Week 16

AP Physics 1

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

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4. Linear Momentum

Starter Quiz · 课前小测

AP Physics 1 Name: ____________________ Score: ______

1. What is the momentum of a 1500 kg car moving at 20 $\frac{m}{s}$, in kg $\cdot$ $\frac{m}{s}$?

   ______________ kg · m/s

2. The impulse–momentum theorem says impulse equals the change in ______.

   ____

3. A 2 kg trolley at 3 $\frac{m}{s}$ hits a stationary 1 kg trolley and they stick. What is their common speed after, in $\frac{m}{s}$?

   ______________ m/s

4. In an **elastic** collision, which quantity is conserved besides momentum?

   ☐ temperature

   ☐ kinetic energy

   ☐ mass only

   ☐ nothing else

5. Momentum is a vector, so its direction matters.

   ☐ True ☐ False

6. A force of 20 N acts for 0.5 s. What is the impulse, in N · s?

   ______________ N · s

7. Momentum is conserved only when the system is:

   ☐ moving fast

   ☐ isolated (no external net force)

   ☐ made of identical objects

   ☐ at rest

8. Momentum is conserved in both elastic and inelastic collisions (for an isolated system).

   ☐ True ☐ False

9. Momentum equals mass times ______.

   ____

10. How does an airbag reduce the force on a passenger in a crash?

    ☐ by reducing the change in momentum

- ☐ by making the stop take longer
- ☐ by adding momentum
- ☐ by removing all the energy

AP Physics 1

1. **30000 kg · m/s**

   $p = mv = 1500 \times 20 = 30\,000 \text{ kg} \cdot \frac{\text{m}}{\text{s}}$.

2. **momentum**

   $\vec{J} = \Delta\vec{p}$ — impulse equals the change in **momentum**.

3. **2 m/s**

   Before: $p = 2(3) = 6$. After: $3v = 6$, so $v = 2 \ \frac{\text{m}}{\text{s}}$.

4. **kinetic energy**

   An elastic collision conserves **kinetic energy** as well as momentum.

5. **True**

   $\vec{p} = m\vec{v}$ points along the velocity; opposite directions give opposite signs.

6. **10 N · s**

   $J = F\Delta t = 20 \times 0.5 = 10 \text{ N} \cdot \text{s}$.

7. **isolated (no external net force)**

   With no external net force, the internal forces cancel and total momentum stays constant.

8. **True**

   Momentum is always conserved in an isolated collision. Kinetic energy is the quantity that distinguishes the two types.

9. **velocity**

   $\vec{p} = m\vec{v}$ — mass times **velocity**.

10. **by making the stop take longer**

    The change in momentum is fixed. A longer stopping time Δt makes $F = \Delta p/\Delta t$ smaller.

4.1 Linear Momentum

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

KEY WORDS total momentum 总动量 • linear momentum 线动量

Objective

Build the skills to answer exam questions on **linear momentum**.

You must be able to:

- define **linear momentum 线动量** as $\vec{p} = m\vec{v}$
- describe momentum as a **vector** pointing in the direction of the velocity
- calculate the **total momentum 总动量** of a system as the vector sum of its parts
- explain how momentum depends on both **mass** and **speed**

1 Worked examples

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

■ Momentum is mass times velocity

$\vec{p} = m\vec{v}$, measured in kg m s^{-1}, and points the same way as the velocity. A 2.0 kg ball at 3.0 m s^{-1} has $p = 6.0$ kg m s^{-1}.

■ Total momentum uses signs

Add momenta as vectors (with signs in 1-D). A $+4$ kg m s^{-1} and a -1 kg m s^{-1} object give a total of $+3$ kg m s^{-1}.

■ Mass and speed both matter

A heavy truck at low speed can carry the same momentum as a light car at high speed.

2 Practice

2.1 Find the momentum of a 0.50 kg ball moving at 8.0 m s^{-1}. [1]

2.2 A 1200 kg car has momentum 18 000 kg m s^{-1}. Find its speed. [2]

2.3 Two carts move along a line: 3.0 kg at +2.0 m s^{-1} and 1.0 kg at −4.0 m s^{-1}. Find the total momentum. [2]

3 Exam-style questions

3.1 Momentum is a [1]

- **A** scalar with the same direction as force
- **B** vector in the direction of the velocity
- **C** scalar equal to mv^2
- **D** vector opposite to the velocity

3.2 Two objects have equal momentum. The one with the greater mass has the [1]

- **A** greater speed
- **B** smaller speed
- **C** same speed
- **D** greater kinetic energy

3.3 A 0.16 kg ball moving at +5.0 m s^{-1} bounces straight back at −3.0 m s^{-1}.

(a) Find its momentum before the bounce. [1]

(b) Find its momentum after the bounce. [1]

(c) State the change in momentum. [1]

Solutions

2.1 $p = mv = 0.50 \times 8.0 = 4.0$ kg m s^{-1}.

2.2 $v = \dfrac{p}{m} = \dfrac{18\,000}{1200} = 15$ m s^{-1}.

2.3 $p = (3.0)(+2.0) + (1.0)(-4.0) = +6.0 - 4.0 = +2.0$ kg m s^{-1}.

3.1 B.

3.2 B — for equal mv, larger m means smaller v.

3.3 (a) $p_i = 0.16 \times (+5.0) = +0.80$ kg m s^{-1}. (b) $p_f = 0.16 \times (-3.0) = -0.48$ kg m s^{-1}. (c) $\Delta p = -0.48 - 0.80 = -1.28$ kg m s^{-1}.

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

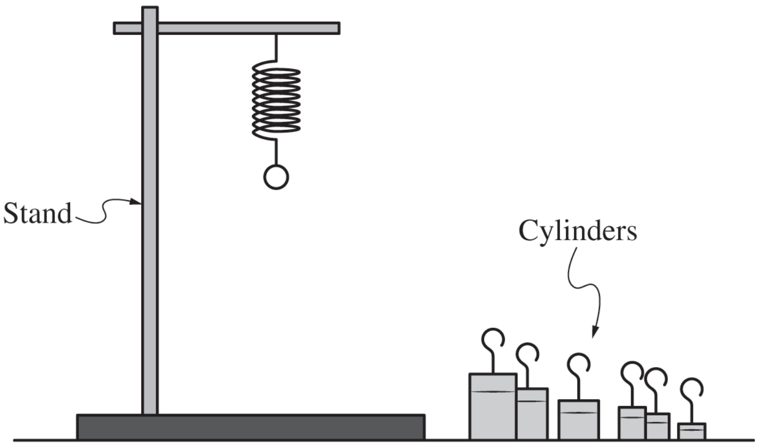

Figure 1

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.

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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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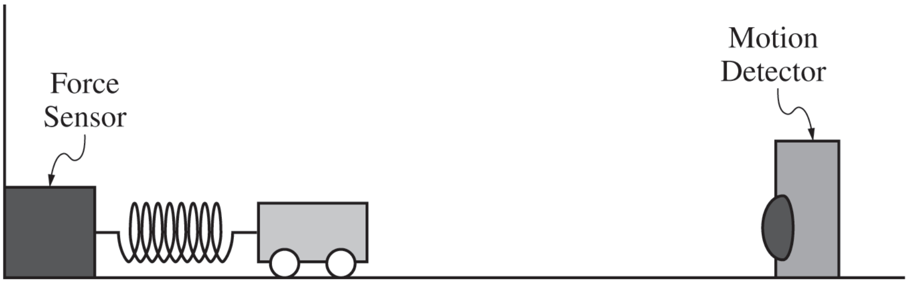
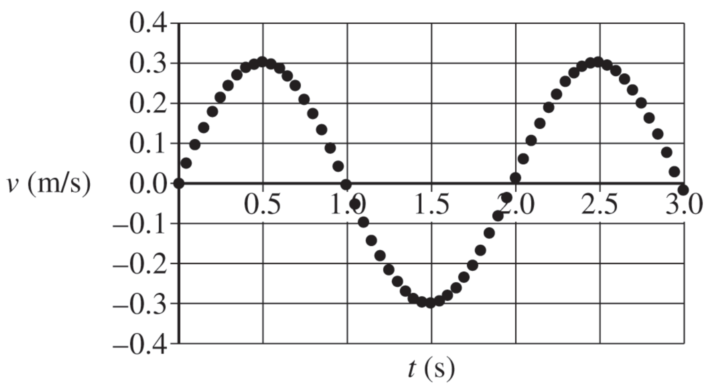
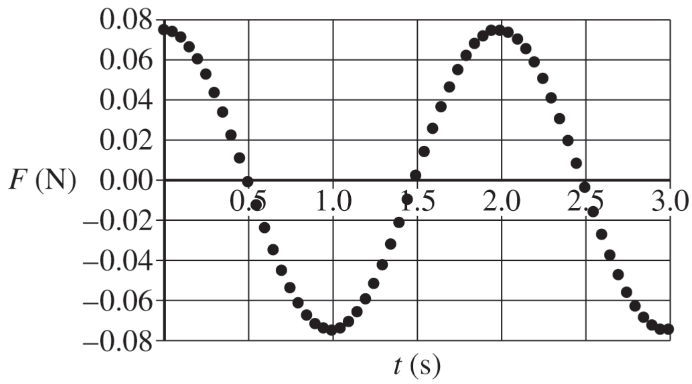


Figure 2

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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AP PHYSICS 1 • EXERCISE SHEET

4.2 Change in Momentum and Impulse

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

KEY WORDS impulse冲量 • contact time接触时间

Objective

Build the skills to answer exam questions on **change in momentum and impulse**.

You must be able to:

- define **impulse** 冲量 as $\vec{J} = \vec{F}_{net}\,\Delta t$
- state the **impulse-momentum theorem** 冲量-动量定理, $\vec{J} = \Delta\vec{p}$
- find the impulse from the **area** under a force-versus-time graph
- explain how a longer **contact time** 接触时间 reduces the average force

1 Worked examples

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

Impulse changes momentum

$\vec{J} = \vec{F}_{net}\,\Delta t = \Delta\vec{p}$, measured in N s (the same as kg m s^{-1}).

Longer time means smaller force

For a fixed change in momentum, a **longer** contact time gives a **smaller** average force. This is why airbags, crumple zones, and bending your knees on landing reduce injury.

Example

A 0.50 kg ball changes velocity from +4.0 to −2.0 m s^{-1}: $\Delta p = 0.50(-2.0 - 4.0) = -3.0$ N s.

2 Practice

2.1 A 2.0 kg object's velocity increases by +3.0 m s^{-1}. Find the impulse on it. [1]

2.2 A 6.0 N force acts for 0.50 s. Find the impulse. [1]

2.3 Explain why a longer stopping time reduces the force on a passenger in a car crash. [2]

2.4 A 0.10 kg ball hits a wall at 8.0 m s^{-1} and rebounds at 6.0 m s^{-1}. Taking "toward the wall" as positive, find the impulse on the ball. [2]

3 Exam-style questions

3.1 Impulse is equal to [1]

- **A** $F\,\Delta t$
- **B** ma
- **C** $\frac{1}{2}mv^2$
- **D** mgh

3.2 An airbag protects a passenger by increasing the [1]

- **A** momentum change
- **B** total impulse
- **C** contact time of the collision
- **D** kinetic energy

3.3 A 0.058 kg tennis ball leaves a racket at 50 m s^{-1} from rest, with a contact time of 5.0 ms.

(a) Find the impulse on the ball. [2]

(b) Find the average force during contact. [1]

Solutions

2.1 $J = \Delta p = m\,\Delta v = 2.0 \times 3.0 = 6.0$ N s.

2.2 $J = F\,\Delta t = 6.0 \times 0.50 = 3.0$ N s.

2.3 A longer time for the same momentum change means a smaller average force, since $F = \Delta p/\Delta t$; a smaller force means less injury.

2.4 $\Delta p = 0.10(-6.0) - 0.10(+8.0) = -1.4$ N s.

3.1 **A**.

3.2 **C**.

3.3 (a) $J = \Delta p = 0.058 \times 50 = 2.9$ N s. (b) $F = \dfrac{J}{\Delta t} = \dfrac{2.9}{5.0 \times 10^{-3}} = 580$ N.

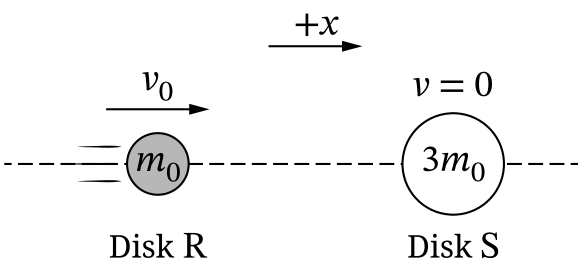
Question 2: Version J

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

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

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

Figure 1



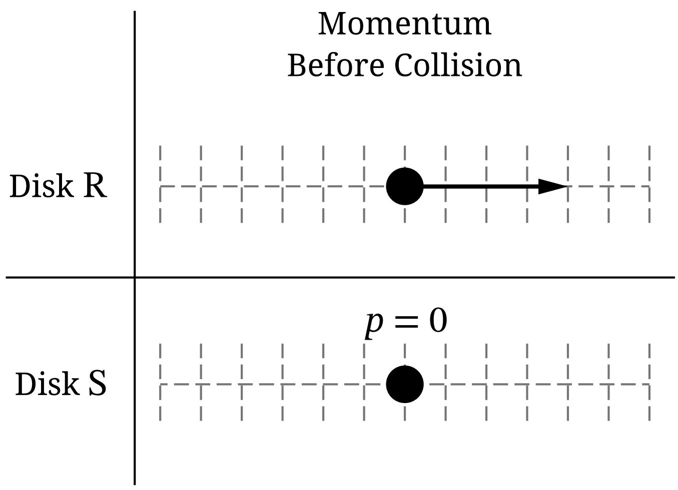
Top View

Note: Figure not drawn to scale.

Part A

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

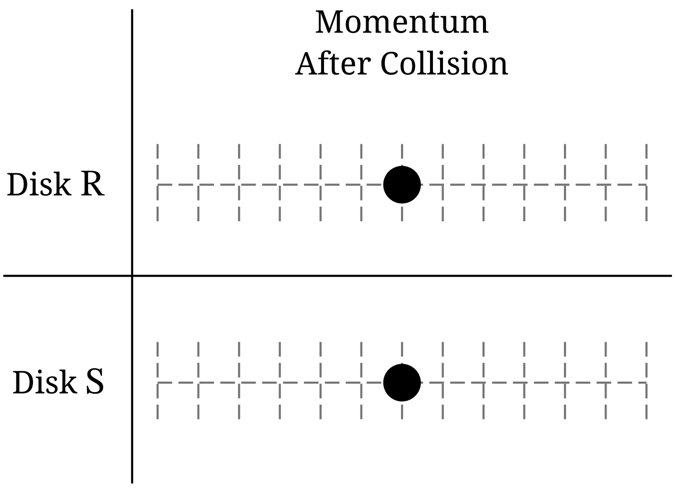
Figure 2



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

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

Figure 3



Part B

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

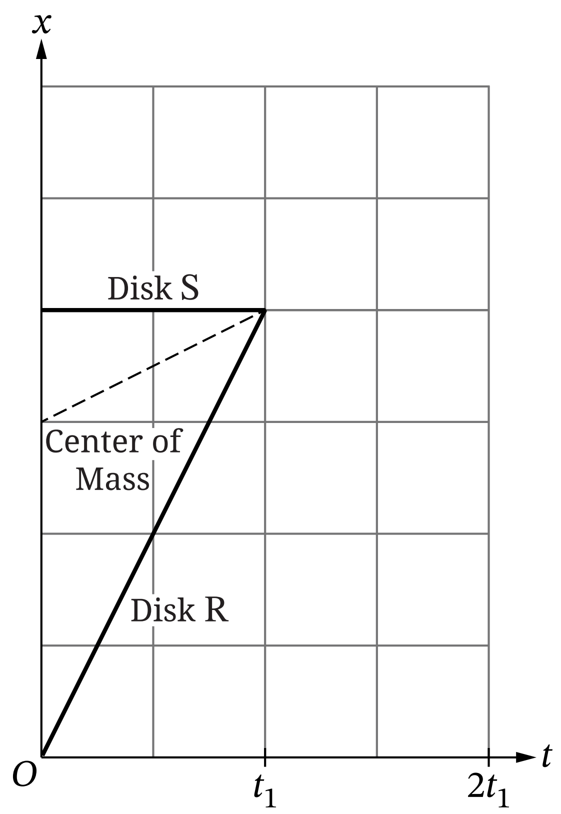
Part C

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

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

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

Figure 4



Part D

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

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

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

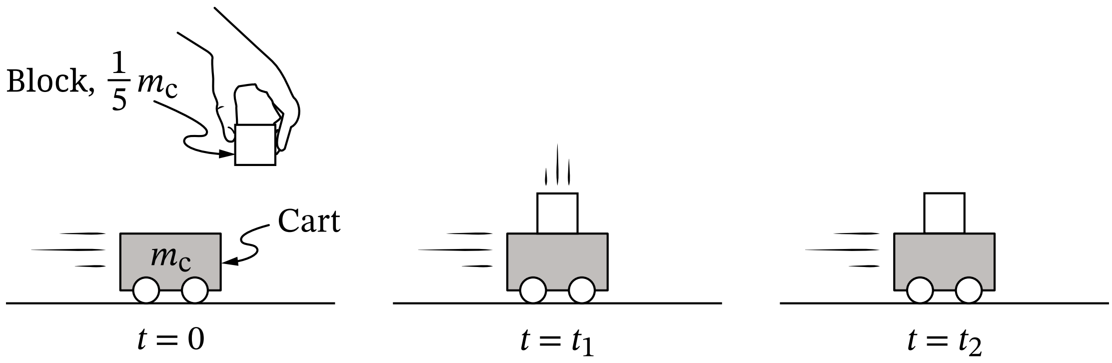
Briefly **justify** your response by referencing a fundamental physics principle.

Question 1: Version J

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

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

Figure 1



A.

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

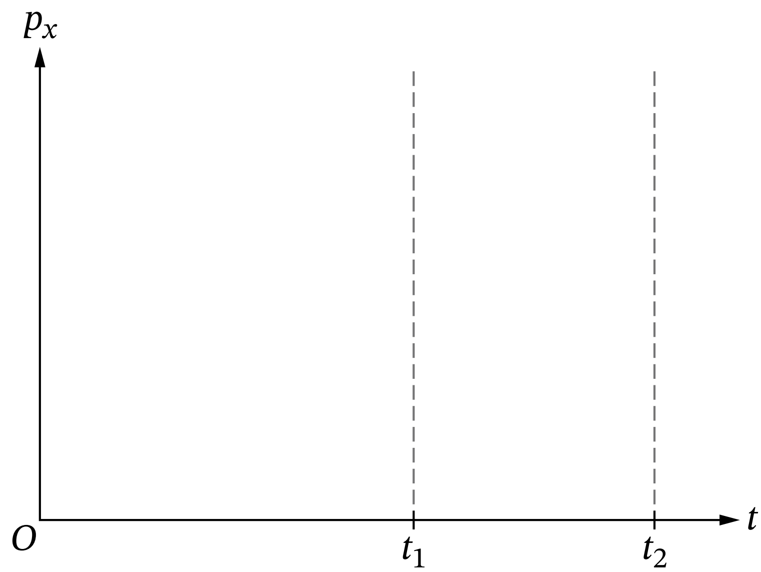


Figure 2

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

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

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

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

______ Increases

______ Decreases

______ Remains constant

Justify your response.

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

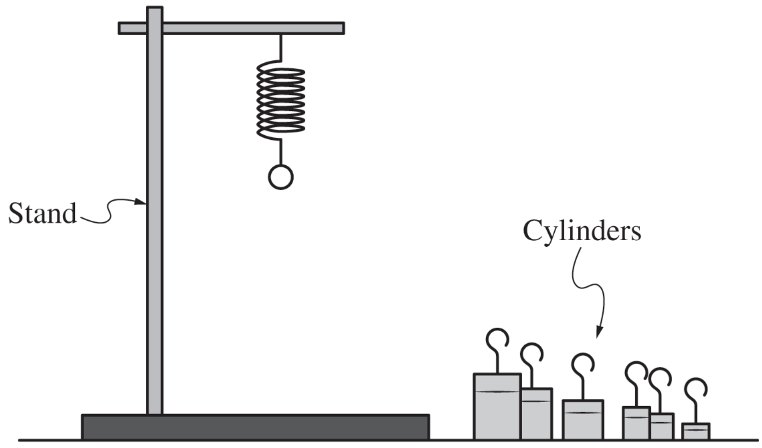


Figure 1

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.

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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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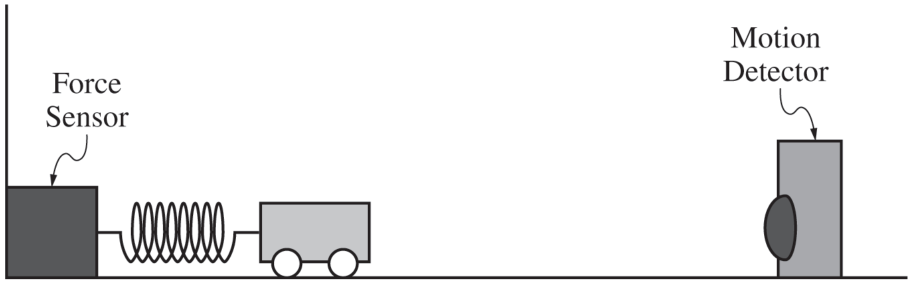
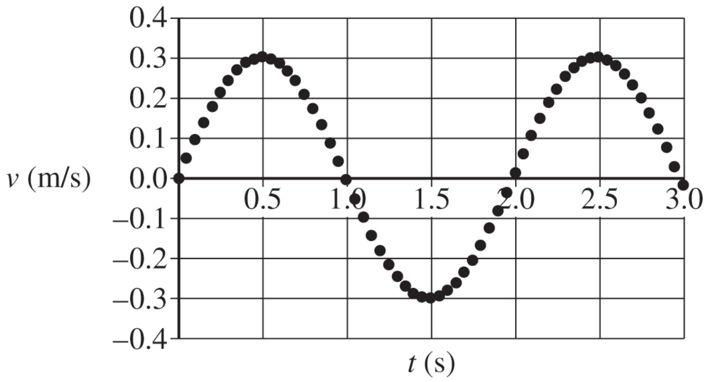
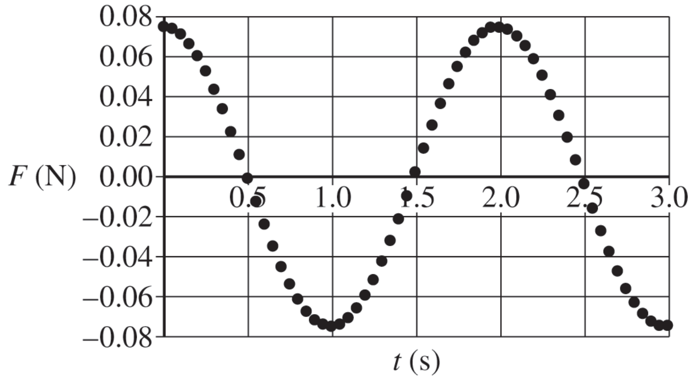


Figure 2

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

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





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

(c)

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

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

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

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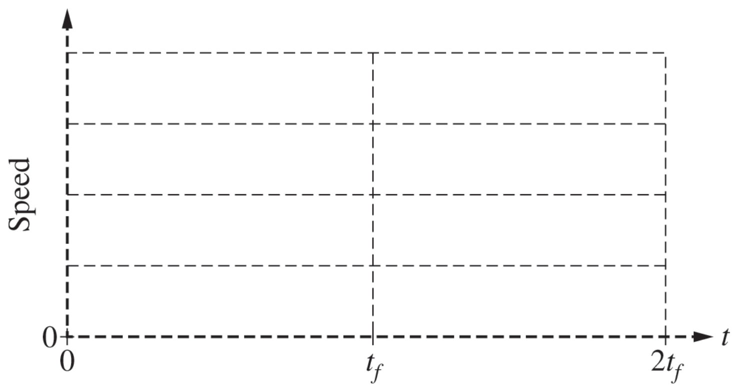
3. (12 points, suggested time 25 minutes)

(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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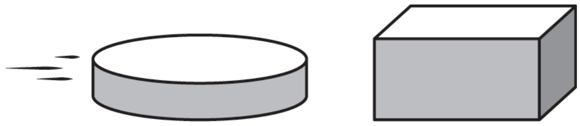

Disk Block

(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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4.3 Conservation of Linear Momentum

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

KEY WORDS collisions 碰撞 • conserved 守恒 • recoil 反冲 • isolated system 孤立系统 • explosions 爆炸

Objective

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

You must be able to:

- state that the total momentum of an **isolated system 孤立系统** is constant
- identify an isolated system as one with **zero net external force**
- explain that **internal forces 内力** cannot change a system's total momentum
- apply conservation of momentum to **collisions 碰撞** and **explosions 爆炸** in one dimension

1 Worked examples

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

■ Conservation of momentum

When the net external force is zero, $\sum p_{\text{before}} = \sum p_{\text{after}}$.

■ Explosions

An object at rest has zero total momentum, so after it bursts apart the fragments carry **equal and opposite** momenta that still sum to zero.

■ Example (collision)

A 2.0 kg cart at 3.0 m s^{-1} strikes a stationary 1.0 kg cart and they stick:

$$2.0(3.0) = (2.0 + 1.0)v \Rightarrow v = 2.0 \text{ m s}^{-1}.$$

2 Practice

2.1 State the condition for the total momentum of a system to be conserved. [1]

2.2 A 3.0 kg cart at 4.0 m s^{-1} hits a stationary 1.0 kg cart and they couple together. Find their common speed. [2]

2.3 A stationary 5.0 kg object explodes into two pieces; a 2.0 kg piece flies off at +6.0 m s^{-1}. Find the velocity of the 3.0 kg piece. [2]

3 Exam-style questions

3.1 The total momentum of a system is conserved when [1]

- **A** kinetic energy is conserved
- **B** the net external force is zero
- **C** there is no friction anywhere
- **D** the velocity is constant

3.2 A 2.0 kg rifle fires a 0.010 kg bullet at 400 m s^{-1}. The rifle recoils at [1]

- **A** 2.0 m s^{-1}
- **B** 4.0 m s^{-1}
- **C** 0.5 m s^{-1}
- **D** 8.0 m s^{-1}

3.3 A 60 kg astronaut, initially at rest in space, throws a 2.0 kg tool at 5.0 m s^{-1}.

(a) Find the astronaut's recoil speed. [2]

(b) State the direction of the recoil relative to the tool. [1]

Solutions

2.1 the net external force on the system must be zero.

2.2 $3.0(4.0) = (3.0 + 1.0)v \Rightarrow v = \dfrac{12}{4.0} = 3.0\ \text{m s}^{-1}$.

2.3 $0 = 2.0(+6.0) + 3.0\,v \Rightarrow v = \dfrac{-12}{3.0} = -4.0\ \text{m s}^{-1}$.

3.1 **B**.

3.2 **A** — $0 = 0.010(400) + 2.0\,v \Rightarrow v = -2.0\ \text{m s}^{-1}$.

3.3 (a) $0 = 2.0(5.0) + 60\,v \Rightarrow v = \dfrac{-10}{60} = -0.17\ \text{m s}^{-1}$, i.e. $0.17\ \text{m s}^{-1}$. (b) opposite to the tool's direction.

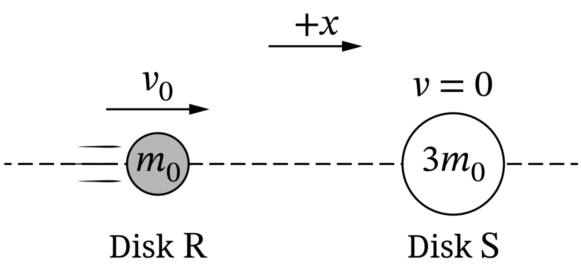
Question 2: Version J

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



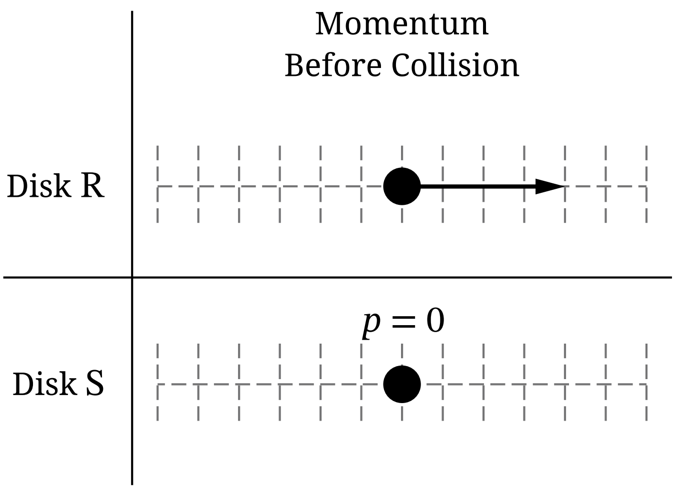
Top View

<u>Note</u>: Figure not drawn to scale.

Part A

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

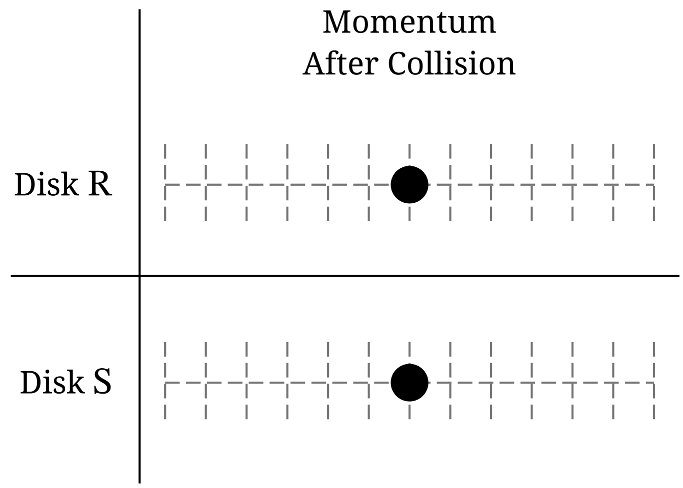
Figure 2



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

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

Figure 3



Part B

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

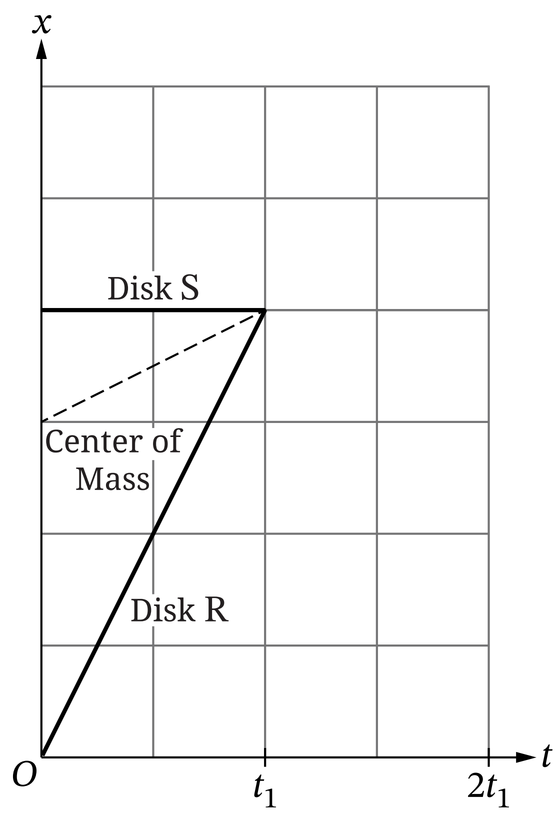
Part C

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

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

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

Figure 4



Part D

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

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

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

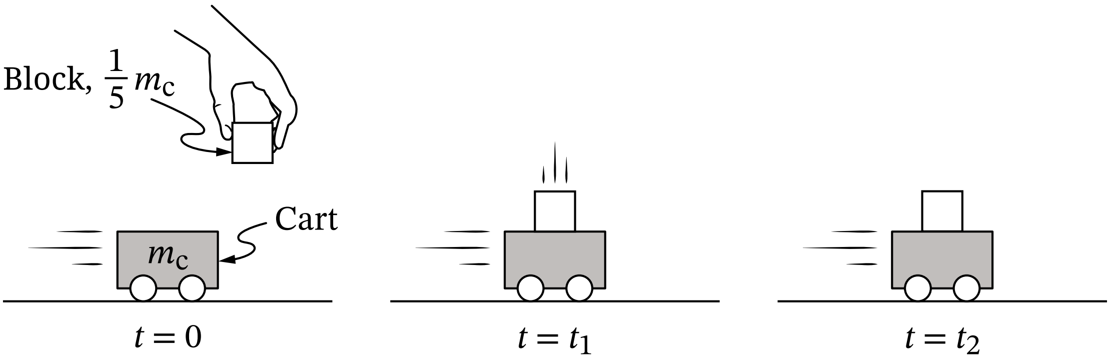
Briefly **justify** your response by referencing a fundamental physics principle.

Question 1: Version J

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

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

Figure 1



A.

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

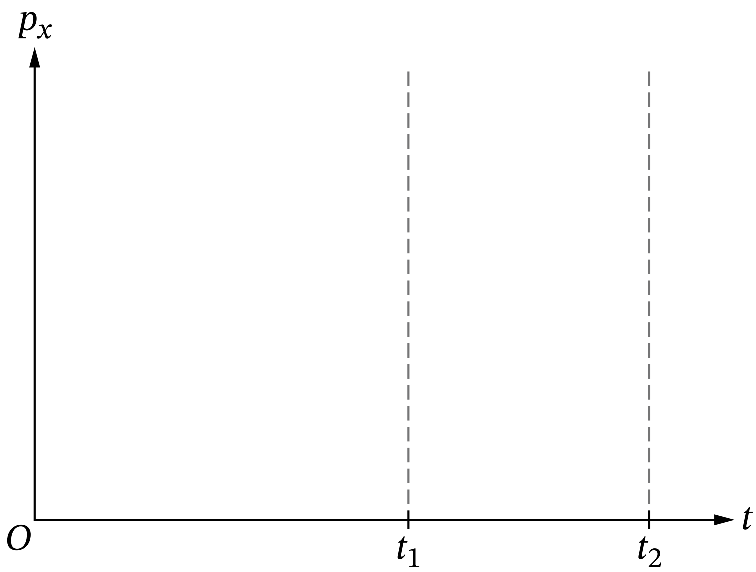


Figure 2

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

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

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

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

______ Increases

______ Decreases

______ Remains constant

Justify your response.

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

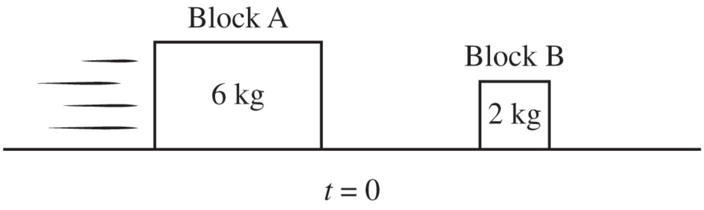


Figure 1

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.

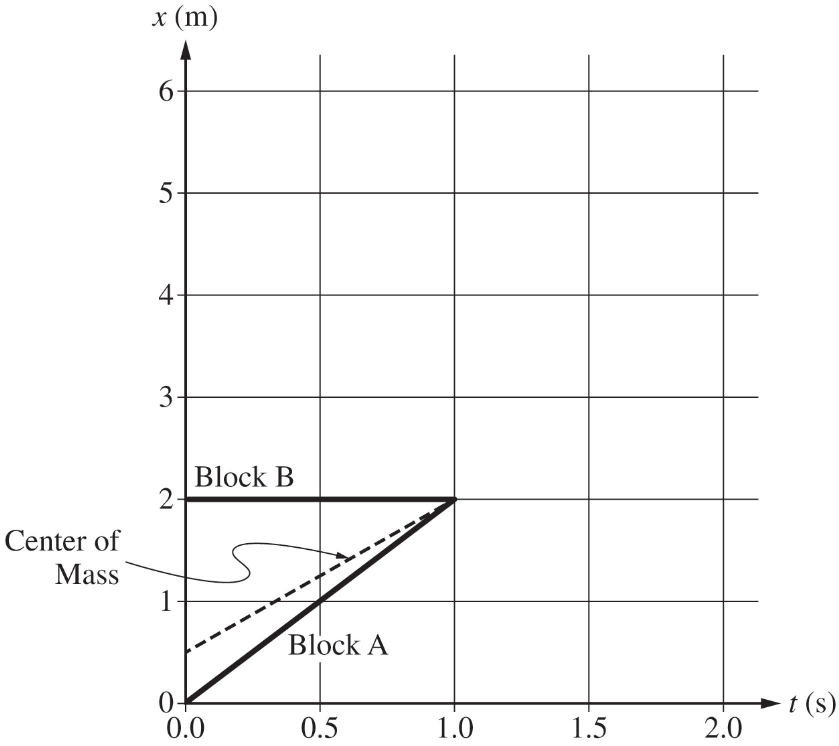


Figure 2

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.

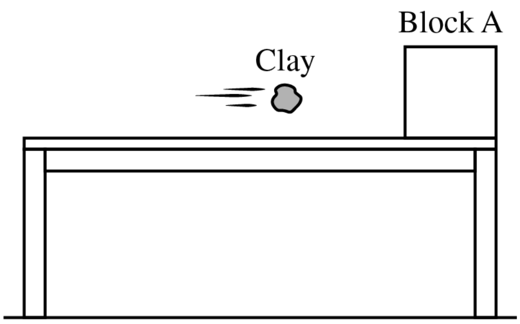
STOP

END OF EXAM

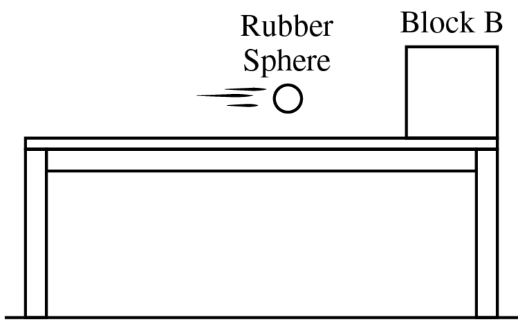
. (7 points, suggested time 13 minutes)

A student has a piece of clay and a rubber sphere, both of the same mass. Both objects are thrown horizontally at the same speed at identical blocks that are at rest at the edge of identical tables, as shown, where friction between the blocks and the table is negligible. After the collisions, both blocks fall to the floor.

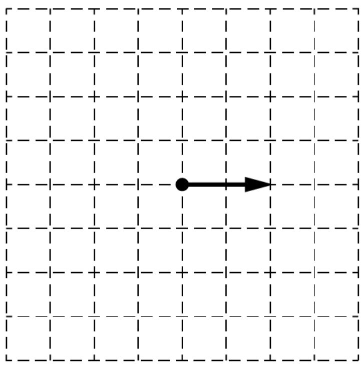
In Case A, the clay sticks to Block A after the collision. In Case B, the rubber sphere bounces off of Block B after the collision.



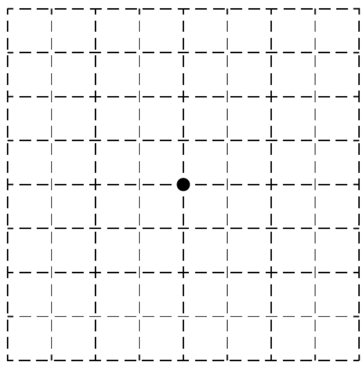
Case A: Clay and Block A
Before Collision



Case B: Rubber Sphere and Block B
Before Collision



Case A: Momentum of
Clay-Block System
Immediately After Collision



Case B: Momentum of
Sphere-Block System
Immediately After Collision

(a) In the figure at left above, the arrow represents the momentum immediately after the collision for the clay-block system in Case A. In the figure at right above, draw an arrow starting on the dot to represent the momentum of the sphere-block system immediately after the collision in Case B. If the momentum is zero, write "zero" next to the dot. The momentum, if it is not zero, must be represented by an arrow starting on, and pointing away from, the dot. The length of the vector, if not zero, should reflect the magnitude of the momentum relative to Case A.

GO ON TO THE NEXT PAGE.

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

(b) After the clay and Block A collide, Block A lands a horizontal distance d_A from the edge of the table. Does Block B land on the floor at a horizontal distance from the edge of the table that is greater than, less than, or equal to d_A ? In a clear, coherent, paragraph-length response that may also contain equations and/or drawings, explain your reasoning. Neglect any frictional effects due to the table or air resistance.

GO ON TO THE NEXT PAGE.

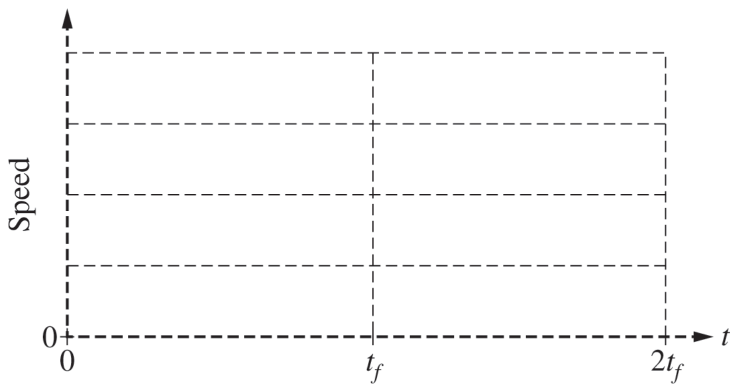
3. (12 points, suggested time 25 minutes)

(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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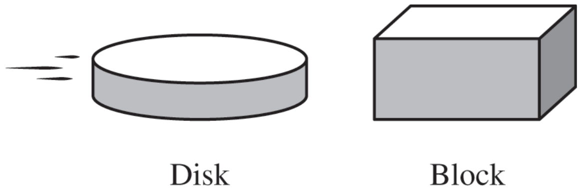


(c) The disk is now moving at a constant speed v_1 on the surface toward a block of mass M_B, which is at rest on the surface, as shown above. The disk and block collide head-on and stick together, and the center of mass of the disk-block system moves with speed v_{cm}.

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.

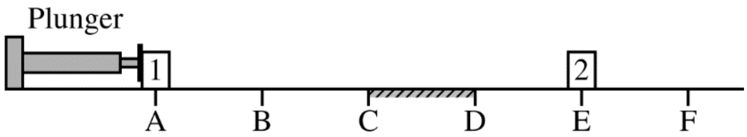
PHYSICS 1

Section II

Time—1 hour and 30 minutes

5 Questions

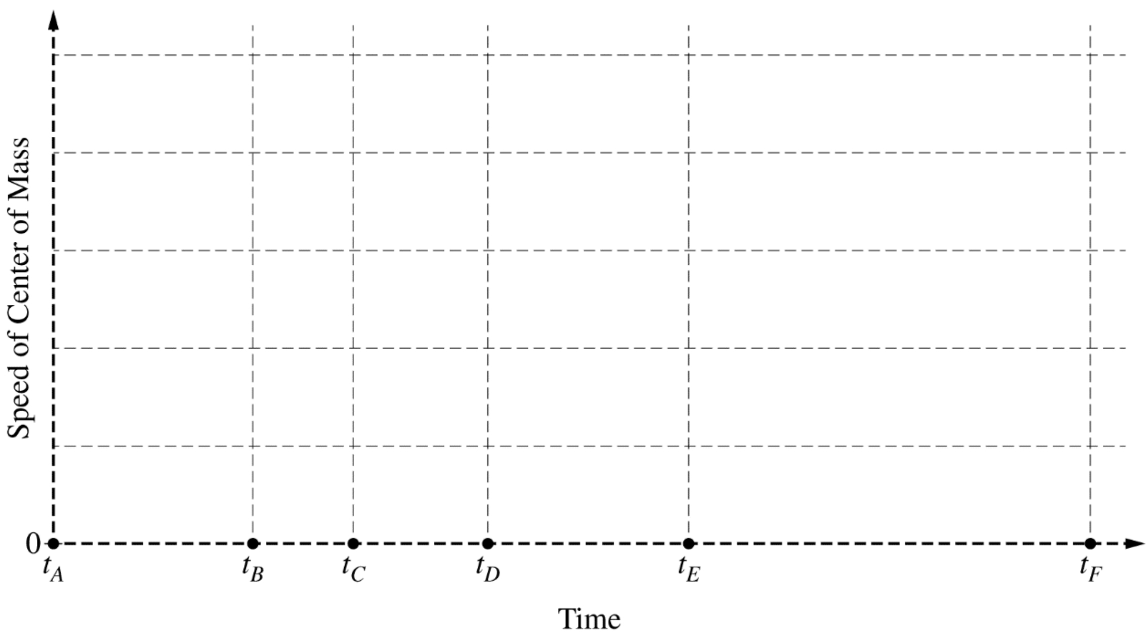
Directions: Questions 1, 4, and 5 are short free-response questions that require about 13 minutes each to answer and are worth 7 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the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

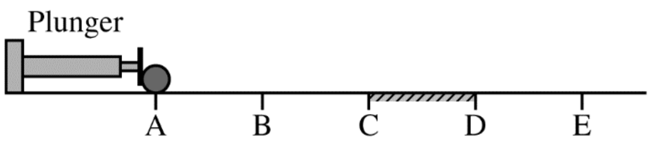


1. (7 points, suggested time 13 minutes)

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 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 new kind of toy ball is advertised to "bounce perfectly elastically" off hard surfaces. A student suspects, however, that no collision can be perfectly elastic. The student hypothesizes that the collisions are very close to being perfectly elastic for low-speed collisions but that they deviate more and more from being perfectly elastic as the collision speed increases.

(a) Design an experiment to test the student's hypothesis about collisions of the ball with a hard surface. The student has equipment that would usually be found in a school physics laboratory.

i. What quantities would be measured?

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

iii. Describe the procedure to be used to test the student's hypothesis. Give enough detail so that another student could replicate the experiment.

(b) Describe how you would represent the data in a graph or table. Explain how that representation would be used to determine whether the data are consistent with the student's hypothesis.

(c) A student carries out the experiment and analysis described in parts (a) and (b). The student immediately concludes that something went wrong in the experiment because the graph or table shows behavior that is elastic for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

i. Give an example of a graph or table that indicates nearly elastic behavior for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

ii. State one physics principle that appears to be violated in the graph or table given in part (c)i. Several physics principles might appear to be violated, but you only need to identify one.

Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.

4.4 Elastic and Inelastic Collisions

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

KEY WORDS elastic collision 弹性碰撞 • inelastic collision 非弹性碰撞 • perfectly inelastic collision 完全非弹性碰撞 • collisions 碰撞 • conserved 守恒

Objective

Build the skills to answer exam questions on **elastic and inelastic collisions**.

You must be able to:

- distinguish an **elastic collision 弹性碰撞** (kinetic energy conserved) from an **inelastic collision 非弹性碰撞**
- describe a **perfectly inelastic collision 完全非弹性碰撞** (objects stick and move with a common velocity)
- apply **conservation of momentum** to find final velocities
- check whether **kinetic energy** is conserved

1 Worked examples

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

■ Momentum is always conserved; energy is not

In **every** collision (no external force), momentum is conserved. Kinetic energy is conserved only in an **elastic** collision; in an inelastic one, some becomes thermal energy.

■ Perfectly inelastic collision

The objects stick: $m_1u_1 + m_2u_2 = (m_1 + m_2)v$.

■ Example

A 2.0 kg cart at 3.0 m s^{-1} sticks to a stationary 2.0 kg cart: $v = \dfrac{2.0(3.0)}{4.0} = 1.5$ m s^{-1}. KE before = 9.0 J, after = $\frac{1}{2}(4.0)(1.5)^2 = 4.5$ J → 4.5 J lost to heat (inelastic).

2 Practice

2.1 State what is conserved in (a) an elastic collision and (b) an inelastic collision. [2]

2.2 A 1.0 kg ball at 6.0 m s^{-1} strikes a stationary 2.0 kg ball and they stick together. Find their common speed. [2]

2.3 For the collision in 2.2, find the kinetic energy lost. [2]

3 Exam-style questions

3.1 In a perfectly inelastic collision, the objects [1]

- **A** bounce apart
- **B** stick together
- **C** conserve kinetic energy
- **D** reverse direction

3.2 Kinetic energy is conserved in [1]

- **A** all collisions
- **B** elastic collisions only
- **C** inelastic collisions only
- **D** explosions only

3.3 A 0.50 kg cart at 4.0 m s^{-1} hits a stationary 0.50 kg cart, and they move off together.

(a) Find their common velocity. [2]

(b) By calculating the kinetic energy before and after, state whether the collision is elastic. [2]

Solutions

2.1 (a) both momentum and kinetic energy; (b) momentum only.

2.2 $1.0(6.0) = (1.0 + 2.0)v \Rightarrow v = 2.0\ \mathrm{m\ s^{-1}}$.

2.3 KE before $= \frac{1}{2}(1.0)(6.0)^2 = 18$ J; after $= \frac{1}{2}(3.0)(2.0)^2 = 6.0$ J; lost $= 12$ J.

3.1 B.

3.2 B.

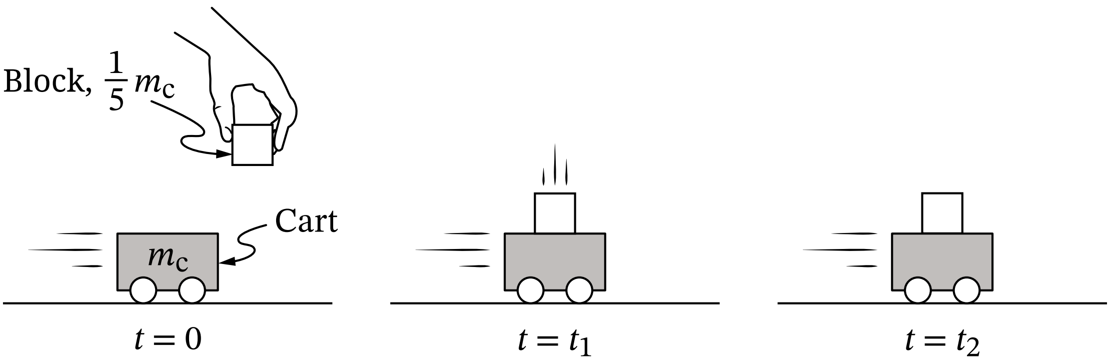
3.3 (a) $0.50(4.0) = (1.0)v \Rightarrow v = 2.0\ \mathrm{m\ s^{-1}}$. (b) KE before $= \frac{1}{2}(0.50)(4.0)^2 = 4.0$ J; after $= \frac{1}{2}(1.0)(2.0)^2 = 2.0$ J; not conserved, so it is **inelastic**.

Question 1: Version J

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

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

Figure 1



A.

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

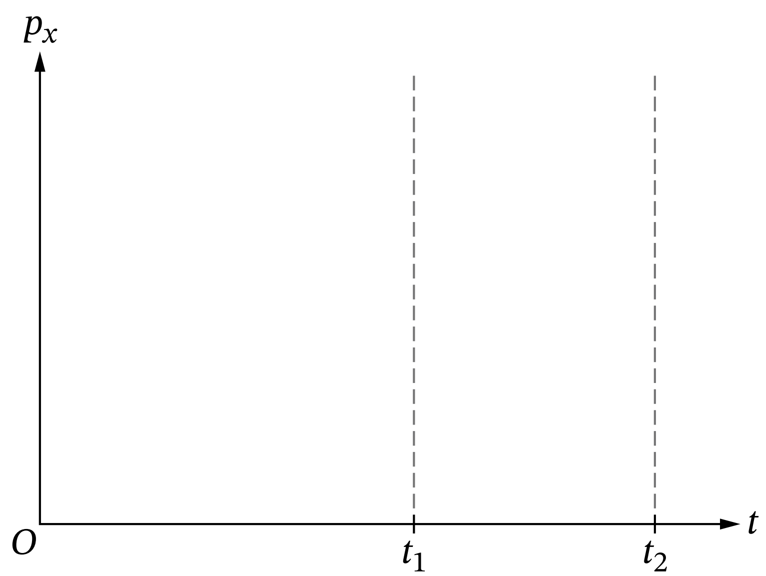


Figure 2

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

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

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

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

______ Increases

______ Decreases

______ Remains constant

Justify your response.

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

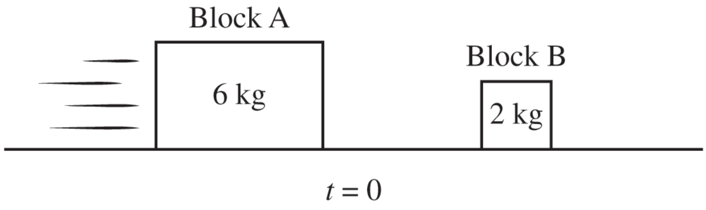


Figure 1

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.

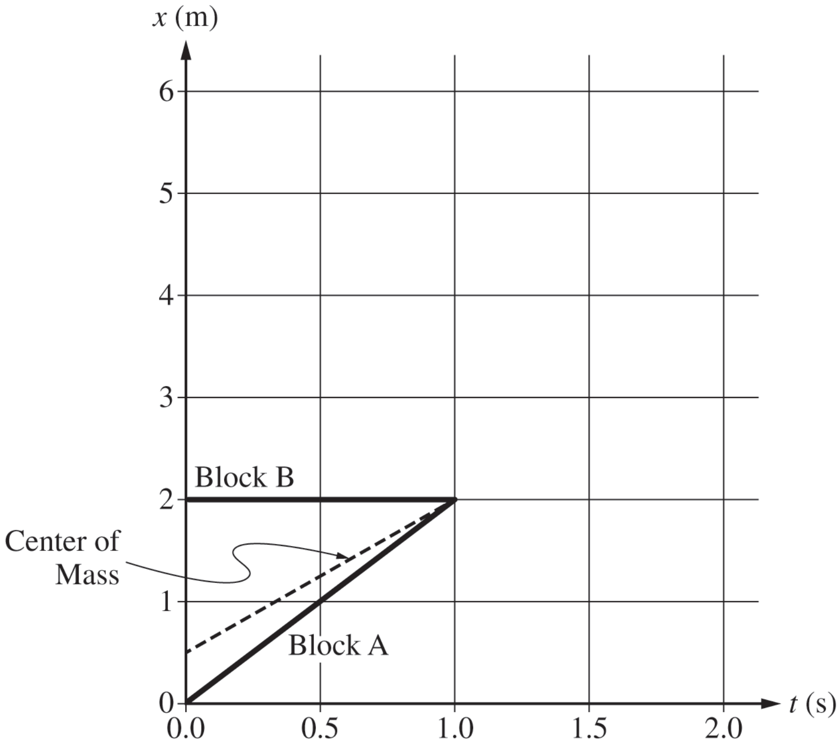


Figure 2

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.

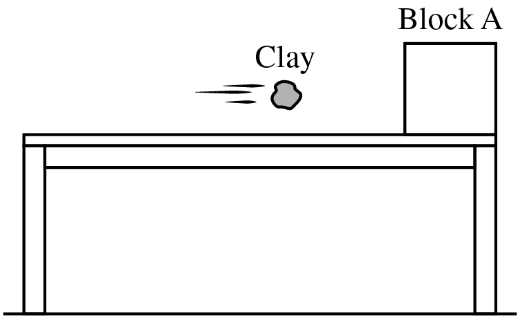
STOP

END OF EXAM

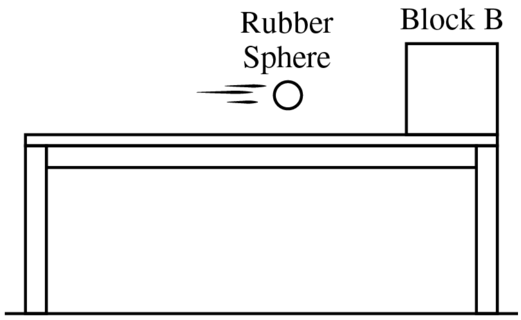
. (7 points, suggested time 13 minutes)

A student has a piece of clay and a rubber sphere, both of the same mass. Both objects are thrown horizontally at the same speed at identical blocks that are at rest at the edge of identical tables, as shown, where friction between the blocks and the table is negligible. After the collisions, both blocks fall to the floor.

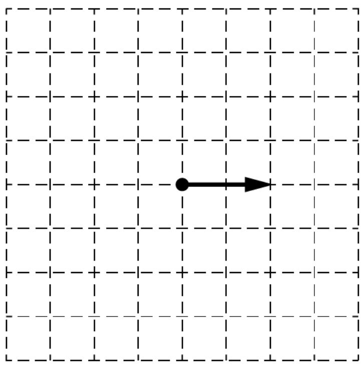
In Case A, the clay sticks to Block A after the collision. In Case B, the rubber sphere bounces off of Block B after the collision.



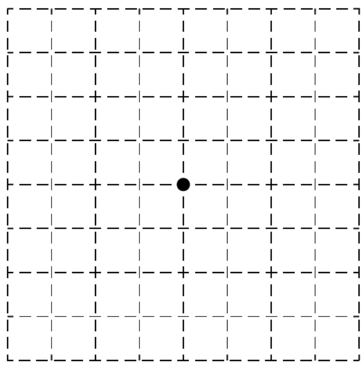
Case A: Clay and Block A
Before Collision



Case B: Rubber Sphere and Block B
Before Collision



Case A: Momentum of
Clay-Block System
Immediately After Collision



Case B: Momentum of
Sphere-Block System
Immediately After Collision

(a) In the figure at left above, the arrow represents the momentum immediately after the collision for the clay-block system in Case A. In the figure at right above, draw an arrow starting on the dot to represent the momentum of the sphere-block system immediately after the collision in Case B. If the momentum is zero, write “zero” next to the dot. The momentum, if it is not zero, must be represented by an arrow starting on, and pointing away from, the dot. The length of the vector, if not zero, should reflect the magnitude of the momentum relative to Case A.

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

(b) After the clay and Block A collide, Block A lands a horizontal distance d_A from the edge of the table. Does Block B land on the floor at a horizontal distance from the edge of the table that is greater than, less than, or equal to d_A ? In a clear, coherent, paragraph-length response that may also contain equations and/or drawings, explain your reasoning. Neglect any frictional effects due to the table or air resistance.

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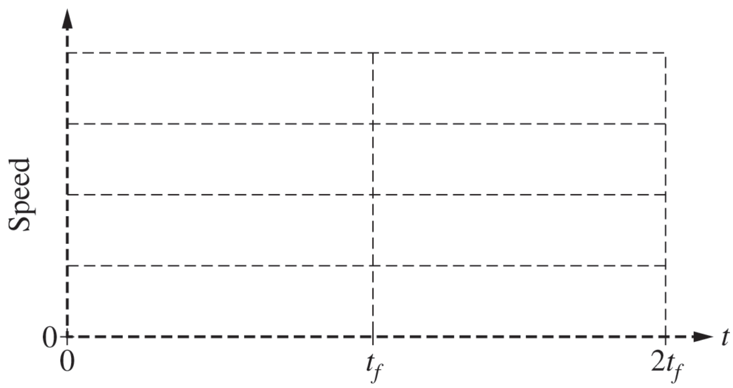
3. (12 points, suggested time 25 minutes)

(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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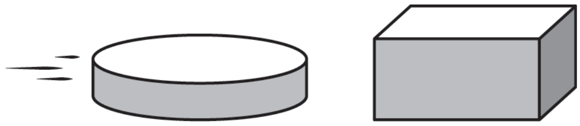

Disk Block

(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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2. (12 points, suggested time 25 minutes)

A new kind of toy ball is advertised to “bounce perfectly elastically” off hard surfaces. A student suspects, however, that no collision can be perfectly elastic. The student hypothesizes that the collisions are very close to being perfectly elastic for low-speed collisions but that they deviate more and more from being perfectly elastic as the collision speed increases.

(a) Design an experiment to test the student’s hypothesis about collisions of the ball with a hard surface. The student has equipment that would usually be found in a school physics laboratory.

i. What quantities would be measured?

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

iii. Describe the procedure to be used to test the student’s hypothesis. Give enough detail so that another student could replicate the experiment.

(b) Describe how you would represent the data in a graph or table. Explain how that representation would be used to determine whether the data are consistent with the student’s hypothesis.

(c) A student carries out the experiment and analysis described in parts (a) and (b). The student immediately concludes that something went wrong in the experiment because the graph or table shows behavior that is elastic for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

i. Give an example of a graph or table that indicates nearly elastic behavior for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

ii. State one physics principle that appears to be violated in the graph or table given in part (c)i. Several physics principles might appear to be violated, but you only need to identify one.

Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.