = 5.0$ m — the masses are equal, so the centre of mass is exactly halfway between them.

3.1 **B**.

3.2 **B** — by symmetry, $x_{cm} = 3.0$ m.

3.3 (a) $x_{cm} = \dfrac{60(0) + 40(5.0)}{100} = 2.0$ m. (b) They meet at the centre of mass, 2.0 m from the 60 kg skater — with no external horizontal force, the centre of mass stays fixed.

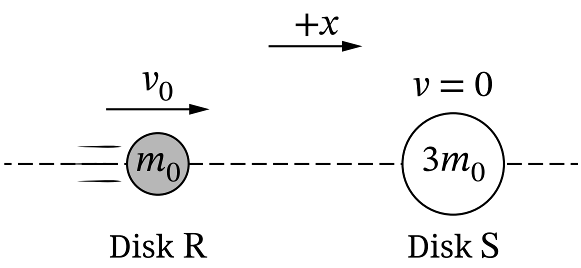
Question 2: Version J

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



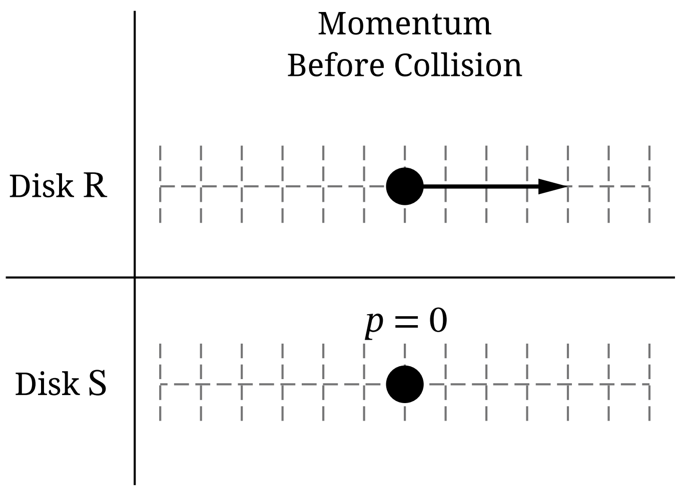
Top View

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.

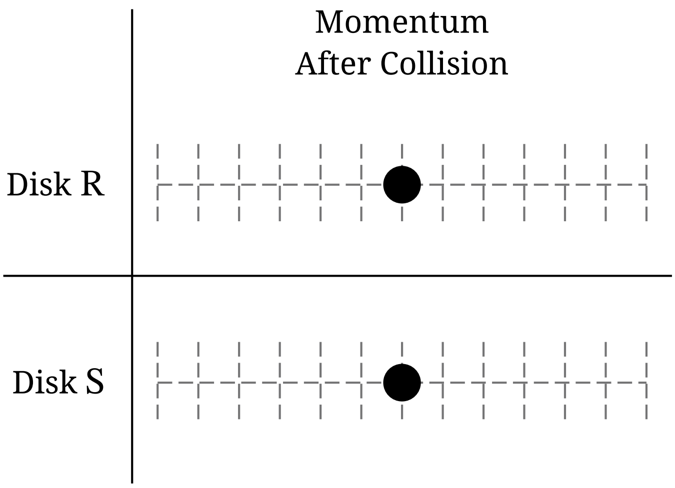
Figure 2



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.

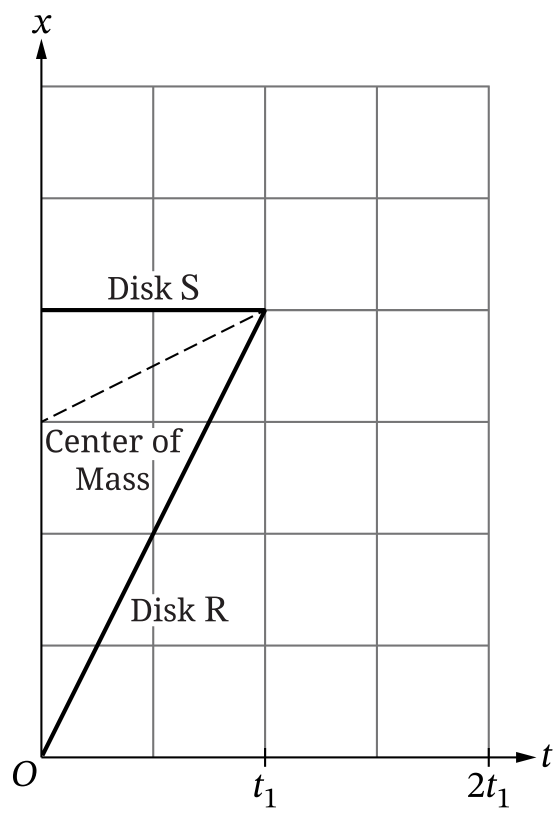
Part C

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.

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

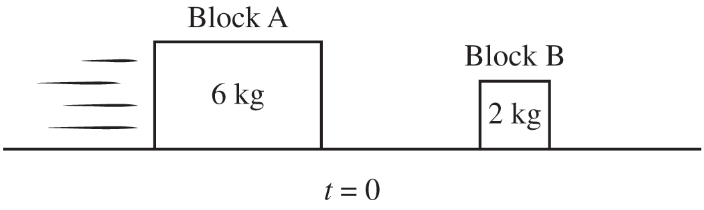


Figure 1

5. (7 points, suggested time 13 minutes)

At time $t = 0$, Block A slides along a horizontal surface toward Block B, which is initially at rest, as shown in Figure 1. The masses of blocks A and B are 6 kg and 2 kg, respectively. The blocks collide elastically at $t = 1.0$ s, and as a result, the magnitude of the change in kinetic energy of Block B is 9 J. All frictional forces are negligible.

(a) **Determine** the speed of Block B immediately after the collision.

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

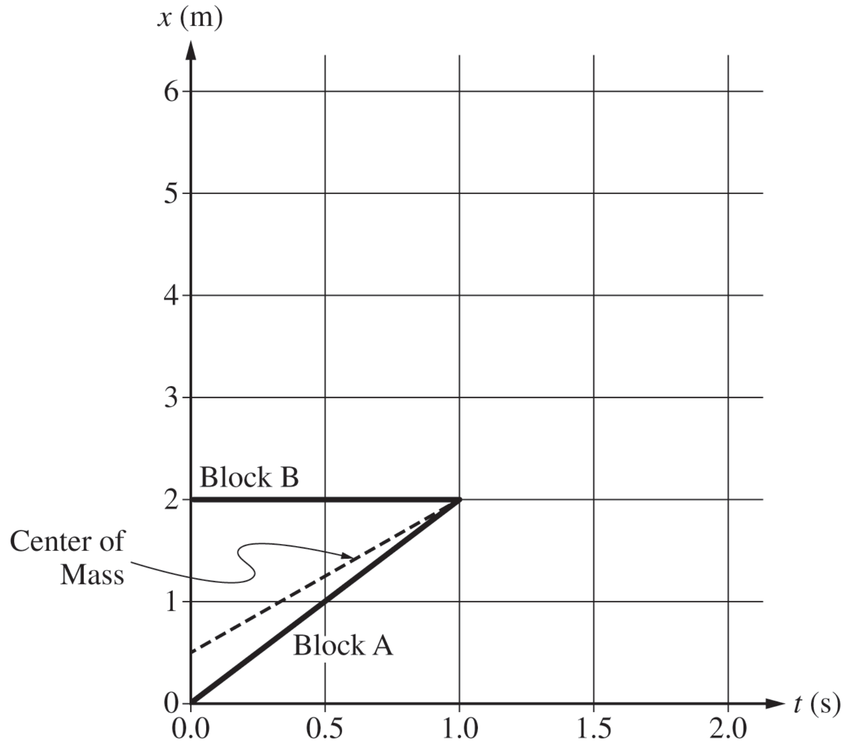

Figure 2

The graph shown in Figure 2 represents the positions x of Block A, Block B, and the center of mass of the two-block system as functions of t between $t = 0$ and $t = 1.0$ s.

(b) On the graph in Figure 2, **draw** and **label** three lines to represent the positions of Block A, Block B, and the center of mass of the two-block system as functions of t between $t = 1.0$ s and $t = 2.0$ s. Each line should be distinctly labeled.

(c) Consider if in the original scenario, instead of colliding elastically, the blocks collided and stuck together. **Describe** how the line drawn for the center of mass in part (b) would change, if at all. Briefly **justify** your response.

GO ON TO THE NEXT PAGE.

STOP

END OF EXAM

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.

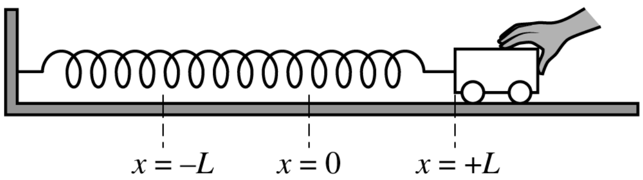

Figure 1

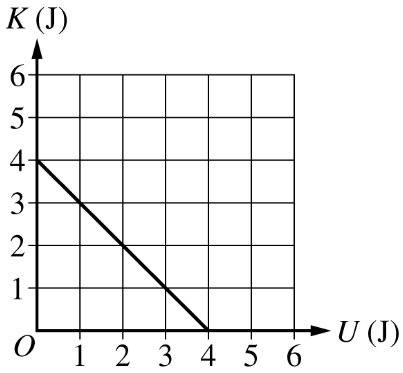

Figure 2

. (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.

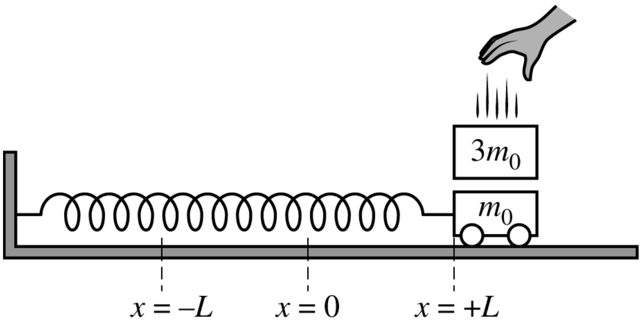

Figure 3

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.

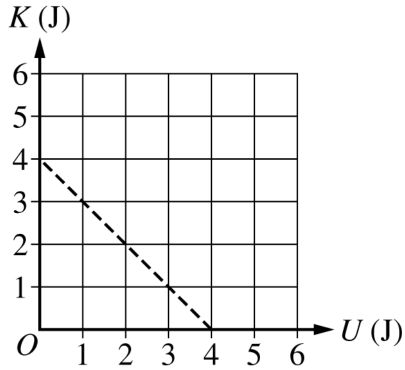

Figure 4

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.

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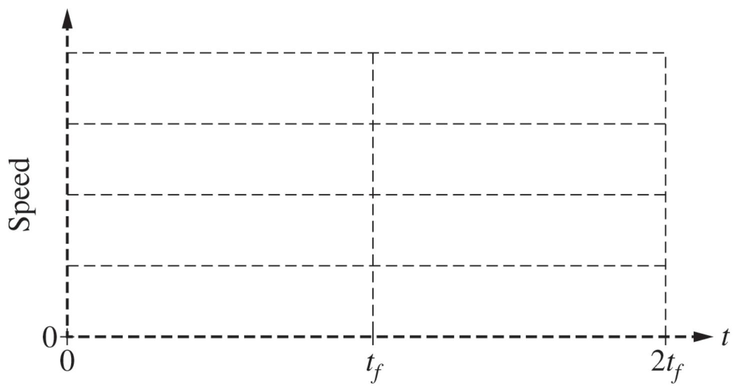
3. (12 points, suggested time 25 minutes)

(a) A student of mass M_S, standing on a smooth surface, uses a stick to push a disk of mass M_D. The student exerts a constant horizontal force of magnitude F_H over the time interval from time $t = 0$ to $t = t_f$ while pushing the disk. Assume there is negligible friction between the disk and the surface.

i. Assuming the disk begins at rest, determine an expression for the final speed v_D of the disk relative to the surface. Express your answer in terms of F_H, t_f, M_S, M_D, and physical constants, as appropriate.

ii. Assume there is negligible friction between the student's shoes and the surface. After time t_f, the student slides with speed v_S. Derive an equation for the ratio v_D / v_S. Express your answer in terms of M_S, M_D, and physical constants, as appropriate.

(b) Assume that the student's mass is greater than that of the disk $(M_S > M_D)$. On the grid below, sketch graphs of the speeds of both the student and the disk as functions of time t between $t = 0$ and $t = 2t_f$. Assume that neither the disk nor the student collides with anything after $t = t_f$. On the vertical axis, label v_D and v_S. Label the graphs "S" and "D" for the student and the disk, respectively.



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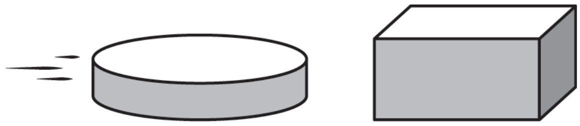

(c) The disk is now moving at a constant speed v_1 on the surface toward a block of mass M_B, which is at rest on the surface, as shown above. The disk and block collide head-on and stick together, and the center of mass of the disk-block system moves with speed v_{cm}.

i. Suppose the mass of the disk is much greater than the mass of the block. Estimate the velocity of the center of mass of the disk-block system. Explain how you arrived at your prediction without deriving it mathematically.

ii. Suppose the mass of the disk is much less than the mass of the block. Estimate the velocity of the center of mass of the disk-block system. Explain how you arrived at your prediction without deriving it mathematically.

iii. Now suppose that neither object's mass is much greater than the other but that they are not necessarily equal. Derive an equation for v_{cm}. Express your answer in terms of v_1, M_D, M_B, and physical constants, as appropriate.

iv. Consider the scenario from part (c)(i), where the mass of the disk was much greater than the mass of the block. Does your equation for v_{cm} from part (c)(iii) agree with your reasoning from part (c)(i) ?

____ Yes ____ No

Explain your reasoning by addressing why, according to your equation, v_{cm} becomes (or approaches) a certain value when M_D is much greater than M_B.

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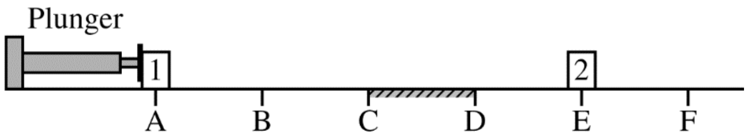
PHYSICS 1

Section II

Time—1 hour and 30 minutes

5 Questions

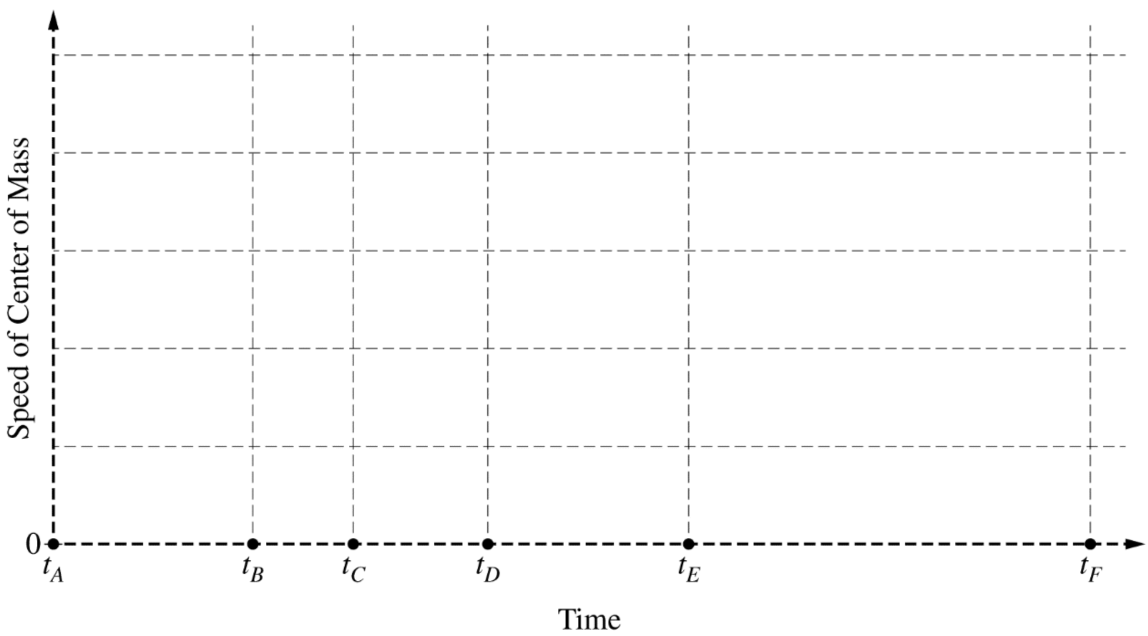
Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the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

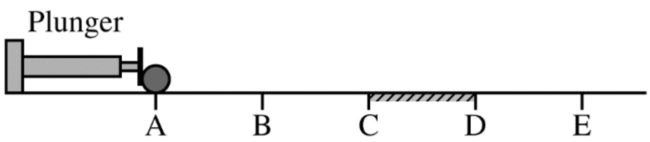


1. (7 points, suggested time 13 minutes)

Identical blocks 1 and 2 are placed on a horizontal surface at points A and E, respectively, as shown. The surface is frictionless except for the region between points C and D, where the surface is rough. Beginning at time t_A, block 1 is pushed with a constant horizontal force from point A to point B by a mechanical plunger. Upon reaching point B, block 1 loses contact with the plunger and continues moving to the right along the horizontal surface toward block 2. Block 1 collides with and sticks to block 2 at point E, after which the two-block system continues moving across the surface, eventually passing point F.

(a) On the axes below, sketch the speed of the center of mass of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.





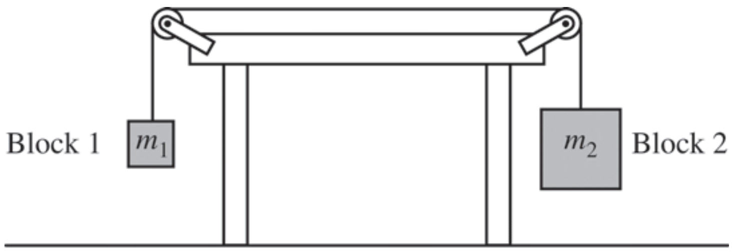
(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a <u>constant</u> horizontal force that is directed toward the sphere's center of mass. The sphere loses contact with the plunger at point B and continues moving across the horizontal surface toward point E. In which interval(s), if any, does the sphere's angular momentum about its center of mass change? Check all that apply.

____ A to B ____ B to C ____ C to D ____ D to E _____ None

Briefly explain your reasoning.

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.

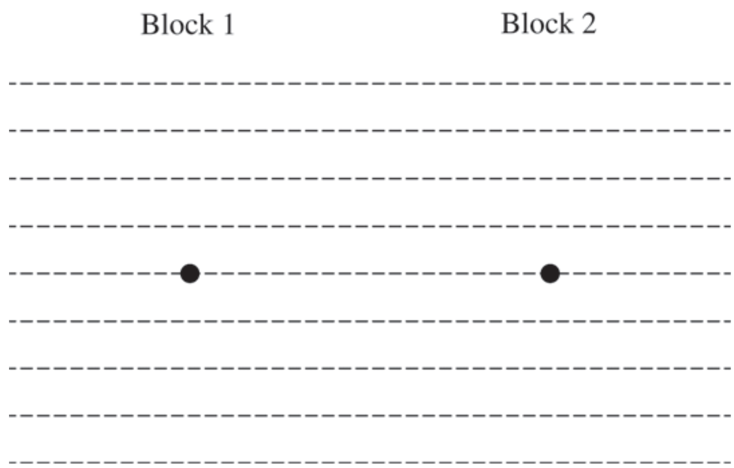


Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

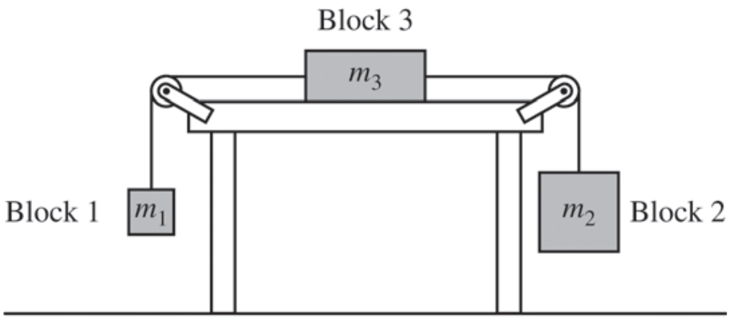
Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

(a) The dots below represent the two blocks. Draw free-body diagrams showing and labeling the forces (not components) exerted on each block. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.



(b) Derive the magnitude of the acceleration of block 2. Express your answer in terms of m_1, m_2, and g.

Block 3 of mass m_3 is added to the system, as shown below. There is no friction between block 3 and the table.



Note: Figure not drawn to scale.

(c) Indicate whether the magnitude of the acceleration of block 2 is now larger, smaller, or the same as in the original two-block system. Explain how you arrived at your answer.

AP PHYSICS 1 • EXERCISE SHEET

2.2 Forces and Free-Body Diagrams

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

KEY WORDS force 力 • friction 摩擦力 • free-body diagram 受力图 • tension 张力 • weight 重力

Objective

Build the skills to answer exam questions on **forces and free-body diagrams**.

You must be able to:

- describe a **force 力** as a push or pull, measured in **newtons 牛顿**
- distinguish **contact forces 接触力** (normal, friction) from **long-range forces 长程力** (gravity)
- draw a **free-body diagram 受力图** showing every force on one object as a labelled arrow
- find the **net force 合力** by adding the force vectors

1 Worked examples

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

■ What goes on a free-body diagram

Only the forces acting **on** the chosen object: weight (mg, down), normal force (F_N, perpendicular to the surface), friction (f, along the surface), tension (T, along a rope), and any applied push. Never draw a "motion" arrow.

■ Net force

Add the force components. A box pulled +10 N to the right against 4 N of friction: $F_{net} = 10 - 4 = 6$ N to the right.

■ Types of force

Contact: normal, friction, tension, applied push. **Long-range (field):** gravity (and, later, electric and magnetic).

2 Practice

2.1 A book rests on a table. Name the two forces acting on it and their directions. [2]

2.2 State whether each is a contact or a long-range force: (a) weight, (b) friction, (c) normal force, (d) the gravitational pull of the Moon. [2]

2.3 A crate is pushed to the right with 25 N while 9.0 N of friction acts. Find the net horizontal force. [1]

2.4 A lamp of weight 15 N hangs in equilibrium from a single cord. State the tension in the cord. [1]

3 Exam-style questions

3.1 Which force is a long-range (field) force? [1]

- **A** the normal force
- **B** friction
- **C** gravity
- **D** tension

3.2 On a free-body diagram of a sliding box, which arrow should **not** appear? [1]

- **A** weight
- **B** normal force
- **C** friction
- **D** the box's velocity

3.3 A 2.0 kg sign hangs at rest from two vertical cords, each with tension T (take $g = 10$ m s^{-2}).

(a) List the forces on the sign (a free-body diagram in words). [1]

(b) Find the tension in each cord. [2]

Solutions

2.1 weight, acting downward; and the normal force from the table, acting upward.

2.2 (a) long-range; (b) contact; (c) contact; (d) long-range.

2.3 $25 - 9.0 = 16$ N to the right.

2.4 15 N (equal to the weight, since it is in equilibrium).

3.1 **C**.

3.2 **D**.

3.3 (a) weight mg downward; two tension forces T upward. (b) $2T = mg = 20$ N, so $T = 10$ N.

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

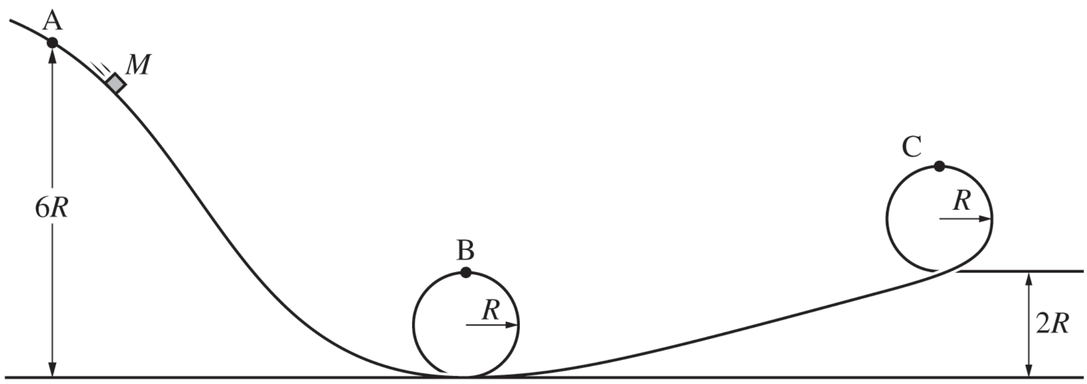
PHYSICS 1

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.

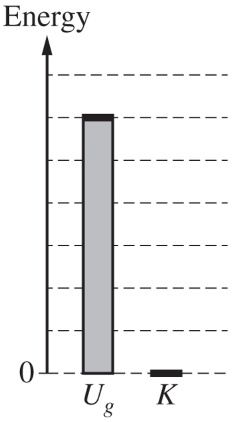

Diagram A

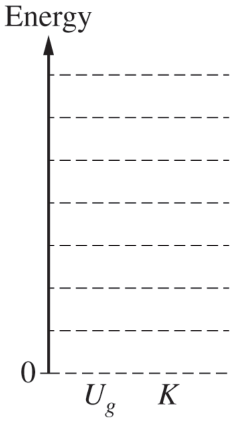

Diagram B

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.

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

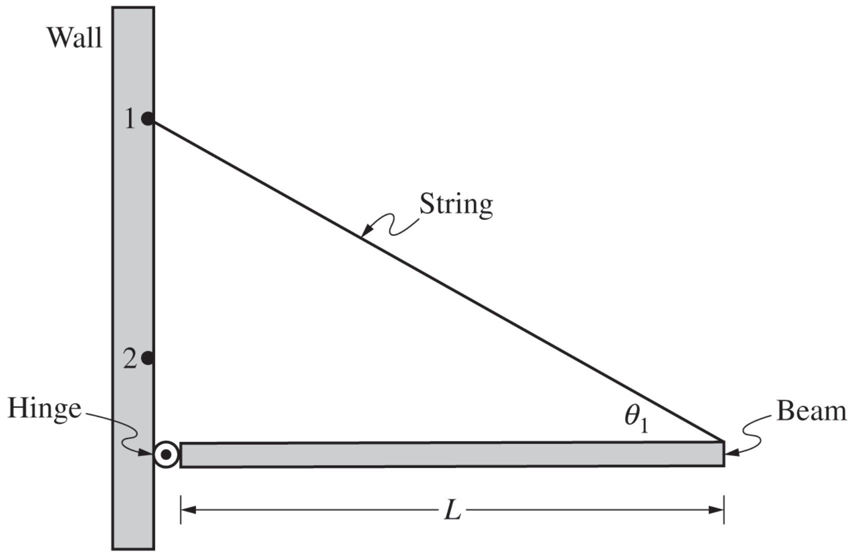

Figure 1

3. (12 points, suggested time 25 minutes)

The left end of a uniform beam of mass M and length L is attached to a wall by a hinge, as shown in Figure 1. One end of a string with negligible mass is attached to the right end of the beam. The other end of the string is attached to the wall above the hinge at Point 1. The beam remains horizontal. The hinge exerts a force on the beam of magnitude F_H, and the angle between the beam and the string is $\theta = \theta_1$.

(a) The following rectangle represents the beam in Figure 1. On the rectangle, **draw** and **label** the forces (not components) exerted on the beam. Draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted.

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

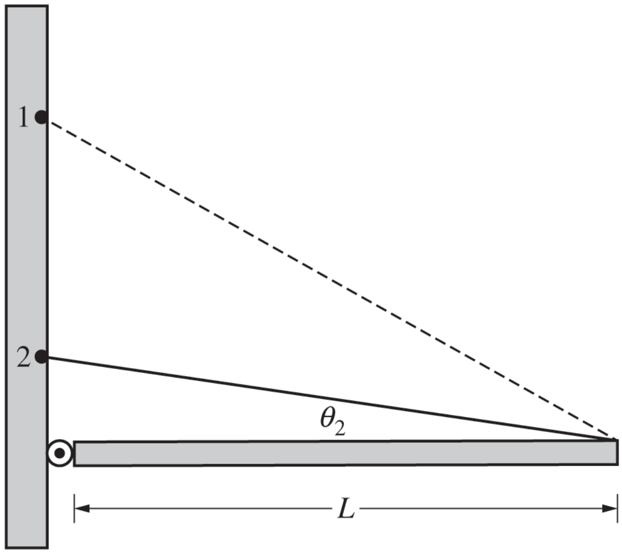


Figure 2

(b) The string is then attached lower on the wall, at Point 2, and the beam remains horizontal, as shown in Figure 2. The angle between the beam and the string is $\theta = \theta_2$. The dashed line represents the string shown in Figure 1.

The magnitude of the tension in the string shown in Figure 1 is F_{T1}. The magnitude of the tension in the string shown in Figure 2 is F_{T2}. **Indicate** which of the following correctly compares F_{T2} with F_{T1}.

_____ $F_{T2} > F_{T1}$ _____ $F_{T2} < F_{T1}$ _____ $F_{T2} = F_{T1}$

Briefly **justify** your answer, using qualitative reasoning beyond referencing equations.

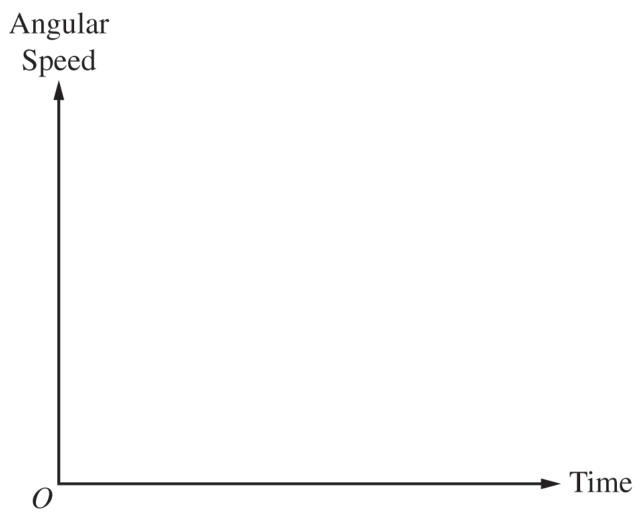
(c) Starting with Newton's second law in rotational form, **derive** an expression for the magnitude of the tension in the string. Express your answer in terms of M, θ, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference book.

GO ON TO THE NEXT PAGE.

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

(d) Is your derived equation in part (c) consistent with your justification in part (b) ? **Explain** your reasoning.

(e) The string is cut, and the beam begins to rotate about the hinge with negligible friction. On the following axes, **sketch** the angular speed of the beam as a function of time for the time interval while the beam falls but before the beam becomes vertical.



GO ON TO THE NEXT PAGE.

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

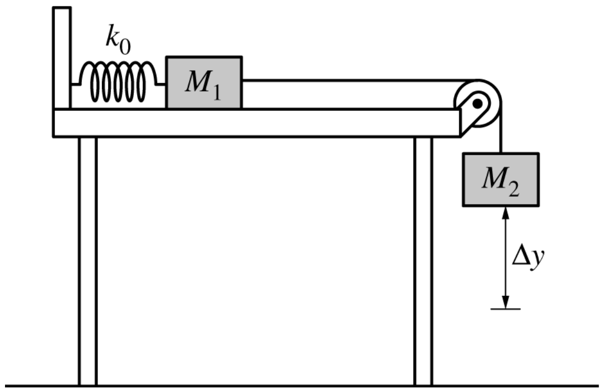
PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

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)

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

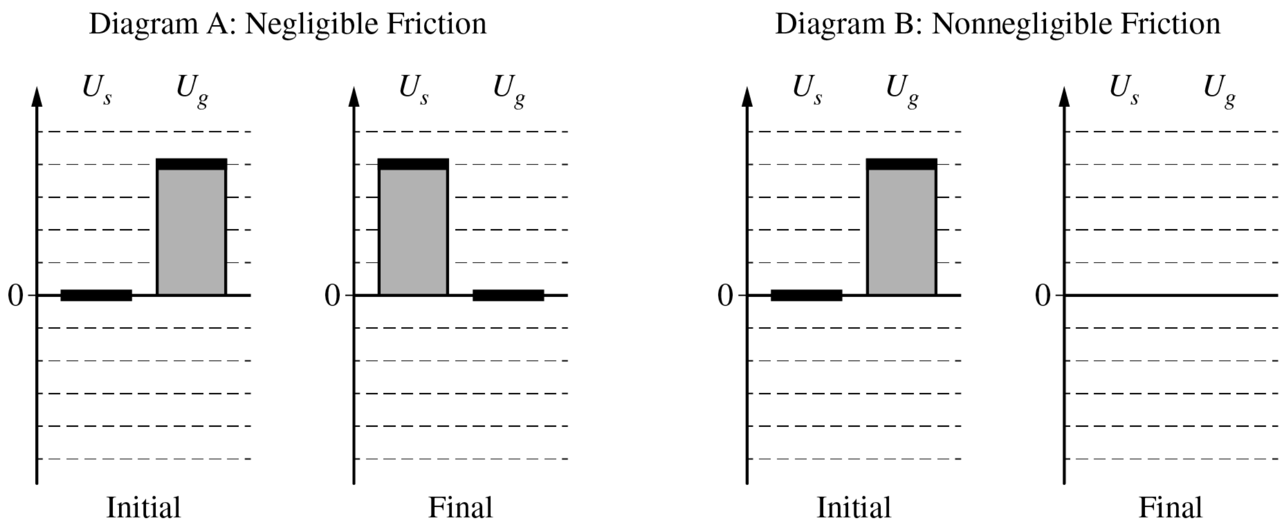
Briefly explain your reasoning.

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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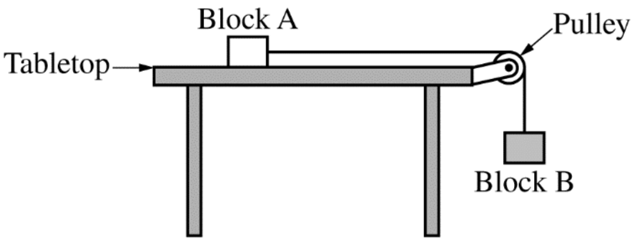


2. (12 points, suggested time 25 minutes)

This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a)

i. Suppose the mass of block A is much <u>greater</u> than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

ii. Now suppose the mass of block A is much <u>less</u> than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.

Block A

Block B

(c) Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

(d) Consider the scenario from part (a)(ii), where the mass of block A is much <u>less</u> than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii) ?

____ Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much <u>less</u> than m_B.

(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

____ $T_2 > T_1$ ____ $T_2 = T_1$ ____ $T_2 < T_1$

Briefly explain your reasoning.

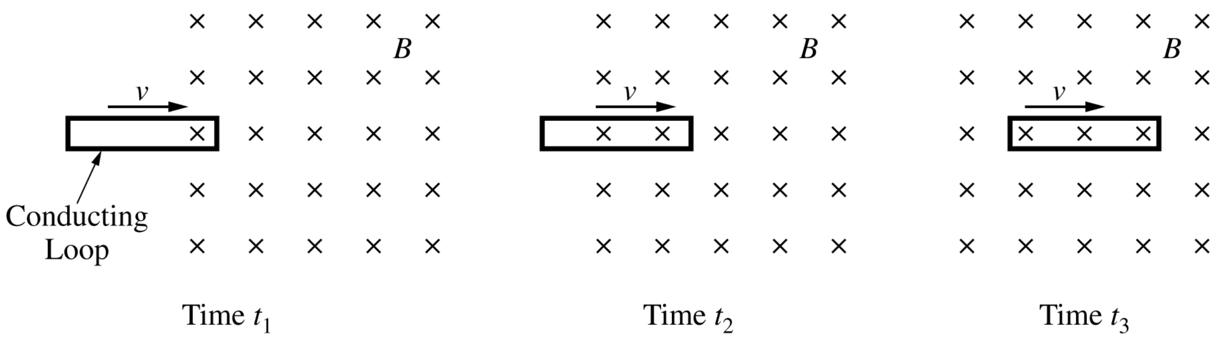
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 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.

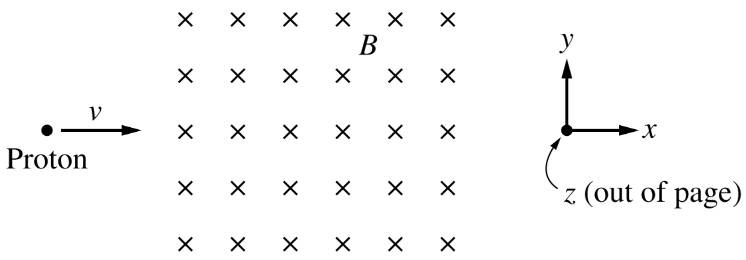


1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

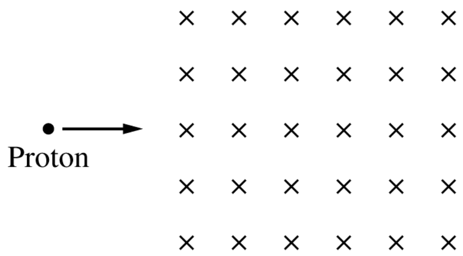
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

2. (12 points, suggested time 25 minutes)

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(a) Describe an experiment for determining the coefficient of static friction between the wood board and the wood block. Assume equipment usually found in a school physics laboratory is available.

i. Draw a diagram of the experimental setup of the board and block. In your diagram, indicate each quantity that would be measured and draw or state what equipment would be used to measure each quantity.

ii. 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) Derive an equation for the coefficient of static friction in terms of quantities measured in the procedure from part (a).

A physics class consisting of six lab groups wants to test the hypothesis that the coefficient of static friction between the board and the block equals the coefficient of kinetic friction between the board and the block. Each group determines the coefficients of kinetic and static friction between the board and the block. The groups' results are shown below, with the class averages indicated in the bottom row.

Lab Group Number	Coefficient of Kinetic Friction	Coefficient of Static Friction
1	0.45	0.54
2	0.46	0.52
3	0.42	0.56
4	0.43	0.55
5	0.74	0.23
6	0.44	0.54
Average	0.49	0.49

(c) Based on these data, what conclusion should the students make about the hypothesis that the coefficients of static and kinetic friction are equal?

____ The static and kinetic coefficients are equal.

____ The static and kinetic coefficients are not equal.

Briefly justify your reasoning.

(d) A metal disk is glued to the top of the wood block. The mass of the block-disk system is twice the mass of the original block. Does the coefficient of static friction between the bottom of the block and the board increase, decrease, or remain the same when the disk is added to the block?

____ Increase ____ Decrease ____ Remain the same

Briefly state your reasoning.

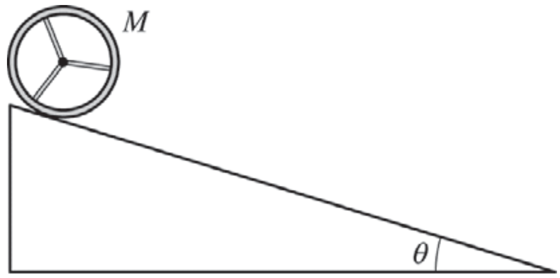
PHYSICS 1

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.

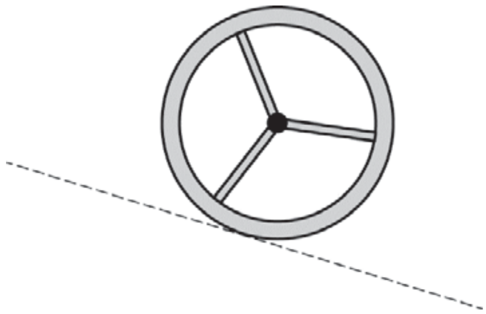


1. (7 points, suggested time 13 minutes)

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

Briefly explain your reasoning.

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel ____ Block ____ Neither; both reach the bottom with the same speed.

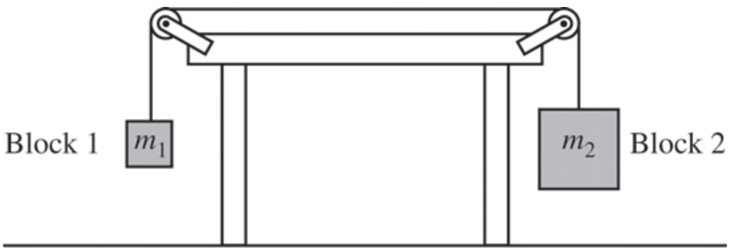
Briefly explain your answer, reasoning in terms of forces.

ii. Briefly explain your answer again, now reasoning in terms of energy.

AP Physics 1: **2015**

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.



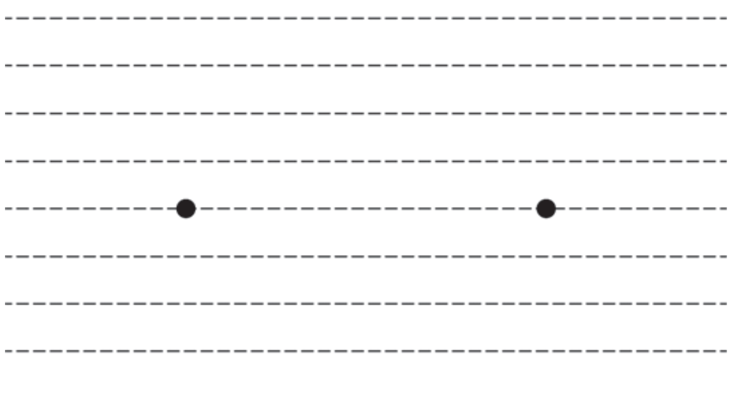
Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

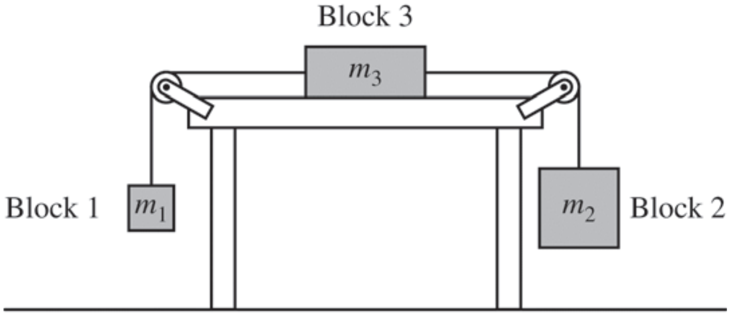
(a) The dots below represent the two blocks. Draw free-body diagrams showing and labeling the forces (not components) exerted on each block. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.

Block 1 Block 2



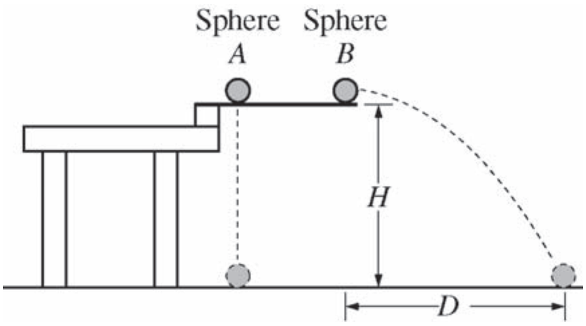
(b) Derive the magnitude of the acceleration of bloc… press your answer in terms of m_1, m_2, and g.

Block 3 of mass m_3 is added to the system, as shown below. There is no friction between block 3 and the table.



Note: Figure not drawn to scale.

(c) Indicate whether the magnitude of the acceleration of block 2 is now larger, smaller, or the same as in the original two-block system. Explain how you arrived at your answer.

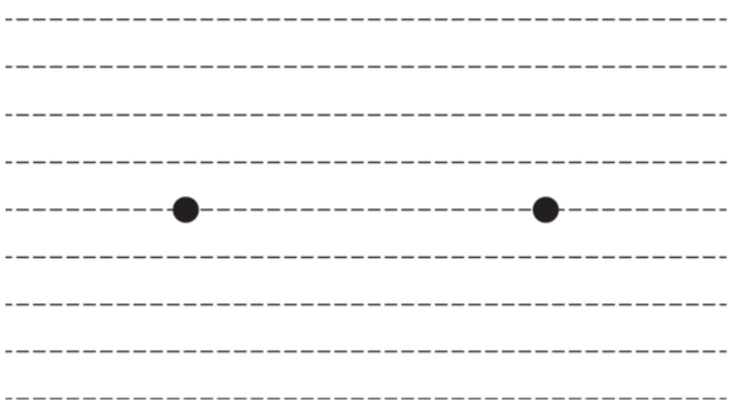


4. (7 points, suggested time 13 minutes)

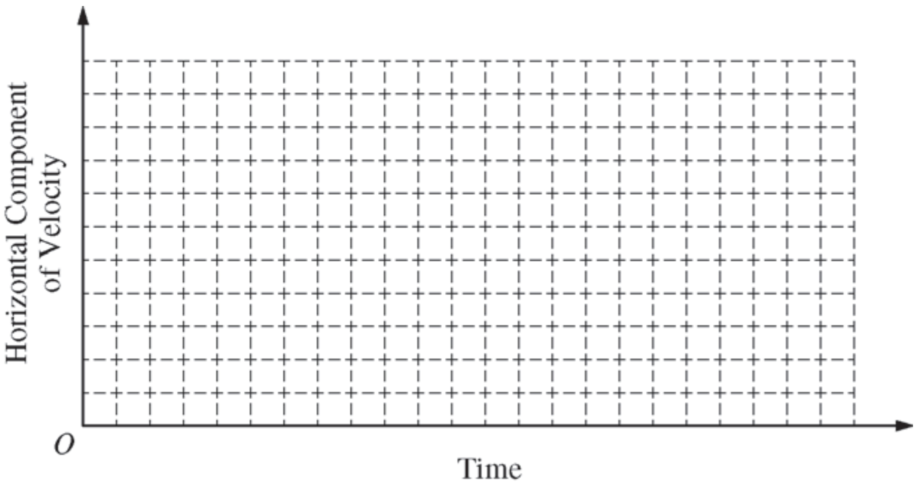
Two identical spheres are released from a device at time $t = 0$ from the same height H, as shown above. Sphere A has no initial velocity and falls straight down. Sphere B is given an initial horizontal velocity of magnitude v_0 and travels a horizontal distance D before it reaches the ground. The spheres reach the ground at the same time t_f, even though sphere B has more distance to cover before landing. Air resistance is negligible.

(a) The dots below represent spheres A and B. Draw a free-body diagram showing and labeling the forces (not components) exerted on each sphere at time $\frac{t_f}{2}$.

Sphere A Sphere B



(b) On the axes below, sketch and label a graph of the horizontal component of the velocity of sphere A and of sphere B as a function of time.



(c) In a clear, coherent, paragraph-length response, explain why the spheres reach the ground at the same time even though they travel different distances. Include references to your answers to parts (a) and (b).

2.3 Newton's Third Law

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

KEY WORDS newton's third law 牛顿第三定律 • normal force 法向力 • tension 张力 • force 力 • weight 重力

Objective

Build the skills to answer exam questions on **Newton's third law**.

You must be able to:

- state **Newton's third law 牛顿第三定律**: forces occur in equal, opposite pairs between two interacting objects
- identify the two objects involved and the force each exerts on the other
- explain that the pair acts on **different objects**, so the two forces never cancel
- apply the law to contact, **tension 张力**, and gravitational interactions

1 Worked examples

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

■ Identifying a third-law pair

"A pushes B" is paired with "B pushes A" — equal in size, opposite in direction, on the **two different objects**. A swimmer pushes the water backward; the water pushes the swimmer forward.

■ Why the pair does not cancel

The two forces act on **different objects**, so they never appear on the same free-body diagram — and forces cancel only when they act on the **same** object.

■ The gravity pair

Earth pulls you down with force mg; you pull Earth upward with the **same** force mg. Earth's enormous mass means its acceleration is negligible.

2 Practice

2.1 A hammer hits a nail with a force of 50 N. State the force the nail exerts on the hammer. [1]

2.2 A person stands still on the ground. Identify the third-law partner of the person's weight. [2]

2.3 Explain why the two forces of a Newton's third law pair can never cancel out. [2]

3 Exam-style questions

3.1 A car tyre pushes back on the road with 2000 N. The road pushes on the tyre [1]

- **A** forward with 2000 N
- **B** backward with 2000 N
- **C** forward with a smaller force
- **D** with zero force

3.2 Which statement about a Newton's third law pair is correct? [1]

- **A** the two forces act on the same object
- **B** the two forces are equal in size and opposite in direction
- **C** the larger object exerts the larger force
- **D** the two forces always cancel

3.3 A book of weight 8.0 N rests on a table.

(a) State the third-law partner of the book's weight. [1]

(b) State the third-law partner of the normal force the table exerts on the book. [1]

(c) Explain why the book's weight and the normal force on the book are **not** a third-law pair. [1]

Solutions

2.1 50 N in the opposite direction, acting on the hammer.

2.2 the gravitational pull of the person **on the Earth**, equal in size and directed upward on the Earth.

2.3 the two forces act on **different** objects; forces can cancel only when they act on the **same** object.

3.1 **A**.

3.2 **B**.

3.3 (a) the gravitational pull of the book on the Earth (upward, on the Earth). (b) the force of the book pushing down on the table. (c) they act on the **same** object (the book) and are different types of force (gravity and contact); a third-law pair must act on two **different** objects.

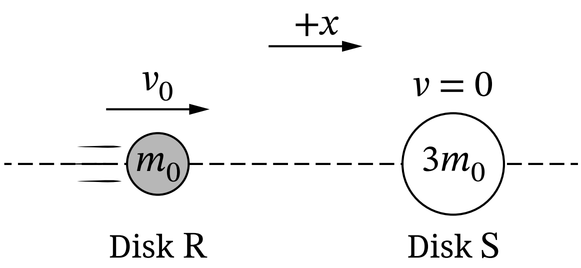
Question 2: Version J

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



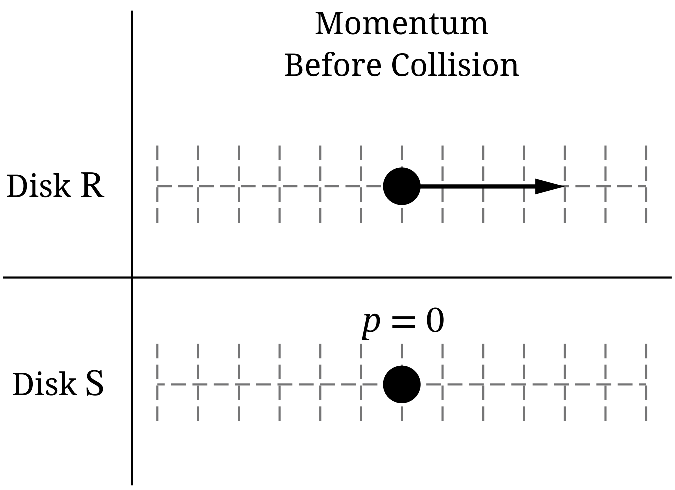
Top View

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.

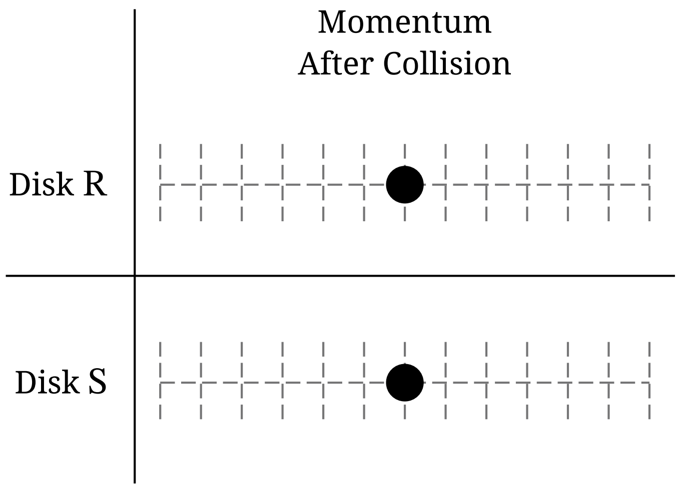
Figure 2



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.

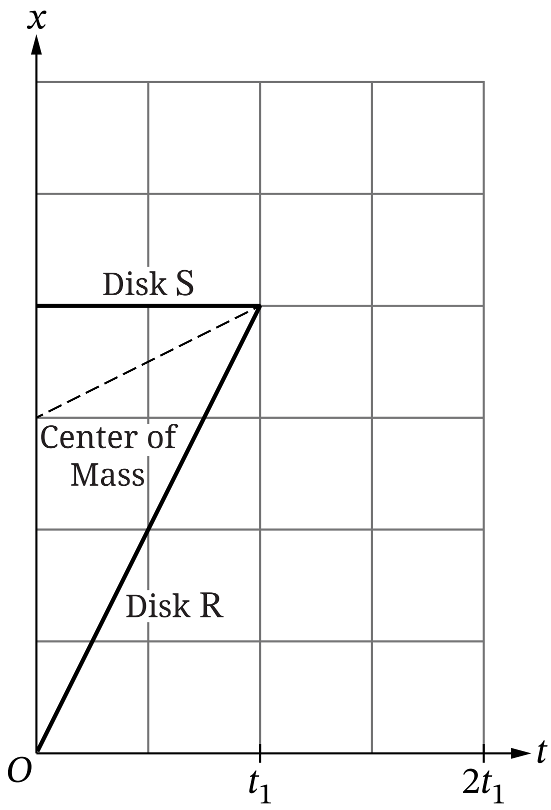
Part C

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.

2.4 Newton's First Law

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

KEY WORDS inertia 惯性 • translational equilibrium 平动平衡 • mass 质量 • newton's first law 牛顿第一定律 • force 力

Objective

Build the skills to answer exam questions on **Newton's first law** — inertia and equilibrium.

You must be able to:

- state **Newton's first law 牛顿第一定律**: an object's velocity stays constant unless a net external force acts
- define **inertia 惯性** as the resistance to a change in motion, measured by **mass 质量**
- state the condition for **translational equilibrium 平动平衡** (net force zero)
- apply the first law to objects at rest or moving at constant velocity

1 Worked examples

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

■ Equilibrium means balanced forces

An object is in **translational equilibrium** when $\sum \vec{F} = 0$. This includes both **at rest** and **constant velocity** — "no net force" does **not** mean "no motion".

■ Inertia and mass

More mass → more inertia → harder to speed up, slow down, or turn. A loaded truck is harder to stop than a bicycle at the same speed.

■ Balancing forces

A crate slides at constant velocity, so the forces balance: if friction is 30 N backward, the applied pull must be 30 N forward.

2 Practice

2.1 A car moves along a straight road at a **constant** 20 m s^{-1}. State the net force on it. [1]

2.2 A box sits still on a floor. Friction can act up to 12 N. A push of 7.0 N is applied. State the friction force and whether the box moves. [2]

2.3 Explain, using inertia, why passengers lurch forward when a bus brakes suddenly. [2]

3 Exam-style questions

3.1 An object is in translational equilibrium. Its velocity must be [1]

- **A** zero
- **B** constant (possibly zero)
- **C** increasing
- **D** decreasing

3.2 Which object has the greatest inertia? [1]

- **A** a 0.5 kg ball
- **B** a 2 kg book
- **C** a 50 kg crate
- **D** a 1 kg brick

3.3 A 500 N lamp hangs at rest from a single cable.

(a) State the tension in the cable. [1]

(b) State the net force on the lamp, and justify with the first law. [2]

Solutions

2.1 zero — constant velocity means the forces are balanced.

2.2 friction = 7.0 N (it matches the push up to its maximum); the box does not move, since $7.0 < 12$ N.

2.3 The passengers have inertia, so they tend to keep moving forward at the original speed while the bus slows beneath them.

3.1 **B**.

3.2 **C**.

3.3 (a) 500 N. (b) zero — at rest is equilibrium, so the net force must be zero by the first law.

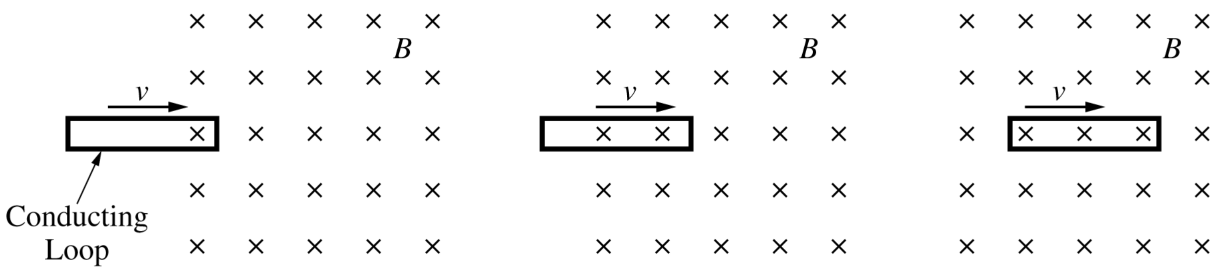
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 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.



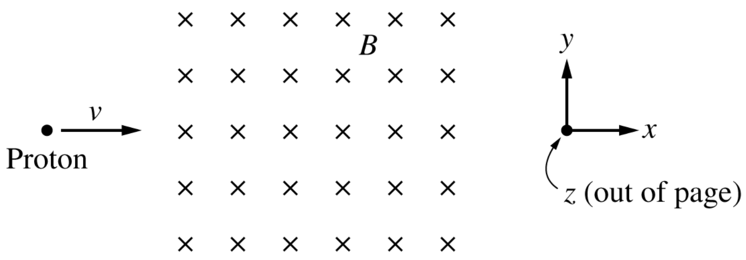
Time t_1 Time t_2 Time t_3

1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

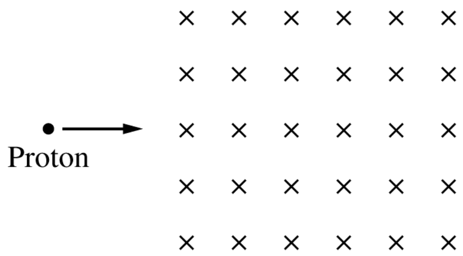
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

2.5 Newton's Second Law

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

KEY WORDS incline 斜面 • newton's second law 牛顿第二定律 • components 分量 • friction 摩擦力 • force 力

Objective

Build the skills to answer exam questions on **Newton's second law** — relating force, mass, and acceleration.

You must be able to:

- state **Newton's second law** 牛顿第二定律, $\vec{a} = \dfrac{\sum \vec{F}}{m}$
- explain that acceleration is **proportional** to net force and **inversely proportional** to mass
- resolve forces into perpendicular **components** 分量 on an inclined surface
- apply the second law to connected objects joined by a string

1 Worked examples

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

■ Applying $F = ma$

A net force of 12 N on a 3.0 kg block gives $a = \dfrac{12}{3.0} = 4.0\ \text{m s}^{-2}$ in the direction of the net force.

■ On an incline

Resolve weight along and perpendicular to the slope. On a frictionless incline of angle θ, the acceleration down the slope is $a = g\sin\theta$.

■ Connected masses

For masses joined by a string, apply $F = ma$ to the **whole system** to find a, then to **one mass** to find the tension. A 2.0 kg and a 3.0 kg block pulled by 10 N: $a = \dfrac{10}{5.0} = 2.0\ \text{m s}^{-2}$.

2 Practice

2.1 A net force of 20 N acts on a 4.0 kg trolley. Find its acceleration. [1]

2.2 A 1500 kg car accelerates at 2.0 m s^{-2}. Find the net force on it. [1]

2.3 A block slides down a frictionless ramp at 30° (take $g = 10$ m s^{-2}). Find its acceleration along the ramp. [2]

2.4 State how the acceleration changes if the net force doubles while the mass stays the same. [1]

3 Exam-style questions

3.1 If the net force on an object doubles and its mass halves, the acceleration becomes [1]

- **A** unchanged
- **B** twice as large
- **C** four times as large
- **D** half as large

3.2 A 2.0 kg object accelerates at 5.0 m s^{-2}. The net force on it is [1]

- **A** 0.4 N
- **B** 2.5 N
- **C** 7.0 N
- **D** 10 N

3.3 Two blocks, 2.0 kg and 3.0 kg, sit in contact on a frictionless floor. A 15 N force pushes on the 2.0 kg block.

(a) Find the acceleration of the pair. [2]

(b) Find the contact force between the blocks. [2]

Solutions

2.1 $a = \dfrac{20}{4.0} = 5.0\ \text{m s}^{-2}$.

2.2 $F = ma = 1500 \times 2.0 = 3000$ N.

2.3 $a = g\sin 30° = 10 \times 0.5 = 5.0\ \text{m s}^{-2}$.

2.4 it also doubles (acceleration is proportional to net force).

3.1 **C**.

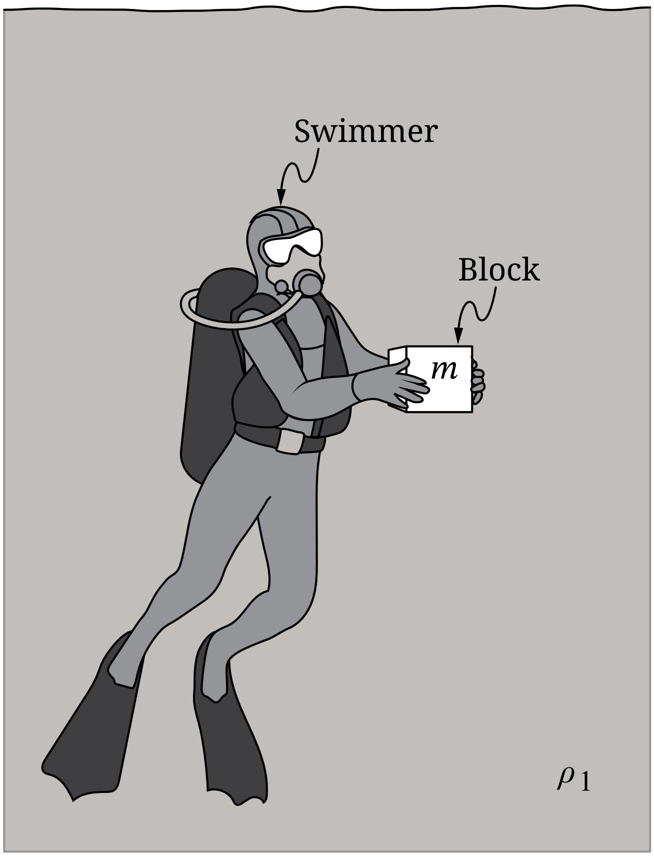
3.2 **D** — $F = 2.0 \times 5.0 = 10$ N.

3.3 (a) $a = \dfrac{15}{2.0 + 3.0} = 3.0\ \text{m s}^{-2}$. (b) On the 3.0 kg block, $F = ma = 3.0 \times 3.0 = 9.0$ N.

Question 4

4. In Scenario 1, a swimmer holds a block of mass m at rest in a tank of freshwater with density ρ_1, as shown in Figure 1. The block is released from rest and accelerates upward with an initial acceleration a_1. All frictional forces are negligible.

Figure 1



In Scenario 2, the swimmer holds the same block at rest in a tank of salt water with density ρ_2, where $\rho_2 > \rho_1$. The swimmer again releases the block from rest, and the block accelerates upward with initial acceleration a_2. All frictional forces are negligible.

A. Indicate whether a_1 is greater than, less than, or equal to a_2 by writing one of the following in your answer booklet.

- $a_1 > a_2$
- $a_1 < a_2$
- $a_1 = a_2$

Justify your answer in terms of ALL forces exerted on the block in each scenario. Use qualitative reasoning beyond referencing equations.

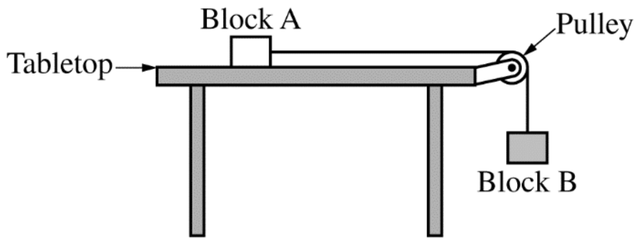
B. Consider the general case where a block of mass m and volume V is completely submerged in a fluid of density ρ.

Starting with Newton's second law, **derive** an expression for the initial upward acceleration a of the block when the block is released from rest. Express your answer in terms of m, V, ρ, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

C. Indicate whether the expression for the acceleration a you derived in part B is or is not consistent with the claim made in part A. Briefly **justify** your answer by referencing your derivation in part B.

STOP

END OF EXAM



2. (12 points, suggested time 25 minutes)

This problem explores how the relative masses of two blocks affect the acceleration of the blocks. Block A, of mass m_A, rests on a horizontal tabletop. There is negligible friction between block A and the tabletop. Block B, of mass m_B, hangs from a light string that runs over a pulley and attaches to block A, as shown above. The pulley has negligible mass and spins with negligible friction about its axle. The blocks are released from rest.

(a)

i. Suppose the mass of block A is much greater than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

ii. Now suppose the mass of block A is much less than the mass of block B. Estimate the magnitude of the acceleration of the blocks after release.

Briefly explain your reasoning without deriving or using equations.

(b) Now suppose neither block's mass is much greater than the other, but that they are not necessarily equal. The dots below represent block A and block B, as indicated by the labels. On each dot, draw and label the forces (not components) exerted on that block after release. Represent each force by a distinct arrow starting on, and pointing away from, the dot.

(c) Derive an equation for the acceleration of the blocks after release in terms of m_A, m_B, and physical constants, as appropriate. If you need to draw anything other than what you have shown in part (b) to assist in your solution, use the space below. Do NOT add anything to the figure in part (b).

(d) Consider the scenario from part (a)(ii), where the mass of block A is much less than the mass of block B. Does your equation for the acceleration of the blocks from part (c) agree with your reasoning in part (a)(ii) ?

____ Yes ____ No

Briefly explain your reasoning by addressing why, according to your equation, the acceleration becomes (or approaches) a certain value when m_A is much less than m_B.

(e) While the blocks are accelerating, the tension in the vertical portion of the string is T_1. Next, the pulley of negligible mass is replaced with a second pulley whose mass is not negligible. When the blocks are accelerating in this scenario, the tension in the vertical portion of the string is T_2. How do the two tensions compare to each other?

____ $T_2 > T_1$ ____ $T_2 = T_1$ ____ $T_2 < T_1$

Briefly explain your reasoning.

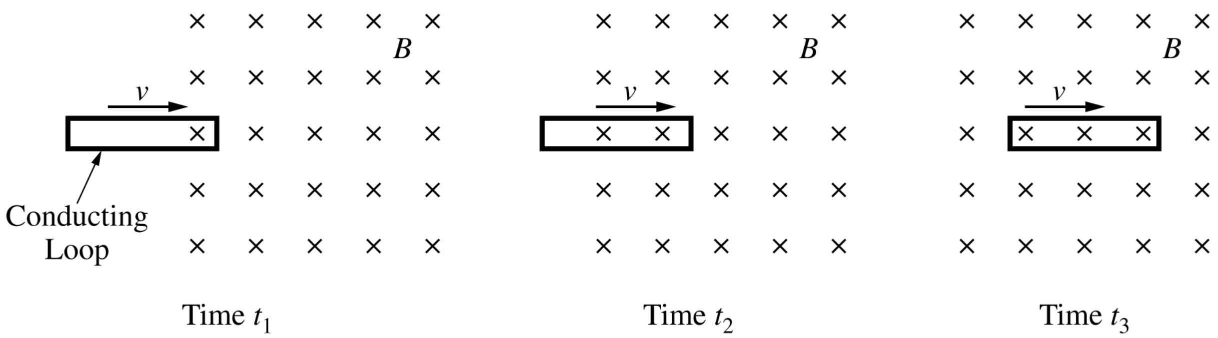
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 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.

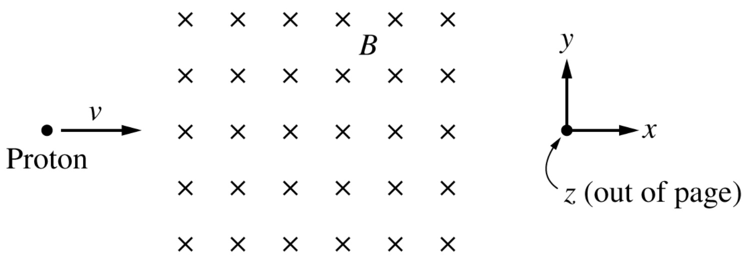


1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

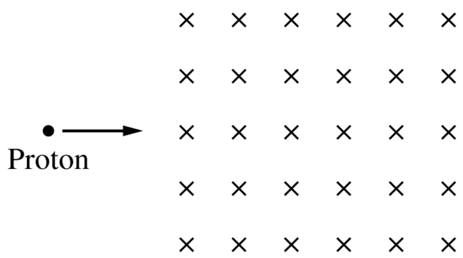
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

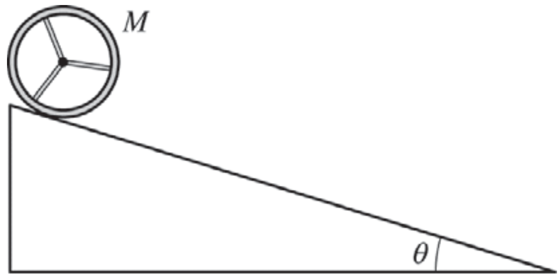
PHYSICS 1

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.

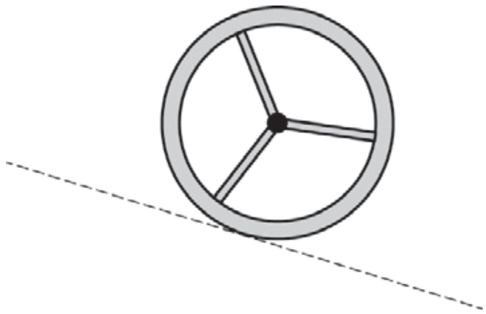


1. (7 points, suggested time 13 minutes)

A wooden wheel of mass M, consisting of a rim with spokes, rolls down a ramp that makes an angle θ with the horizontal, as shown above. The ramp exerts a force of static friction on the wheel so that the wheel rolls without slipping.

(a)

i. On the diagram below, draw and label the forces (not components) that act on the wheel as it rolls down the ramp, which is indicated by the dashed line. To clearly indicate at which point on the wheel each force is exerted, draw each force as a distinct arrow starting on, and pointing away from, the point at which the force is exerted. The lengths of the arrows need not indicate the relative magnitudes of the forces.



ii. As the wheel rolls down the ramp, which force causes a change in the angular velocity of the wheel with respect to its center of mass?

Briefly explain your reasoning.

(b) For this ramp angle, the force of friction exerted on the wheel is less than the maximum possible static friction force. Instead, the magnitude of the force of static friction exerted on the wheel is 40 percent of the magnitude of the force or force component directed opposite to the force of friction. Derive an expression for the linear acceleration of the wheel's center of mass in terms of M, θ, and physical constants, as appropriate.

(c) In a second experiment on the same ramp, a block of ice, also with mass M, is released from rest at the same instant the wheel is released from rest, and from the same height. The block slides down the ramp with negligible friction.

i. Which object, if either, reaches the bottom of the ramp with the greatest speed?

____ Wheel ____ Block ____ Neither; both reach the bottom with the same speed.

Briefly explain your answer, reasoning in terms of forces.

ii. Briefly explain your answer again, now reasoning in terms of energy.

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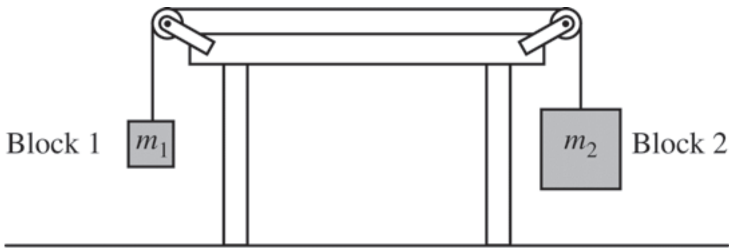
PHYSICS 1

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.

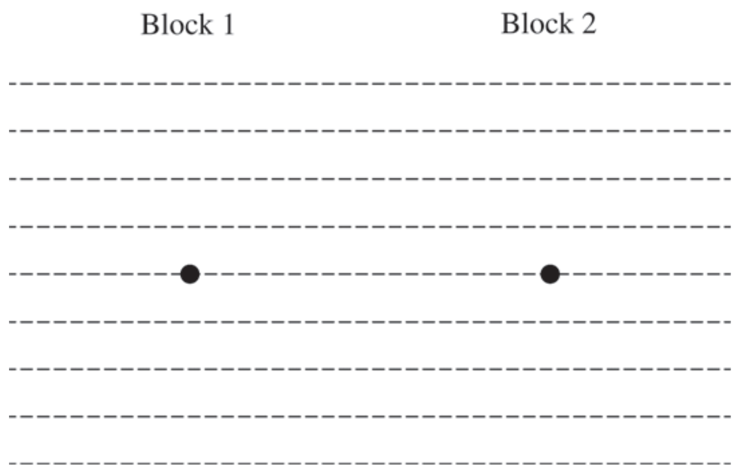


Note: Figure not drawn to scale.

1. (7 points, suggested time 13 minutes)

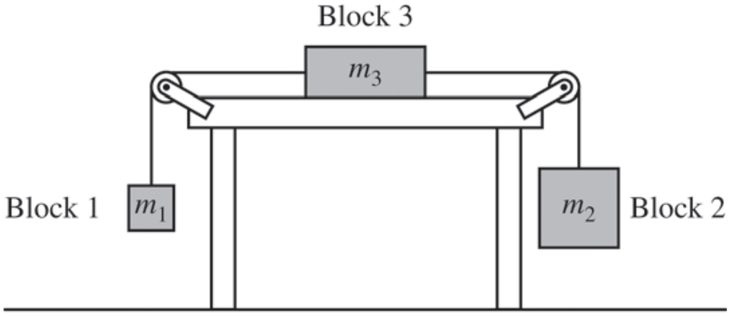
Two blocks are connected by a string of negligible mass that passes over massless pulleys that turn with negligible friction, as shown in the figure above. The mass m_2 of block 2 is greater than the mass m_1 of block 1. The blocks are released from rest.

(a) The dots below represent the two blocks. Draw free-body diagrams showing and labeling the forces (not components) exerted on each block. Draw the relative lengths of all vectors to reflect the relative magnitudes of all the forces.



(b) Derive the magnitude of the acceleration of bloc[illegible] press your answer in terms of m_1, m_2, and g.

Block 3 of mass m_3 is added to the system, as shown below. There is no friction between block 3 and the table.



Note: Figure not drawn to scale.

(c) Indicate whether the magnitude of the acceleration of block 2 is now larger, smaller, or the same as in the original two-block system. Explain how you arrived at your answer.

2.6 Gravitational Force

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

KEY WORDS mass 质量 • weight 重量 • gravitational field strength 引力场强度 • force 力

Objective

Build the skills to answer exam questions on **gravitational force**.

You must be able to:

- state **Newton's law of universal gravitation** 万有引力定律, $F_g = \frac{Gm_1m_2}{r^2}$
- distinguish **mass** 质量 (an intrinsic property) from **weight** 重量 (a gravitational force)
- calculate the **gravitational field strength** 引力场强度 $g = \frac{GM}{r^2}$ and use $F_g = mg$
- explain how the force changes with **separation** and with the **masses**

1 Worked examples

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

■ The inverse-square law

$F_g = \frac{Gm_1m_2}{r^2}$ with $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}. **Double the separation → force falls to one quarter** ($1/2^2$).

■ Mass versus weight

Mass (in kg) never changes; weight $F_g = mg$ (in N) depends on the local field g. A 60 kg student weighs ≈ 590 N on Earth ($g = 9.8$) but ≈ 100 N on the Moon ($g = 1.6$).

■ Field of a planet

$g = \frac{GM}{r^2}$ points toward the planet's centre. It is the force per unit mass, so weight $= mg$.

2 Practice

2.1 State the difference between the mass and the weight of an object. [2]

2.2 Find the weight of a 50 kg crate on Earth (take $g = 9.8$ m s^{-2}). [1]

2.3 The distance between two masses is tripled. State the factor by which the gravitational force changes. [1]

2.4 A rock has mass 2.0 kg. State its mass and find its weight on the Moon ($g = 1.6$ m s^{-2}). [2]

3 Exam-style questions

3.1 If the separation between two masses is halved, the gravitational force between them [1]

- **A** halves
- **B** doubles
- **C** is one quarter as large
- **D** is four times as large

3.2 The weight of an object depends on [1]

- **A** its mass only
- **B** the local gravitational field only
- **C** both its mass and the local gravitational field
- **D** neither

3.3 A planet has twice Earth's mass and the same radius.

(a) State how its surface gravitational field compares with Earth's. [1]

(b) A 10 kg object is taken there. State its mass and find its weight (Earth $g =$

$9.8\ \mathrm{m\ s^{-2}}$). [2]

Solutions

2.1 Mass is the amount of matter (kg), the same everywhere; weight is the gravitational force on it (N) and depends on the local field.

2.2 $F_g = mg = 50 \times 9.8 = 490$ N.

2.3 it becomes $\dfrac{1}{9}$ as large ($1/3^2$).

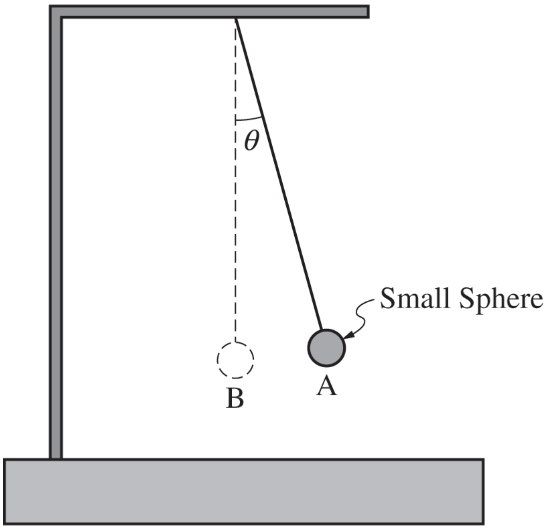
2.4 mass = 2.0 kg (unchanged); weight = $2.0 \times 1.6 = 3.2$ N.

3.1 **D**.

3.2 **C**.

3.3 (a) twice as strong ($g \propto M$ at fixed r). (b) mass = 10 kg; weight = $10 \times (2 \times 9.8) =$ 196 N.

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



4. (7 points, suggested time 13 minutes)

A simple pendulum consists of a small sphere that hangs from a string with negligible mass. The top end of the string is fixed. The sphere is pulled to Point A so that the string makes a small angle θ with the vertical, as shown. The sphere is then released from rest and swings through its lowest point at Point B. The work done on the sphere by Earth between points A and B is W_E.

The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X.

(a) **Justify** why W_X is less than W_E.

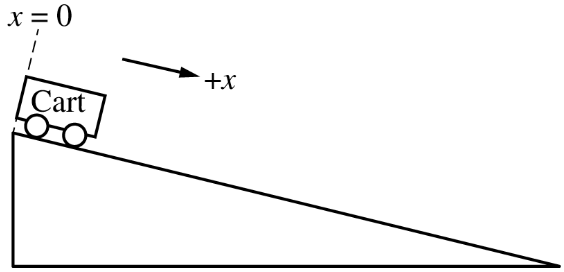
GO ON TO THE NEXT PAGE.

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

A new pendulum is made by hanging the same small sphere from a different string with negligible mass. The new string is slightly elastic, and the length of the string may increase or decrease depending on the tension applied to the string. On Earth, when the sphere is again displaced θ from the vertical and released from rest, the new pendulum oscillates with period T_E.

The new pendulum is then taken to a different planet, Planet Y. The radius of Planet Y is the same as the radius of Earth, but the mass of Planet Y is larger than the mass of Earth. On Planet Y, when the sphere is again displaced from the vertical and released from rest, the new pendulum oscillates with period T_Y.

(b) In a clear, coherent paragraph-length response that may also contain drawings, **explain** how T_Y could be larger than T_E but also could be smaller than T_E.



. (12 points, suggested time 25 minutes)

(a) Students conduct an experiment to determine the acceleration a of a cart. The cart is released from rest at the top of the ramp at time $t = 0$ and moves down the ramp. The x-axis is defined to be parallel to the ramp with its origin at the top, as shown in the figure. The students collect the data shown in the following table.

	Position x (m)	Time t (s)	
	0.06	0.39	
	0.14	0.59	
	0.24	0.77	
	0.37	0.96	
	0.55	1.20	

i. Indicate which quantities could be graphed to yield a straight line whose slope could be used to determine the acceleration a of the cart. You may use the remaining columns in the table, as needed, to record any quantities (including units) that are not already in the table.

Vertical axis: ________________ Horizontal axis: ________________

GO ON TO THE NEXT PAGE.

ii. On the following grid, plot the appropriate quantities to create a graph that can be used to determine the acceleration a of the cart as it rolls down the ramp. Clearly scale and label all axes (including units), as appropriate. Draw a straight line that best represents the data.

iii. Using the line you drew in part (a)(ii), calculate an experimental value for the acceleration a of the cart as it rolls down the ramp.

(b) The students are asked to determine an experimental value for the acceleration due to gravity g_{exp} using their data.

i. What additional quantities do the students need to measure in order to calculate g_{exp} from a ?

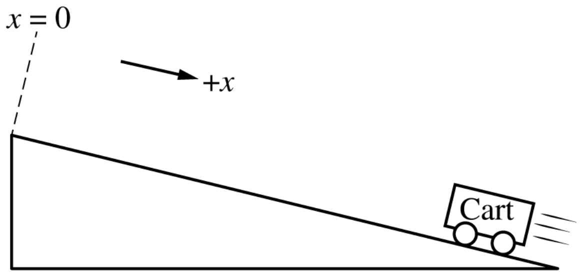
ii. Write an expression for the value of g_{exp} in terms of a.

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

(c) The students calculate the value of g_{exp} to be significantly lower than the accepted value of 9.8 m/s^2.

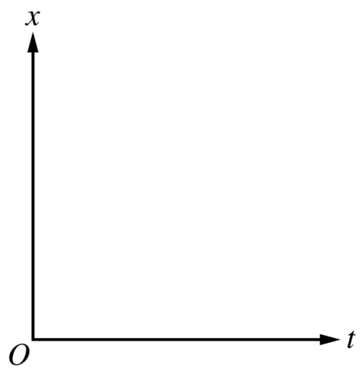
i. What is a physical reason, other than friction or air resistance, that could lead to a significant difference in the experimentally determined value of g_{exp} ?

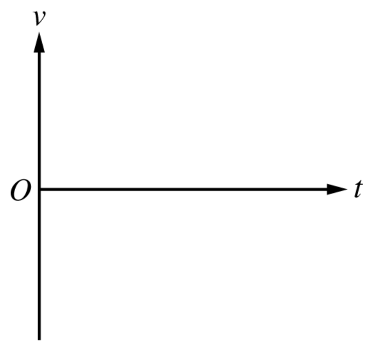
ii. Briefly explain how the physical reason you identified in part (c)(i) would lead to the decrease in the experimentally determined value of g_{exp} .



The students want to confirm that the acceleration is the same whether the cart rolls up or down the ramp. The students start the cart at the bottom and give the cart a quick push so that it rolls up the ramp and momentarily comes to rest. The x-axis is still defined to be parallel to the ramp with the origin at the top.

(d) On the following graphs, sketch the position x and velocity v as functions of time t that correspond to the scenario shown while the cart moves up the ramp.





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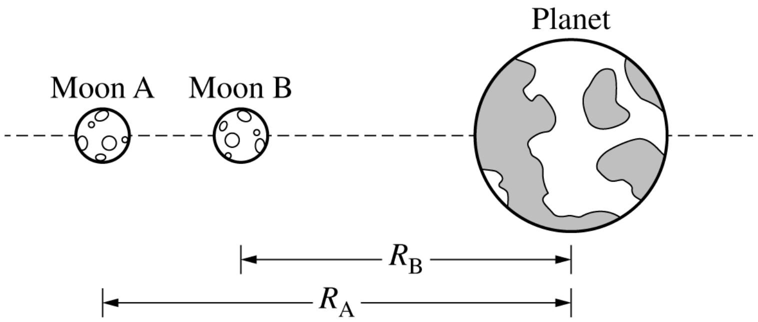
Begin your response to **QUESTION 2** on this page.

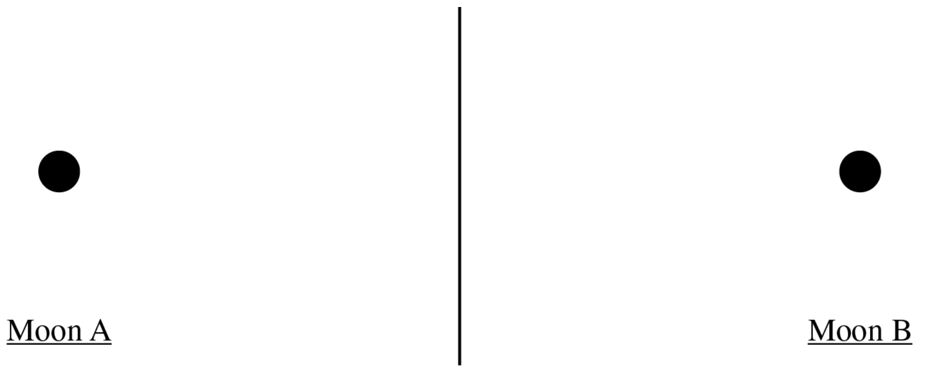


Note: Figure not drawn to scale.

. (12 points, suggested time 25 minutes)

Two identical moons, Moon A and Moon B, orbit a planet. The mass m_0 of each moon is significant, but less than the mass m_p of the planet. At some point in their orbits, the planet and the two moons are aligned as shown in the figure.

(a) The following dots represent the two moons when they are at the locations shown in the previous figure. On each dot, draw and label the forces (not components) exerted on Moon A and on Moon B. Each force must be represented by a distinct arrow starting on, and pointing away from, the appropriate dot.



(b) Consider the net gravitational force exerted on each moon due to the planet and the other moon.

i. Justify why the magnitude of the net force exerted on Moon A could be larger than the magnitude of the net force exerted on Moon B.

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

ii. Justify why the magnitude of the net force exerted on Moon B could be larger than the magnitude of the net force exerted on Moon A.

(c) Derive expressions for both of the following quantities. Express your answers in terms of m_0, m_p, R_A, R_B, and physical constants, as appropriate.

- The net force F_A exerted on Moon A

- The net force F_B exerted on Moon B

GO ON TO THE NEXT PAGE.

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

(d)

i. Could the expressions in part (c) support your reasoning in part (b)(i) ?

___ Yes ___ No

Explain your reasoning.

ii. Could the expressions in part (c) support your reasoning in part (b)(ii) ?

___ Yes ___ No

Explain your reasoning.

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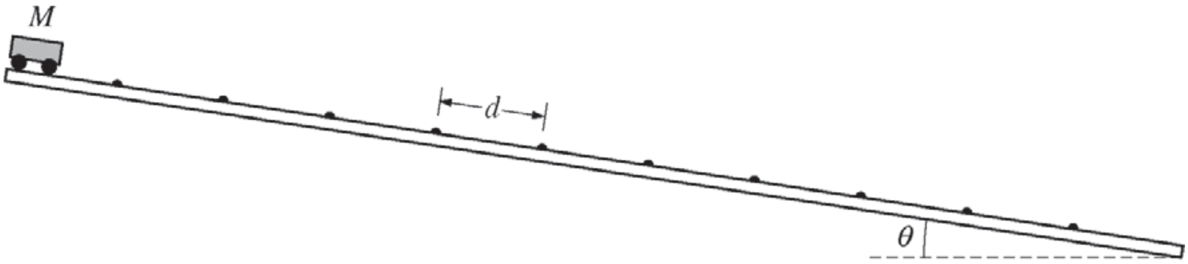


Note: Figure not drawn to scale.

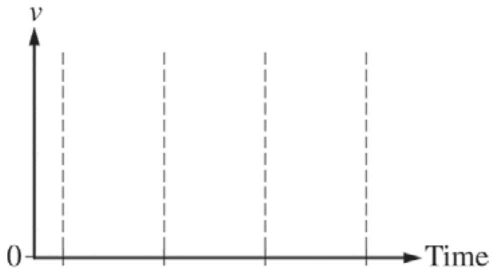
3. (12 points, suggested time 25 minutes)

A long track, inclined at an angle θ to the horizontal, has small speed bumps on it. The bumps are evenly spaced a distance d apart, as shown in the figure above. The track is actually much longer than shown, with over 100 bumps. A cart of mass M is released from rest at the top of the track. A student notices that after reaching the 40th bump the cart's average speed between successive bumps no longer increases, reaching a maximum value v_{avg}. This means the time interval taken to move from one bump to the next bump becomes constant.

(a) Consider the cart's motion between bump 41 and bump 44.

i. In the figure below, sketch a graph of the cart's velocity v as a function of time from the moment it reaches bump 41 until the moment it reaches bump 44.

ii. Over the same time interval, draw a dashed horizontal line at $v = v_{avg}$. Label this line "v_{avg}".



(b) Suppose the distance between the bumps is increased but everything else stays the same.

Is the maximum speed of the cart now greater than, less than, or the same as it was with the bumps closer together?

____ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

(c) With the bumps returned to the original spacing, the track is tilted to a greater ramp angle θ. Is the maximum speed of the cart greater than, less than, or the same as it was when the ramp angle was smaller?

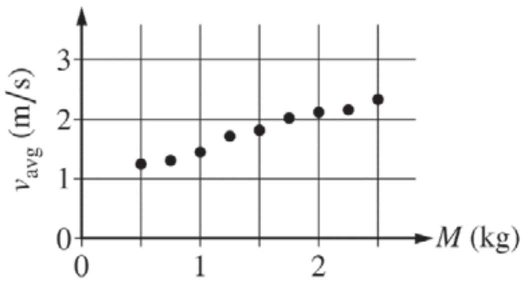
____ Greater than ____ Less than ____ The same as

Briefly explain your reasoning.

(d) Before deriving an equation for a quantity such as v_{avg}, it can be useful to come up with an equation that is intuitively expected to be true. That way, the derivation can be checked later to see if it makes sense physically. A student comes up with the following equation for the cart's maximum average speed:

$v_{avg} = C\dfrac{Mg\sin\theta}{d}$, where C is a positive constant.

i. To test the equation, the student rolls a cart down the long track with speed bumps many times in front of a motion detector. The student varies the mass M of the cart with each trial but keeps everything else the same. The graph shown below is the student's plot of the data for v_{avg} as a function of M.



Are these data consistent with the student's equation?

____ Yes ____ No

Briefly explain your reasoning.

ii. Another student suggests that whether or not the data above are consistent with the equation, the equation could be incorrect for other reasons. Does the equation make physical sense?

____ Yes ____ No

Briefly explain your reasoning.

2.7 Kinetic and Static Friction

Name: ______________ Class: __________ Date: ____________ **Total: 12 marks**

KEY WORDS kinetic friction 动摩擦 • static friction 静摩擦 • coefficient of friction 摩擦系数 • normal force 法向力 • friction 摩擦力

Objective

Build the skills to answer exam questions on **kinetic and static friction**.

You must be able to:

- distinguish **static friction 静摩擦** (prevents sliding) from **kinetic friction 动摩擦** (opposes sliding)
- use $f_s \le \mu_s F_N$ for maximum static friction and $f_k = \mu_k F_N$ for kinetic friction
- explain that friction depends on the **normal force 法向力** and the **coefficient of friction 摩擦系数**, not on contact area
- analyse the role of friction in motion and equilibrium

1 Worked examples

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

■ Static friction adjusts itself

Static friction matches the applied force up to a maximum $f_{s,\max} = \mu_s F_N$. Below that, the object stays put; push harder than $f_{s,\max}$ and it starts to slide.

■ Kinetic friction is fixed

Once sliding, $f_k = \mu_k F_N$ (usually $\mu_k < \mu_s$). A 10 kg box on a floor, $\mu_k = 0.30$, $g = 10$: $F_N = 100$ N, so $f_k = 0.30 \times 100 = 30$ N.

■ Area doesn't matter

Friction depends on F_N and the surfaces, **not** on the contact area — a brick slides with the same friction on its large or small face.

2 Practice

2.1 State the difference between static and kinetic friction. [2]

2.2 A 5.0 kg block rests on a floor, $\mu_k = 0.40$ (take $g = 10$ m s^{-2}). Find the kinetic friction force once it slides. [2]

2.3 A box needs 18 N to start moving but only 12 N to keep moving. State which coefficient is larger, μ_s or μ_k. [1]

2.4 State what happens to the friction force if the same box is turned to rest on a smaller face. [1]

3 Exam-style questions

3.1 The maximum static friction force is given by [1]

- **A** $\mu_s F_N$
- **B** $\mu_k F_N$
- **C** $\mu_s mg \sin\theta$
- **D** F_N/μ_s

3.2 Doubling the contact area (same weight) changes the kinetic friction force by a factor of [1]

- **A** 0.5
- **B** 1 (no change)
- **C** 2
- **D** 4

3.3 A 4.0 kg block sits on a level floor, $\mu_s = 0.50$, $\mu_k = 0.30$ (take $g = 10$ m s^{-2}).

(a) Find the maximum static friction. [2]

(b) A horizontal push of 15 N is applied. State whether the block moves, and find the friction force acting. [2]

Solutions

2.1 Static friction acts on a surface that is **not sliding** and adjusts up to a maximum; kinetic friction acts on a **sliding** surface and has a fixed value $\mu_k F_N$.

2.2 $F_N = mg = 50$ N; $f_k = 0.40 \times 50 = 20$ N.

2.3 μ_s is larger (more force is needed to start it moving).

2.4 it is unchanged — friction does not depend on contact area.

3.1 **A**.

3.2 **B**.

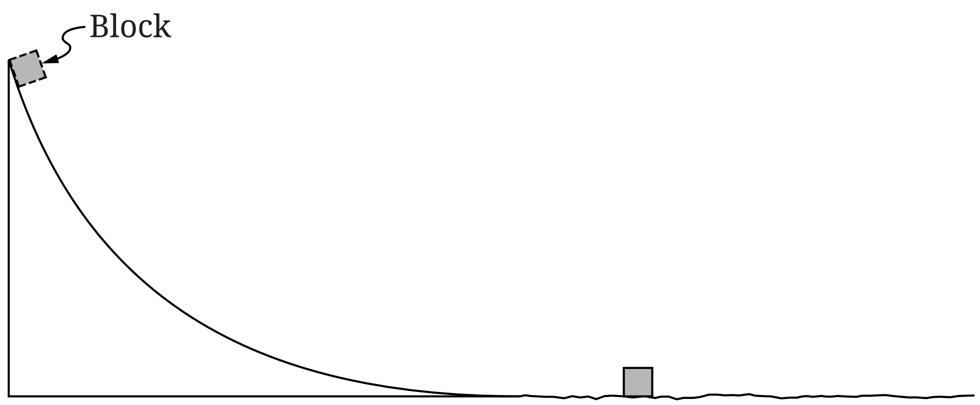
3.3 (a) $F_N = 40$ N, $f_{s,\text{max}} = 0.50 \times 40 = 20$ N. (b) $15 < 20$ N, so it does not move; static friction $= 15$ N, matching the push.

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

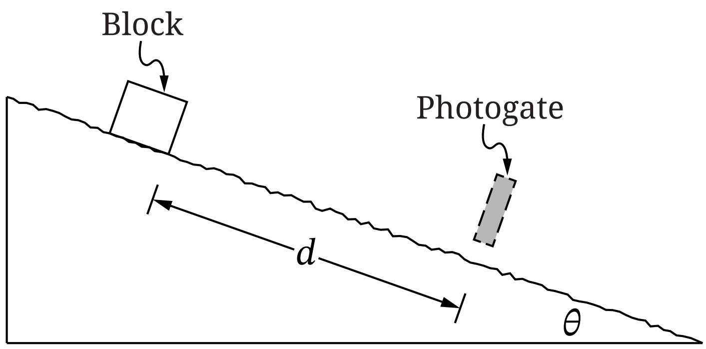
i. **Indicate** what quantities the students could graph on the horizontal and vertical axes to create a linear graph that can be used to determine μ_k. Clearly state which quantity will be graphed on each axis.

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.

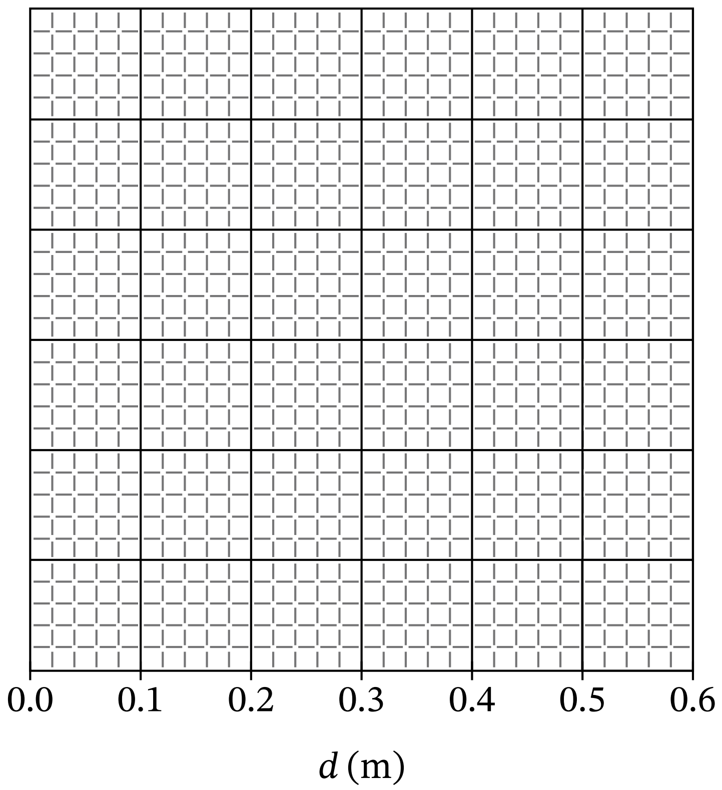
ii. On the grid provided in Figure 3, create a graph that can be used to determine μ_k.

- 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.

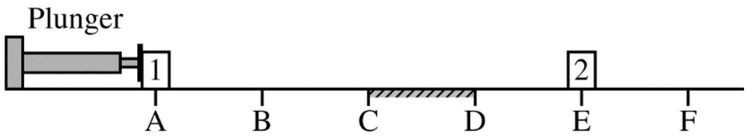
PHYSICS 1

Section II

Time—1 hour and 30 minutes

5 Questions

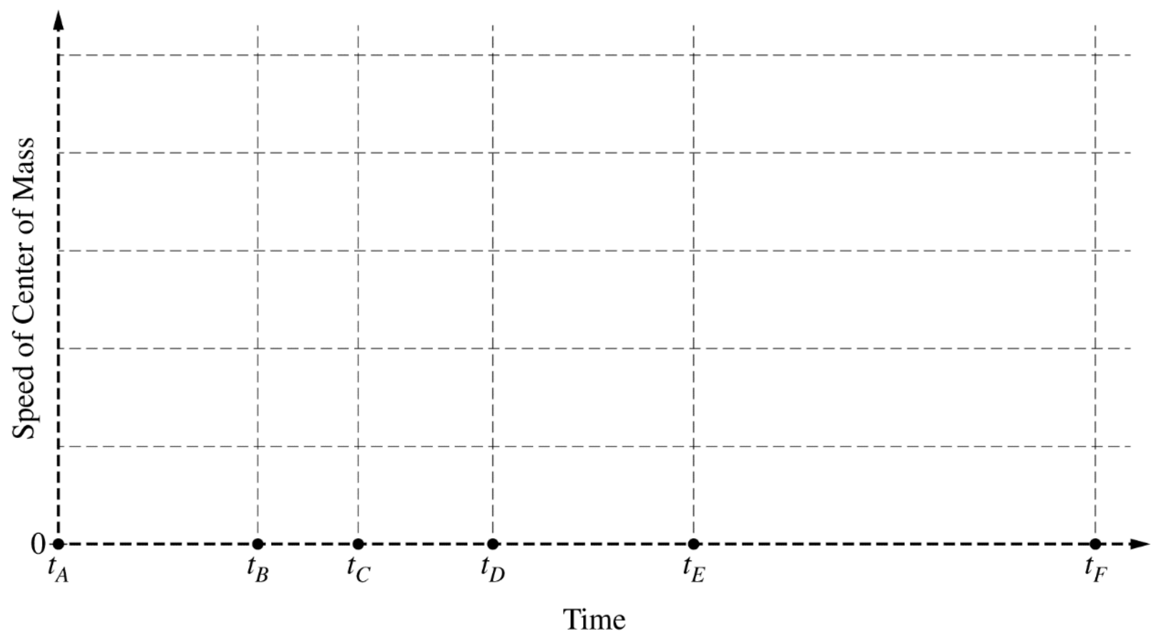
Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the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

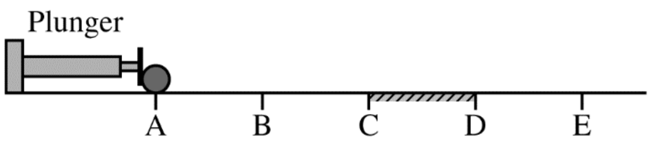


1. (7 points, suggested time 13 minutes)

Identical blocks 1 and 2 are placed on a horizontal surface at points A and E, respectively, as shown. The surface is frictionless except for the region between points C and D, where the surface is rough. Beginning at time t_A, block 1 is pushed with a <u>constant</u> horizontal force from point A to point B by a mechanical plunger. Upon reaching point B, block 1 loses contact with the plunger and continues moving to the right along the horizontal surface toward block 2. Block 1 collides with and sticks to block 2 at point E, after which the two-block system continues moving across the surface, eventually passing point F.

(a) On the axes below, sketch the speed of the <u>center of mass</u> of the two-block system as a function of time, from time t_A until the blocks pass point F at time t_F. The times at which block 1 reaches points A through F are indicated on the time axis.





(b) The plunger is returned to its original position, and both blocks are removed. A uniform solid sphere is placed at point A, as shown. The sphere is pushed by the plunger from point A to point B with a constant horizontal force that is directed toward the sphere's center of mass. The sphere loses contact with the plunger at point B and continues moving across the horizontal surface toward point E. In which interval(s), if any, does the sphere's angular momentum about its center of mass change? Check all that apply.

____ A to B ____ B to C ____ C to D ____ D to E _____ None

Briefly explain your reasoning.

2. (12 points, suggested time 25 minutes)

A student wants to determine the coefficient of static friction between a long, flat wood board and a small wood block.

(a) Describe an experiment for determining the coefficient of static friction between the wood board and the wood block. Assume equipment usually found in a school physics laboratory is available.

i. Draw a diagram of the experimental setup of the board and block. In your diagram, indicate each quantity that would be measured and draw or state what equipment would be used to measure each quantity.

ii. 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) Derive an equation for the coefficient of static friction in terms of quantities measured in the procedure from part (a).

A physics class consisting of six lab groups wants to test the hypothesis that the coefficient of static friction between the board and the block equals the coefficient of kinetic friction between the board and the block. Each group determines the coefficients of kinetic and static friction between the board and the block. The groups' results are shown below, with the class averages indicated in the bottom row.

Lab Group Number	Coefficient of Kinetic Friction	Coefficient of Static Friction
1	0.45	0.54
2	0.46	0.52
3	0.42	0.56
4	0.43	0.55
5	0.74	0.23
6	0.44	0.54
Average	0.49	0.49

(c) Based on these data, what conclusion should the students make about the hypothesis that the coefficients of static and kinetic friction are equal?

____ The static and kinetic coefficients are equal.

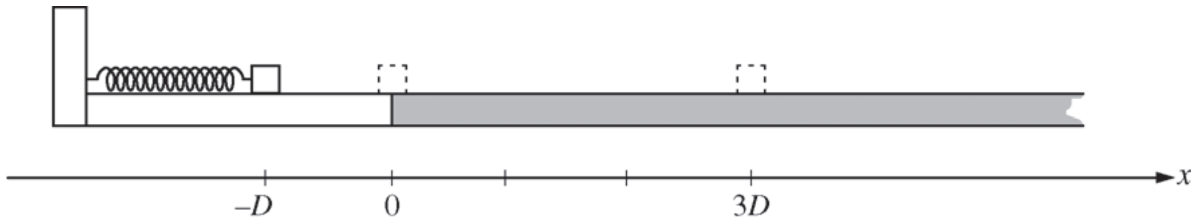
____ The static and kinetic coefficients are not equal.

Briefly justify your reasoning.

(d) A metal disk is glued to the top of the wood block. The mass of the block-disk system is twice the mass of the original block. Does the coefficient of static friction between the bottom of the block and the board increase, decrease, or remain the same when the disk is added to the block?

____ Increase ____ Decrease ____ Remain the same

Briefly state your reasoning.



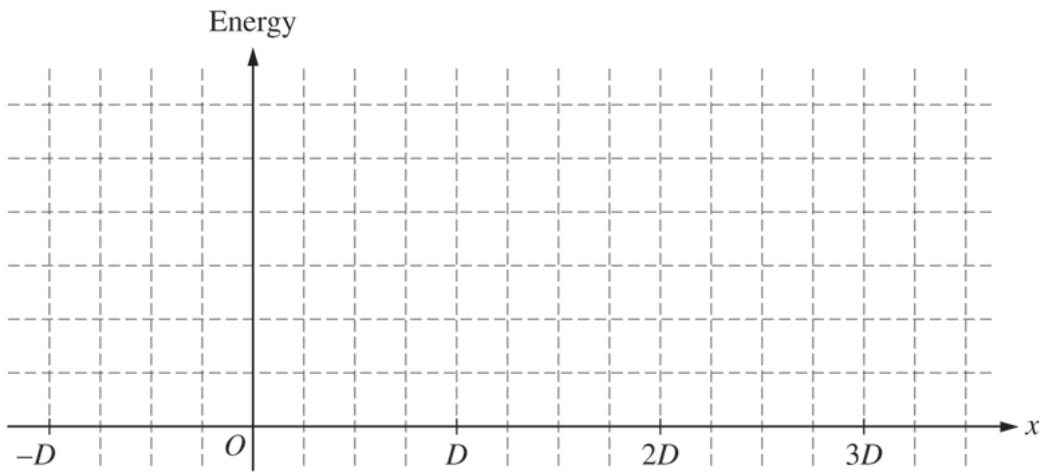
3. (12 points, suggested time 25 minutes)

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.

2.8 Spring Forces

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

KEY WORDS spring constant 弹簧常数 • slope 斜率 • hooke's law 胡克定律 • restoring force 回复力 • force 力

Objective

Build the skills to answer exam questions on **spring forces**.

You must be able to:

- state **Hooke's law** 胡克定律, $F_s = -k\,\Delta x$
- define the **spring constant** 弹簧常数 k as a measure of stiffness
- explain that the spring force is a **restoring force** 回复力 directed opposite to the displacement
- find k from the **slope** 斜率 of a force-versus-displacement graph

1 Worked examples

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

■ Hooke's law

$F_s = -k\,\Delta x$: the restoring force is proportional to the stretch or compression Δx from the natural length, and points **back toward equilibrium**. The magnitude is $|F_s| = k\,|\Delta x|$.

■ Finding the spring constant

A force of 6.0 N stretches a spring by 0.020 m: $k = \dfrac{F}{\Delta x} = \dfrac{6.0}{0.020} = 300\ \text{N m}^{-1}$.

■ Reading a force-extension graph

For a spring that obeys Hooke's law, force vs extension is a straight line through the origin; its **slope is** k. A steeper line means a stiffer spring.

2 Practice

2.1 A spring is stretched 0.10 m by a force of 25 N. Find its spring constant. [2]

2.2 State the direction of the spring force when a spring is **compressed**. [1]

2.3 A spring has $k = 400$ N m^{-1}. Find the force needed to stretch it 0.05 m. [1]

2.4 Two springs have force-extension graphs; spring P has a steeper line than spring Q. State which is stiffer. [1]

3 Exam-style questions

3.1 The negative sign in $F_s = -k\,\Delta x$ shows that the spring force [1]

- **A** is always downward
- **B** opposes the displacement from equilibrium
- **C** decreases with time
- **D** is a contact force

3.2 A force of 12 N stretches a spring 0.03 m. Its spring constant is [1]

- **A** 0.36 N m^{-1}
- **B** 4.0 N m^{-1}
- **C** 36 N m^{-1}
- **D** 400 N m^{-1}

3.3 A spring hangs vertically. Adding a 2.0 kg mass stretches it 0.08 m (take $g = 10$ m s^{-2}).

(a) Find the spring constant. [2]

(b) Find the extension produced by a 5.0 kg mass. [2]

Solutions

2.1 $k = \dfrac{F}{\Delta x} = \dfrac{25}{0.10} = 250\ \text{N m}^{-1}$.

2.2 outward, away from the compression — back toward the natural length.

2.3 $F = k\,\Delta x = 400 \times 0.05 = 20$ N.

2.4 spring P (steeper slope = larger k).

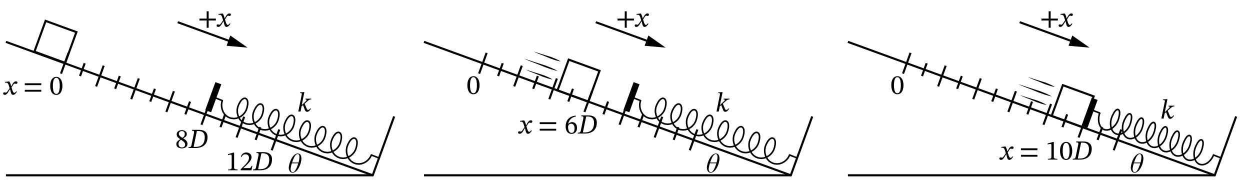
3.1 **B**.

3.2 **D** — $k = 12/0.03 = 400\ \text{N m}^{-1}$.

3.3 (a) $F = mg = 20$ N; $k = \dfrac{20}{0.08} = 250\ \text{N m}^{-1}$. (b) $F = 50$ N; $\Delta x = \dfrac{50}{250} = 0.20$ m.

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.

$x = 0$

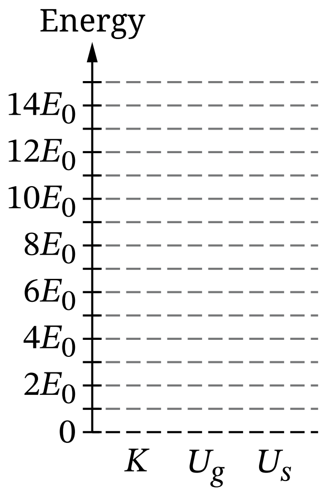


Figure 2

$x = 6D$

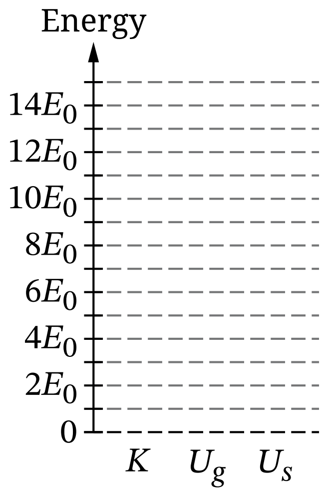


Figure 3

$x = 10D$

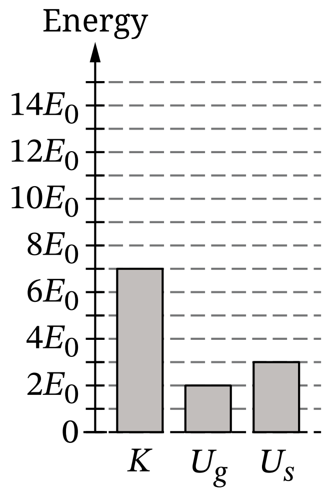
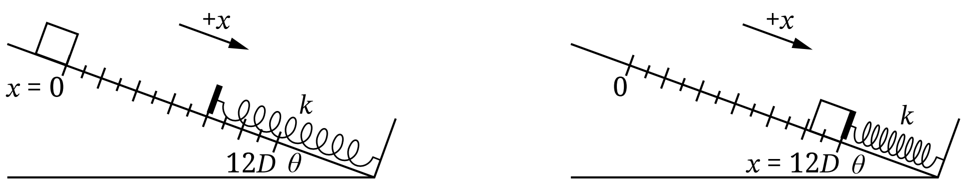


Figure 4

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 $x = 12D$.

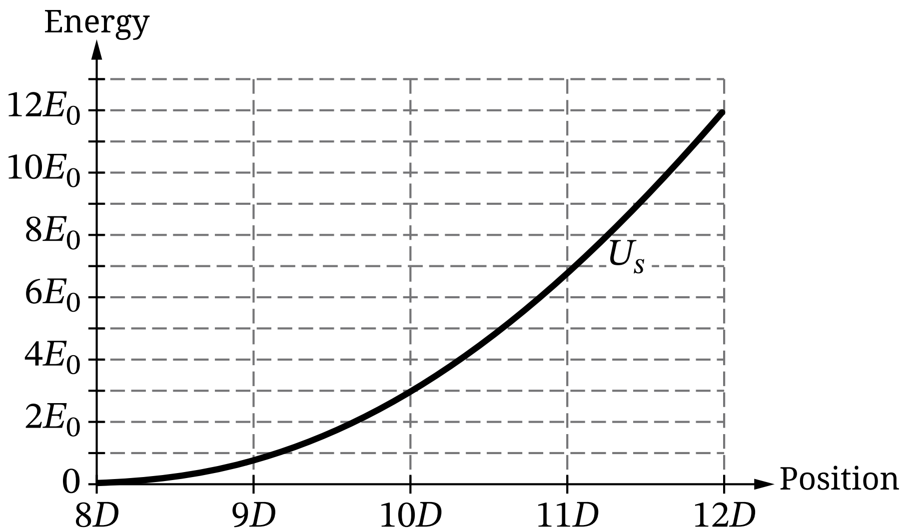


Figure 6

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 2** on this page.

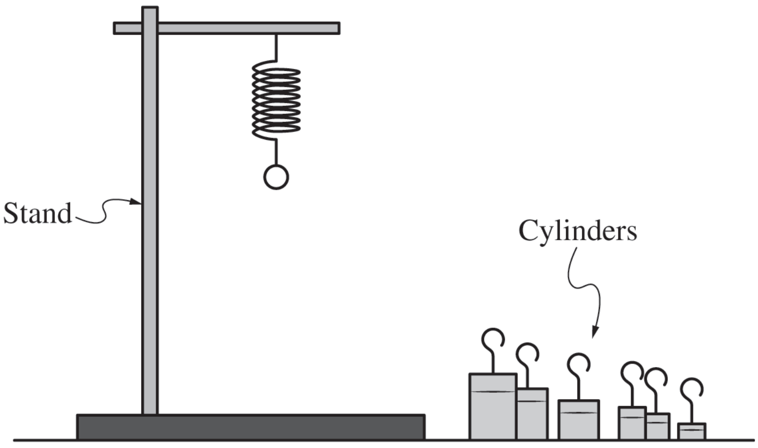


Figure 1

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.

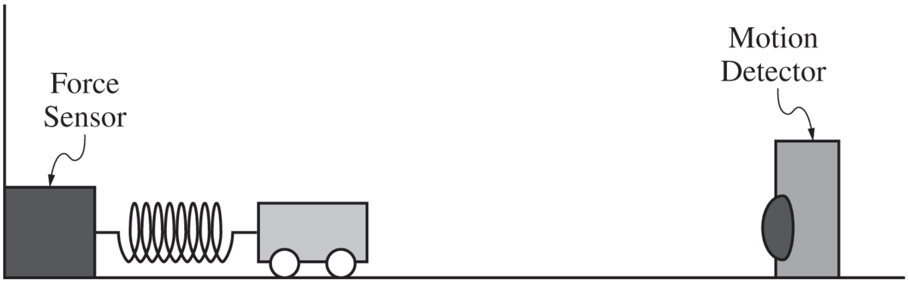
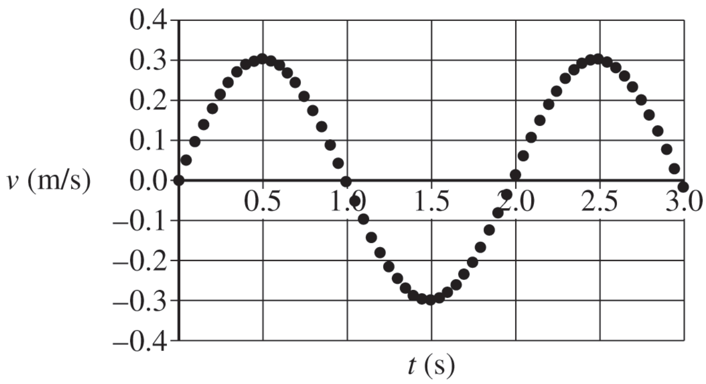
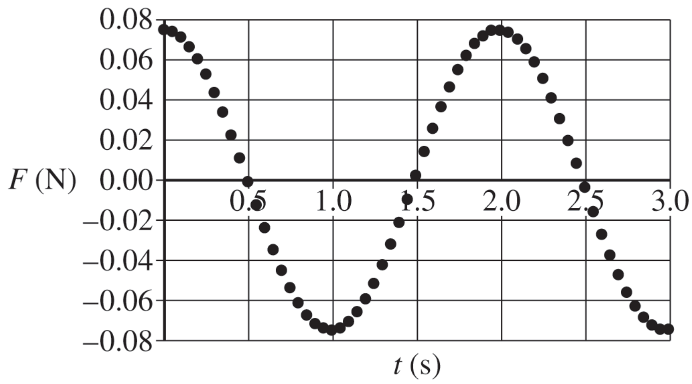


Figure 2

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 $t = 0.5\text{ s}$ to $t = 2.0\text{ s}$. Show your steps and substitutions.

ii. Using the data in the force-time graph, **estimate** the change in momentum of the cart from $t = 0.5\text{ s}$ to $t = 2.5\text{ s}$. 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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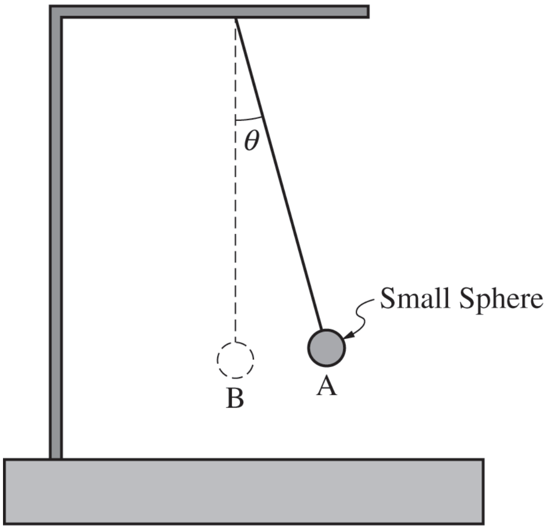
Begin your response to **QUESTION 4** on this page.



4. (7 points, suggested time 13 minutes)

A simple pendulum consists of a small sphere that hangs from a string with negligible mass. The top end of the string is fixed. The sphere is pulled to Point A so that the string makes a small angle θ with the vertical, as shown. The sphere is then released from rest and swings through its lowest point at Point B. The work done on the sphere by Earth between points A and B is W_E.

The pendulum is then taken to Planet X. The mass of Planet X is the same as the mass of Earth, but the radius of Planet X is greater than the radius of Earth. The sphere is again brought to Point A (displaced θ from the vertical), released from rest, and swings through its lowest point at Point B. The work done on the sphere by Planet X between points A and B is W_X.

(a) **Justify** why W_X is less than W_E.

GO ON TO THE NEXT PAGE.

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

A new pendulum is made by hanging the same small sphere from a different string with negligible mass. The new string is slightly elastic, and the length of the string may increase or decrease depending on the tension applied to the string. On Earth, when the sphere is again displaced θ from the vertical and released from rest, the new pendulum oscillates with period T_E.

The new pendulum is then taken to a different planet, Planet Y. The radius of Planet Y is the same as the radius of Earth, but the mass of Planet Y is larger than the mass of Earth. On Planet Y, when the sphere is again displaced from the vertical and released from rest, the new pendulum oscillates with period T_Y.

(b) In a clear, coherent paragraph-length response that may also contain drawings, **explain** how T_Y could be larger than T_E but also could be smaller than T_E.

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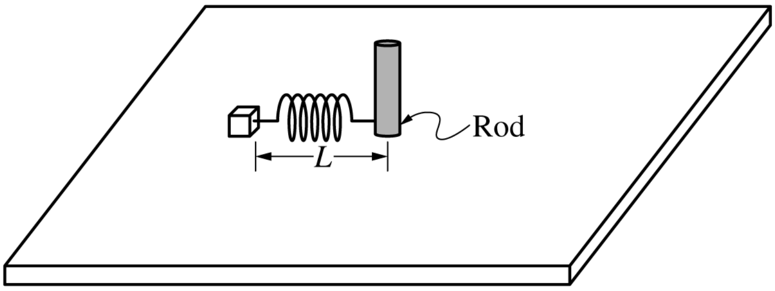


. (12 points, suggested time 25 minutes)

A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.

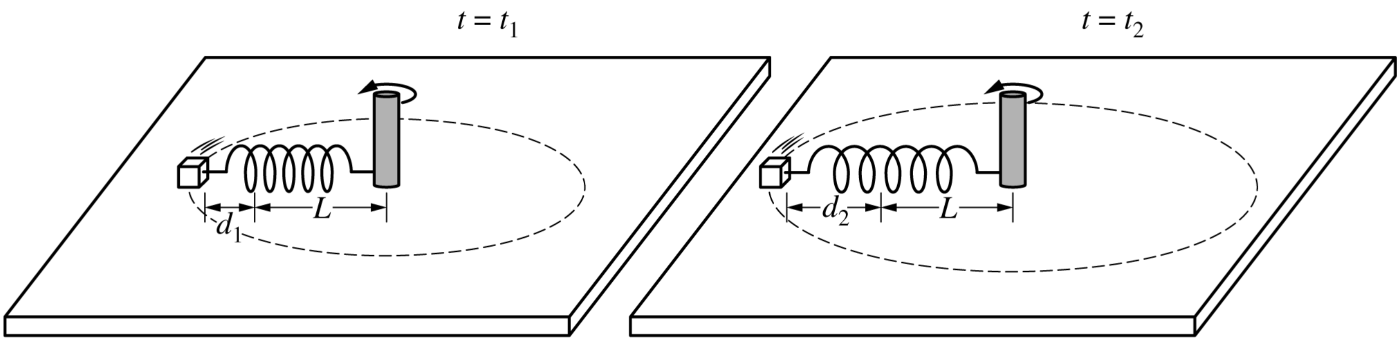


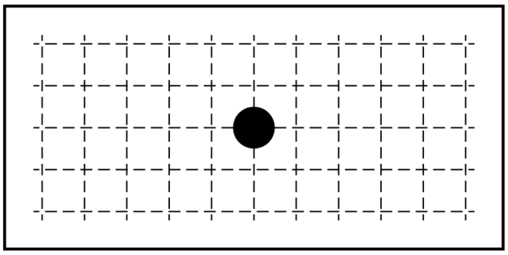
Figure 1 Figure 2

(a) At time $t = t_1$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_1 and the spring is stretched a distance d_1 from the spring's unstretched length, as shown in Figure 1. At time $t = t_2$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_2 and the spring is stretched a distance d_2 from the spring's unstretched length, where $d_2 > d_1$, as shown in Figure 2.

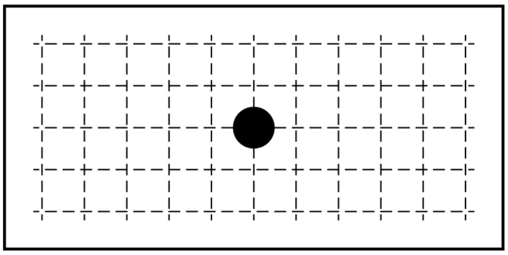
GO ON TO THE NEXT PAGE.

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

i. On the following dots, which represent the block at the locations shown in Figure 1 and Figure 2, draw the force that is exerted on the block by the spring at times $t = t_1$ and $t = t_2$. The spring force must be represented by a distinct arrow starting on, and pointing away from, the dot.
Note: Draw the relative lengths of the vectors to reflect the relative magnitudes of the forces exerted by the spring at both times.



$t = t_1$



$t = t_2$

ii. Referencing d_1 and d_2, describe your reasoning for drawing the arrows the length that you did in part (a)(i).

iii. Is the tangential speed v_1 of the block at time $t = t_1$ greater than, less than, or equal to the tangential speed v_2 of the block at time $t = t_2$?

_____ $v_1 > v_2$ _____ $v_1 < v_2$ _____ $v_1 = v_2$

Justify your answer without using equations.

GO ON TO THE NEXT PAGE.

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

(b) Consider a scenario where the block travels in a circular path where the spring is stretched a distance d from its unstretched length L.

i. Determine an expression for the magnitude of the net force F_{net} exerted on the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

ii. Derive an equation for the tangential speed v of the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

(c) Does your equation for the tangential speed v of the block from part (b)(ii) agree with your reasoning from part (a) ?

____ Yes ____ No

Explain your reasoning.

GO ON TO THE NEXT PAGE.

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

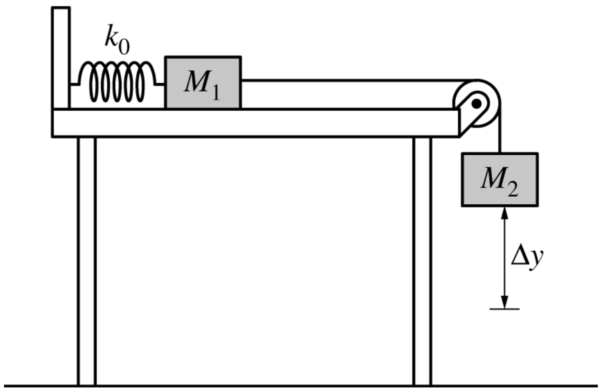
PHYSICS 1

SECTION II

Time—1 hour and 30 minutes

5 Questions

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)

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

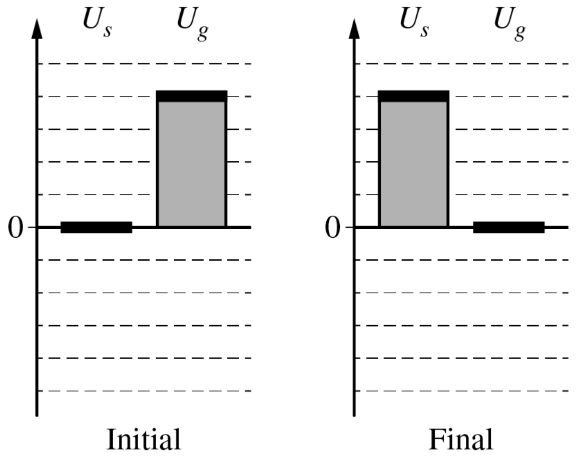
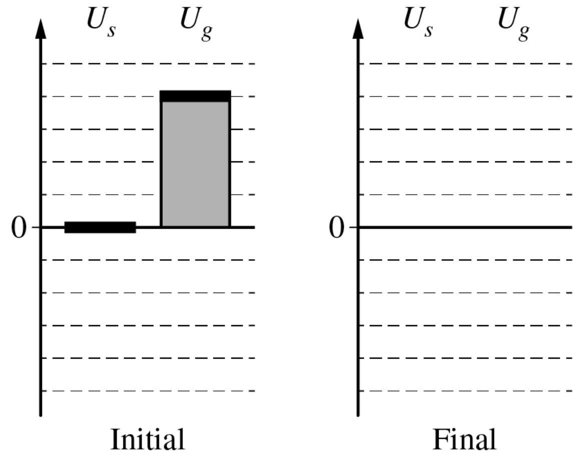


Diagram B: Nonnegligible Friction



(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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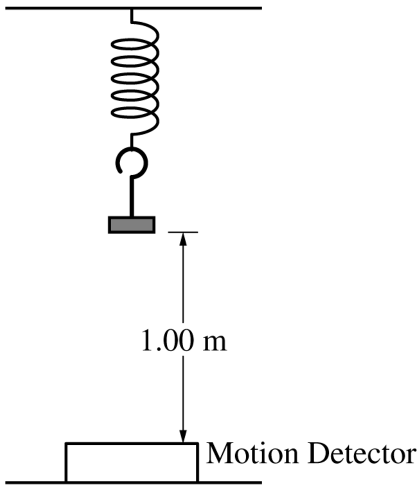

. (7 points, suggested time 13 minutes)

A spring of unknown spring constant k_0 is attached to a ceiling. A lightweight hanger is attached to the lower end of the spring, and a motion detector is placed on the floor facing upward directly under the hanger, as shown in the figure above. The bottom of the hanger is 1.00 m above the motion detector.

A 0.50 kg object is placed on the hanger and allowed to come to rest at the equilibrium position. The spring is then stretched downward a distance d_0 from equilibrium and released at time $t = 0$. The motion detector records the height of the bottom of the hanger as a function of time. The output from the motion detector is shown in the graph on the following page.

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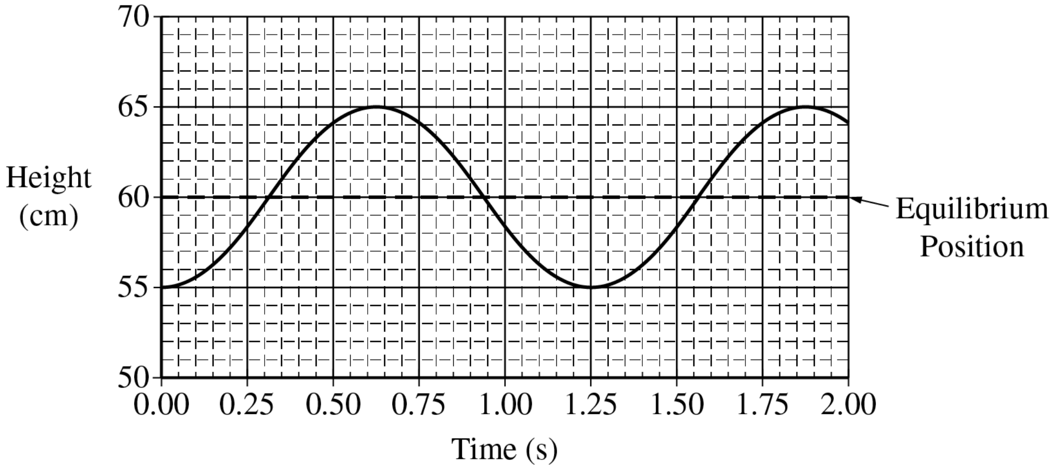
Continue your response to **QUESTION 5** on this page.



(a) Using the information given and information taken from the graph, calculate the spring constant.

(b) At time 0.75 s, the object-spring-Earth system has a total kinetic energy K_0 and a total potential energy U_0. At 1.13 s, the object-spring-Earth system again has a total kinetic energy K_0 and a total potential energy U_0.

i. Explain how a feature of the graph indicates that the total kinetic energy of the system is the same at these two times.

ii. Briefly explain why the total potential energy of the system is the same at these two times.

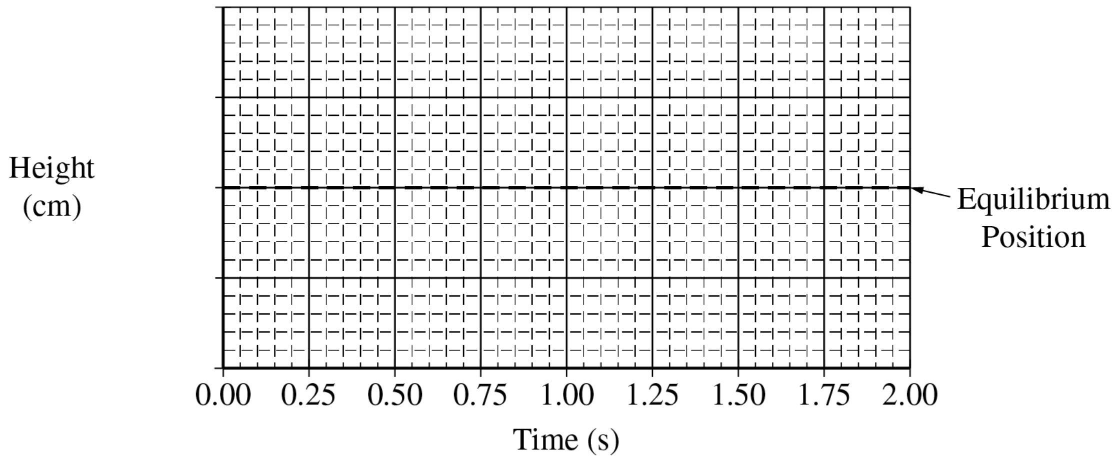
GO ON TO THE NEXT PAGE.

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

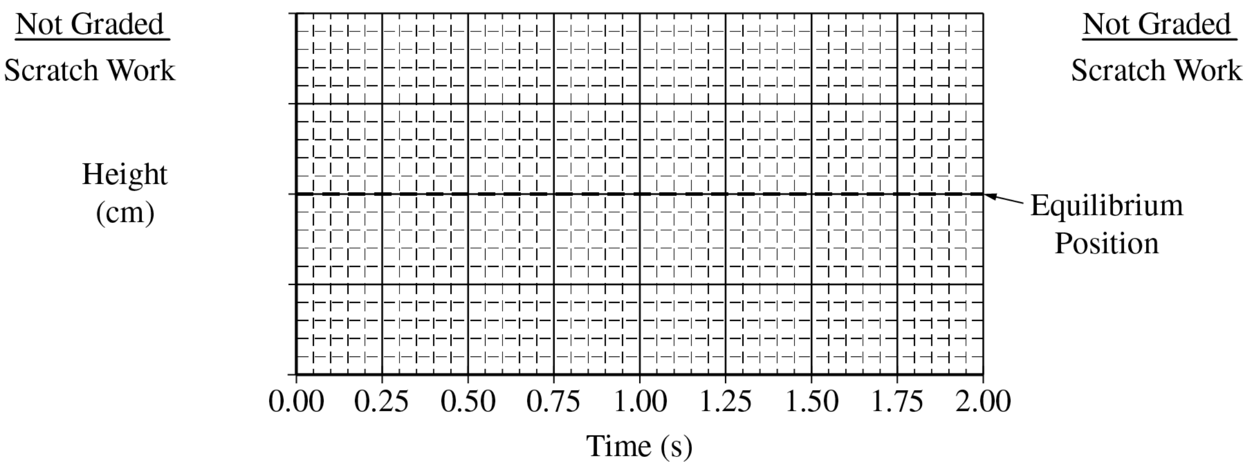
(c) The experiment is repeated with a spring of spring constant $4k_0$ and that has the same length as the original spring. The 0.50 kg object is hung from the new spring and allowed to come to rest at a new equilibrium position.

i. Determine the new equilibrium position above the motion detector.

ii. The object is again pulled down the same distance d_0 from the equilibrium position and released. On the following graph, draw a curve representing the motion of the object after it is released. Label the vertical axis with an appropriate numerical scale. A grid for scratch (practice) work is also provided.



The following graph is provided for scratch work only and will not be graded.



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STOP

END OF EXAM

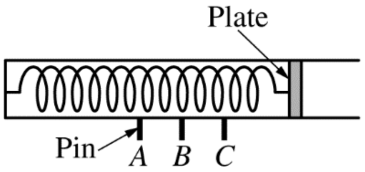


Figure 1. Uncompressed spring

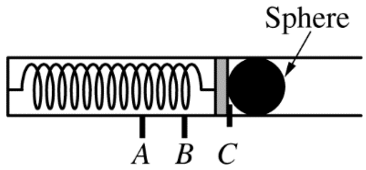


Figure 2. Compressed spring

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.

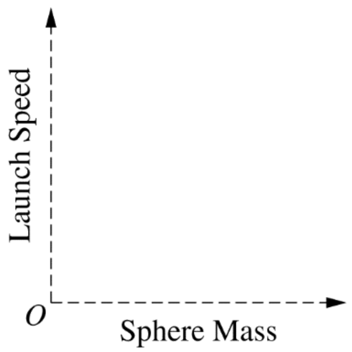
Quantity to be Measured	Symbol for Quantity	Equipment for Measurement

(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.



AP PHYSICS 1 • EXERCISE SHEET

2.9 Circular Motion

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

KEY WORDS period 周期 • centripetal acceleration 向心加速度 • centripetal force 向心力 • frequency 频率 • uniform circular motion 匀速圆周运动

Objective

Build the skills to answer exam questions on **circular motion**.

You must be able to:

- define **uniform circular motion 匀速圆周运动** as motion in a circle at constant speed
- use the **centripetal acceleration 向心加速度** $a_c = \frac{v^2}{r}$, directed toward the centre
- identify the net force that provides the **centripetal force 向心力** $F_c = \frac{mv^2}{r}$
- relate the **period 周期**, **frequency 频率**, and speed of circular motion

1 Worked examples

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

■ Centripetal acceleration points inward

Even at constant speed, the **direction** of velocity changes, so there is an acceleration $a_c = \frac{v^2}{r}$ toward the centre. A car at 10 m s^{-1} on a 20 m radius bend: $a_c = \frac{10^2}{20} =$ 5.0 m s^{-2}.

■ The centripetal force is a role, not a new force

Some **real** force (friction, tension, gravity, normal) provides $F_c = \frac{mv^2}{r}$. For the car, friction supplies it: $F_c = \frac{mv^2}{r}$.

■ Period and frequency

The object covers one circumference per period: $v = \frac{2\pi r}{T}$, and frequency $f = \frac{1}{T}$.

2 Practice

2.1 A ball moves at 4.0 m s^{-1} in a circle of radius 2.0 m. Find its centripetal acceleration. [2]

2.2 Name the force that keeps a car moving around a flat circular track. [1]

2.3 A 0.50 kg ball moves in a circle with centripetal acceleration 8.0 m s^{-2}. Find the centripetal force. [1]

2.4 An object completes a circle in 0.25 s. Find its frequency. [1]

3 Exam-style questions

3.1 For an object in uniform circular motion, the net force points [1]

- **A** along the velocity
- **B** opposite the velocity
- **C** toward the centre
- **D** away from the centre

3.2 If the speed of an object in a circle doubles (same radius), the centripetal acceleration becomes [1]

- **A** unchanged
- **B** twice as large
- **C** four times as large
- **D** half as large

3.3 A 0.20 kg ball on a string moves in a horizontal circle of radius 0.50 m at 3.0 m s^{-1}.

(a) Find the centripetal acceleration. [2]

(b) Find the tension in the string (the centripetal force). [2]

Solutions

2.1 $a_c = \dfrac{v^2}{r} = \dfrac{4.0^2}{2.0} = 8.0 \text{ m s}^{-2}$.

2.2 friction (between the tyres and the road).

2.3 $F_c = ma_c = 0.50 \times 8.0 = 4.0$ N.

2.4 $f = \dfrac{1}{T} = \dfrac{1}{0.25} = 4.0$ Hz.

3.1 **C**.

3.2 **C** — $a_c \propto v^2$.

3.3 (a) $a_c = \dfrac{3.0^2}{0.50} = 18 \text{ m s}^{-2}$. (b) $F_c = ma_c = 0.20 \times 18 = 3.6$ N.

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

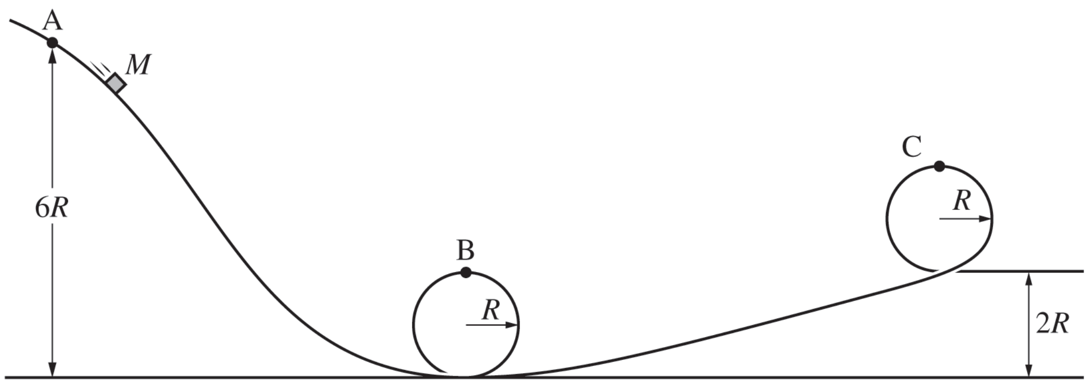
PHYSICS 1

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.

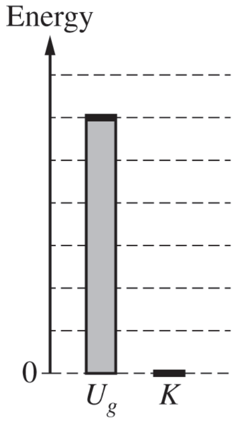

Diagram A

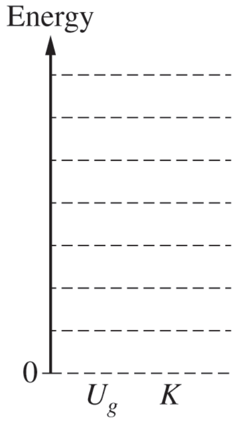

Diagram B

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.

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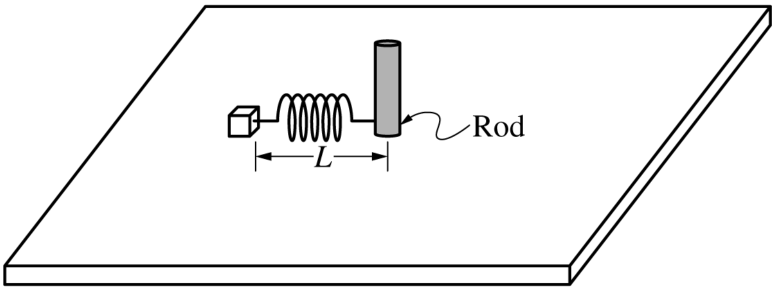

. (12 points, suggested time 25 minutes)

A small block of mass m_0 is attached to the end of a spring of spring constant k_0 that is attached to a rod on a horizontal table. The rod is attached to a motor so that the rod can rotate at various speeds about its axis. When the rod is not rotating, the block is at rest and the spring is at its unstretched length L, as shown. All frictional forces are negligible.

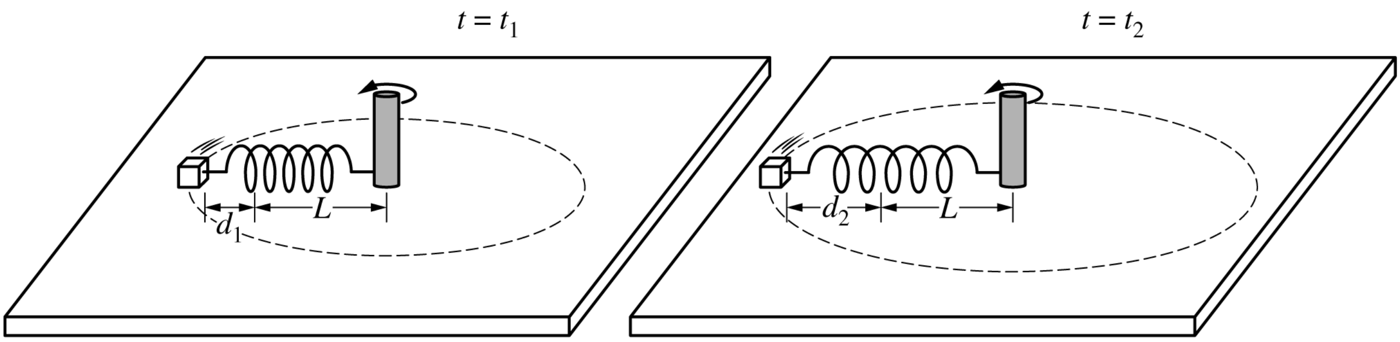

Figure 1 Figure 2

(a) At time $t = t_1$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_1 and the spring is stretched a distance d_1 from the spring's unstretched length, as shown in Figure 1. At time $t = t_2$, the rod is spinning such that the block moves in a circular path with a constant tangential speed v_2 and the spring is stretched a distance d_2 from the spring's unstretched length, where $d_2 > d_1$, as shown in Figure 2.

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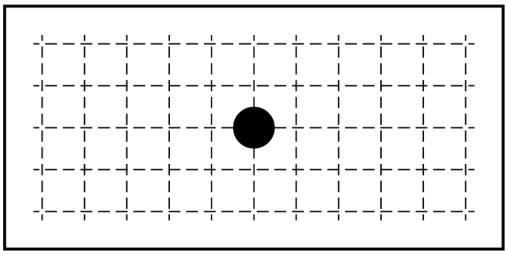
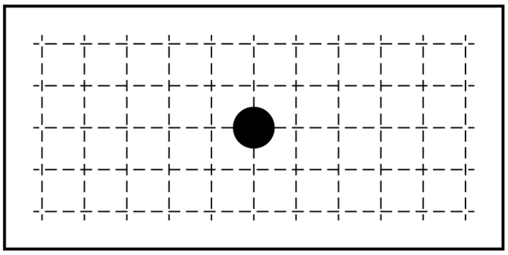
Continue your response to **QUESTION 3** on this page.

i. On the following dots, which represent the block at the locations shown in Figure 1 and Figure 2, draw the force that is exerted on the block by the spring at times $t = t_1$ and $t = t_2$. The spring force must be represented by a distinct arrow starting on, and pointing away from, the dot.
<u>Note:</u> Draw the relative lengths of the vectors to reflect the relative magnitudes of the forces exerted by the spring at both times.



$t = t_1$



$t = t_2$

ii. Referencing d_1 and d_2, describe your reasoning for drawing the arrows the length that you did in part (a)(i).

iii. Is the tangential speed v_1 of the block at time $t = t_1$ greater than, less than, or equal to the tangential speed v_2 of the block at time $t = t_2$?

_____ $v_1 > v_2$ _____ $v_1 < v_2$ _____ $v_1 = v_2$

Justify your answer without using equations.

GO ON TO THE NEXT PAGE.

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

(b) Consider a scenario where the block travels in a circular path where the spring is stretched a distance d from its unstretched length L.

i. Determine an expression for the magnitude of the net force F_{net} exerted on the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

ii. Derive an equation for the tangential speed v of the block. Express your answer in terms of m_0, k_0, L, d, and fundamental constants, as appropriate.

(c) Does your equation for the tangential speed v of the block from part (b)(ii) agree with your reasoning from part (a) ?

____ Yes ____ No

Explain your reasoning.

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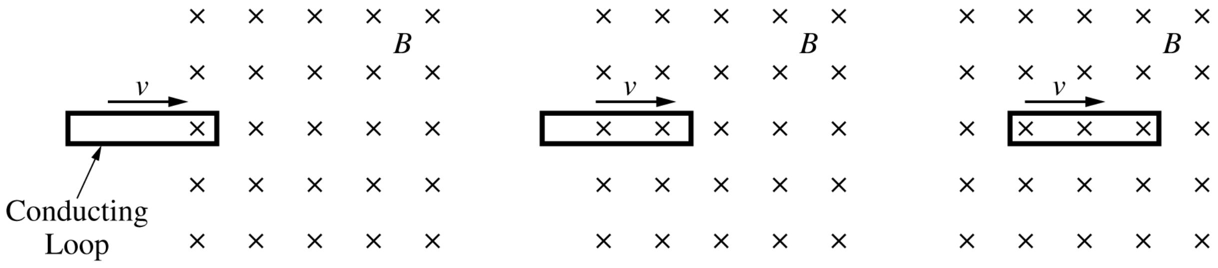
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 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.



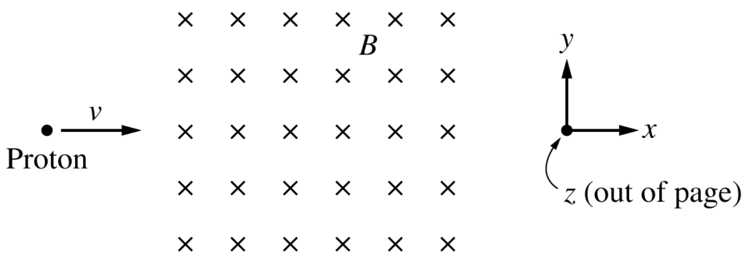
Time t_1 Time t_2 Time t_3

1. (10 points, suggested time 20 minutes)

   The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

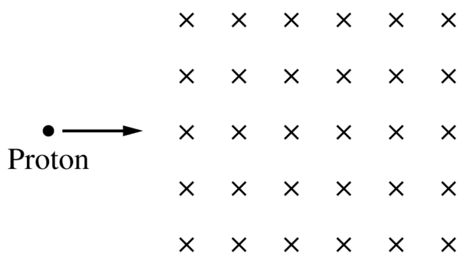
   (a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).