1. A hand pushes two blocks, block A and block B, along a frictionless table for a distance \(d\). The mass of block A is greater than the mass of block B \((m_A > m_B)\).

a. Draw a free-body diagram for each block.

<table>
<thead>
<tr>
<th>Free-body diagram for block A</th>
<th>Free-body diagram for block B</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

- Does block A do work on block B?
- Does block B do work on block A?

If each block does work on the other, how do the works compare in magnitude and in sign? Explain.

b. How does the net force on block A compare to the net force on block B? Explain.

What does your result suggest about how the net work done on block A compares to the net work done on block B? Explain.

c. How do the final kinetic energies of the blocks compare? *Base your answer on the work-energy theorem* and your answer to part b above.

d. When the hand starts to push, the blocks are moving with a speed of 2 m/s. Suppose that the work done on block A by the hand during a given displacement is 10 J. Determine the final kinetic energy of each block. Use \(m_A = 4\) kg, \(m_B = 1\) kg. Show your work.
2. An object moves clockwise along the trajectory shown in the top-view diagram below. The acceleration varies, but is always directed toward point $K$.

   a. Draw and label arrows on the diagram at points $A$--$G$ to indicate:

      - the direction of the velocity of the object, and
      - the direction of the net force on the object.

   Top view diagram

   Explain how you knew to draw the arrows as you did.

   b. For points $B$, $D$, and $G$, determine whether the object is speeding up, slowing down, or moving at constant speed. Explain your reasoning. *Base your answers on the work-energy theorem.*
3. A block is placed on an elevator platform that moves downward with decreasing speed. Consider the time interval $\Delta t$, in which the speed of the platform changes from $v_p$ to zero.

a. In the space provided, sketch a free-body diagram for the block.

b. Is the net work done on the block positive, negative, or zero?

For each force on the free-body diagram, state whether the work done on the block by that force is positive, negative, or zero. Explain.

Rank the works you identified above in order of decreasing absolute value. Explain.


i. In the spaces provided, draw arrows to indicate the direction of the velocity and the acceleration of the block in reference frame R during the interval $\Delta t$. Explain.

ii. In reference frame R:

- is the block speeding up, slowing down, or moving with constant speed? (Base your answer on the directions of the velocity and acceleration).

- is the change in kinetic energy of the block positive, negative, or zero? Explain.

iii. The work-energy theorem can be applied in any inertial frame of reference. Apply the theorem to determine whether the net work done on the block is positive, negative, or zero in reference frame R. Explain.
iv. In reference frame R, during the interval $\Delta t_o$:

- is the displacement (i.e., change in position) of the block upward, downward, or zero? Explain. (Base your answer on your velocity arrow in part c.i.)

- is the net force on the block upward, downward, or zero? Explain. (Base your answer on your acceleration arrow in part c.i.)

- is the work done on the block by the net force positive, negative, or zero? Explain. (Base your answer on your answers to the previous two questions.)

Make sure your result for the work done on the block by the net force is consistent with your answer to part c.iii.

4. A block is launched up a frictionless ramp, as shown, with initial speed $v_o$. The block travels up the ramp and continues across the level section.

a. List the forces exerted on the block after it has been launched, as it moves up the ramp.

Which forces, if any, do non-zero work on the block?

Which forces, if any, do zero work on the block?

b. Write an expression for the net work done on the block from the bottom to the top of the ramp. Express your answer in terms of one or more of the following quantities: the weight $mg$ of the block, the angle $\theta$, and the height $H$ of the ramp. Show your work.
5. Suppose the block in the previous problem were launched with the same initial speed on the following frictionless ramps. In each case state whether the magnitude of the net work done on the block from the bottom to the top of the ramp is greater than, less than, or equal to the magnitude of the net work done on the block in problem 2. Explain your answer in each case.

a. The ramp is steeper ($\alpha > \theta$).

b. The ramp has two sections of different slope.

c. The ramp has several sections of gradually increasing steepness.

d. The ramp is curved.

Use the work-energy theorem to rank the final speeds of the block on the ramps (a–d), assuming the block is launched with the same initial speed in each case. If the final speeds are the same in any of the cases, state that explicitly. Explain.
1. Ball A leaves the edge of a level table with speed $v_{A_i}$ and falls to the floor. At the instant ball A leaves the table edge, another identical ball, B, is released from rest at the height of the table top and also falls to the floor. It is observed that the balls reach the floor at the same time.

   ![Diagram](image)

   a. In each question below, consider the interval that begins when the balls begin falling and ends just before they reach the floor.

   i. Is the magnitude of the impulse imparted to ball B greater than, less than, or equal to the magnitude of the impulse imparted to ball A? Explain your reasoning.

   ii. In the spaces provided at right, draw an arrow to indicate the direction of the impulse imparted to each ball. Explain your reasoning.

   iii. Is the work done on ball B greater than, less than, or equal to the work done on ball A? Explain your reasoning.

b. In each question below, consider the balls just before they reach the floor.

   i. Is the magnitude of the momentum of ball B greater than, less than, or equal to the magnitude of the momentum of ball A? Explain your reasoning.

   ii. Is the kinetic energy of ball B greater than, less than, or equal to the kinetic energy of ball A? Explain your reasoning.
2. Two identical pucks slide across a level, frictionless table. Initially, the pucks have the same speed, but their velocities are perpendicular to each other as shown.

The same constant force is exerted on each puck for the same interval of time: from the instant shown until puck 1 crosses the second dotted line. The pucks remain on the table and do not collide during this time interval.

a. When puck 1 crosses the second dotted line, is puck 2 to the left of, to the right of, or crossing the second dotted line? Explain how you can tell.

In the diagram above, sketch the trajectory of each of the pucks. Explain how you decided to draw the trajectories the way you did.

b. When puck 1 crosses the second dotted line, is the magnitude of its momentum greater than, less than, or equal to the magnitude of the momentum of puck 2 at the same instant? Explain the reasoning you used in making this comparison.

c. When puck 1 crosses the second dotted line, is the kinetic energy of puck 1 greater than, less than, or equal to the kinetic energy of puck 2 at the same instant? Explain the reasoning you used in making this comparison.
1. Two gliders are on a frictionless, level air track. Initially, glider A moves to the right and glider B is at rest. After the collision, glider A has reversed direction and moves to the left. System C consists of both gliders A and B.

The mass of glider A is one-fourth the mass of glider B.

a. Draw an arrow for each glider and for system C to represent the direction of the change in momentum in this collision. Explain how you determined your answer.

Is the magnitude of the change in momentum vector for glider A greater than, less than, or equal to the magnitude of the change in momentum vector for glider B? Explain.

b. Draw an arrow for each glider to represent the direction of the change in velocity from before to after the collision. Explain how you determined your answer.

Is the magnitude of the change in velocity vector for glider A greater than, less than, or equal to the magnitude of the change in velocity vector for glider B? Explain.

c. Consider the following incorrect statement:

"Glider B will move to the right after this collision, but it would move faster if glider A were to come to a stop, giving glider B all its momentum."

Describe what is incorrect about this statement and explain how you can tell.
2. a. A firecracker is at rest on a frictionless horizontal table. The firecracker explodes into two pieces of unequal mass that move in opposite directions on the table.

   i. Is the net force on the left piece always zero? Explain.

   ii. Is the net force on the system consisting of both pieces always zero? Explain.

   iii. Is the momentum of the left piece conserved? Explain.

   iv. Is the momentum of the system consisting of both pieces conserved? Explain.

b. A block slides down a frictionless incline. The incline is fixed in place on a table.

   i. Is the net force on the block always zero? Explain.

   ii. Is the net force on the incline always zero? Explain.

   iii. Is the net force on the block-incline system always zero? *Hint: Draw free-body diagrams for the block, incline, and system consisting of both objects.*) Explain.

   iv. Is the momentum of the block conserved? Explain.

   v. Is the momentum of the incline conserved? Explain.

   vi. Is the momentum of the block-incline system conserved? Explain.
c. Suppose the incline in part b is now placed on a frictionless table.
   i. Is the net force on the block always zero? Explain.

   ii. Is the net force on the incline always zero? Explain.

   iii. Is the net force on the block-incline system always zero? Explain.

   iv. Is the momentum of the block conserved? Explain.

   v. Is the momentum of the incline conserved? Explain.

   vi. Is the momentum of the block-incline system conserved? Explain.

d. Two blocks, A and B, are connected by a massless and inextensible string. Their masses are \( m_A = 200 \) g and \( m_B = 400 \) g. The blocks are released from rest. The pulley has negligible mass. Let \( S \) represent the system of blocks A, B, the string, and the pulley.

   i. Is the net force on block A always zero? Explain.

   ii. Is the net force on system \( S \) always zero? Explain.

   iii. Is the momentum of block A conserved? Explain.

   iv. Is the momentum of system \( S \) conserved? Explain.
3. Glider A, of mass \( m \), moves to the right with constant speed \( v_o \) on a frictionless track toward glider B. Glider B has mass \( 2m \) and is initially at rest.

System S consists of gliders A and B.

a. In the spaces provided, draw momentum vectors for glider A, glider B, and system S. Label each vector with its magnitude (express magnitudes in terms of the given quantities \( m \) and \( v_o \)).

Glider X, of mass \( 5m \), (not shown in the diagram) moves to the right with speed \( v \), (i.e., the same speed as glider A) on a second frictionless track parallel to the original track.

b. Apply the Galilean transformation of velocities to determine the velocity vectors of gliders A and B in the reference frame of glider X. Draw the vectors in the space at right. Label each vector with its magnitude. (Express the magnitudes in terms of the given quantities.)

c. Draw momentum vectors of gliders A and B in the reference frame of glider X. Label each vector with its magnitude. Explain your reasoning.

d. Consider the following incorrect statement:

"Glider X has momentum \( 5mv_o \) to the right, so in the reference frame of glider X, the momentum of glider A is \( mv_o - 5mv_o = -4mv_o \) or \( 4mv_o \) to the left."

Explain the error(s) in the reasoning.

Suppose glider X had a different mass (i.e., something other than \( 5m \)). Would the magnitude of the momentum of glider A in the reference frame of glider X be the same as or different than the value you determined in part c? Explain.
CONSERVATION OF MOMENTUM
IN ONE DIMENSION

e. Use your momentum vectors from part c to determine the magnitude and direction of the momentum of system S in the reference frame of glider X. Explain.

f. Compare your results from part a and part e to answer the following:

• Is the magnitude of the momentum of system S the same in the reference frame of glider X as it is in the reference frame of the track? Explain.

• Is the direction of the momentum of system S the same in the reference frame of glider X as in the reference frame of the track? Explain.

4. Gliders C and D, of mass 2 kg and 4 kg, respectively, collide on a frictionless track. Glider C initially moves to the right with speed 0.6 m/s relative to the track, while glider D is at rest. After the collision, glider C moves to the left with speed 0.2 m/s. System S consists of gliders C and D.

\[
\begin{array}{c}
\text{C} \quad 0.6 \text{ m/s} \\
\begin{array}{c}
\text{2 kg} \\
\rightarrow
\end{array}
\end{array} \quad \begin{array}{c}
\text{D} \quad v_D = 0 \\
\begin{array}{c}
\text{4 kg} \\
\rightarrow
\end{array}
\end{array} \quad \begin{array}{c}
\text{C} \quad 0.2 \text{ m/s} \\
\begin{array}{c}
\text{2 kg} \\
\rightarrow
\end{array}
\end{array} \quad \begin{array}{c}
\text{D} \quad v_D = ? \\
\begin{array}{c}
\text{4 kg} \\
\rightarrow
\end{array}
\end{array}
\]

before collision \hspace{2cm} after collision

a. In the table at right, draw the momentum vectors of glider C, glider D, and system S before and after the collision.

Is the momentum of system S before the collision the same as it is after the collision? Explain.

\[
\begin{array}{c|c|c}
\text{Before collision} & \text{After collision} \\
\hline
\vec{p}_C & \hline \\
\vec{p}_D & \hline \\
\vec{p}_{\text{system}} & \hline \\
\end{array}
\]

1 unit = 0.4 kg·m/s

b. Use your results from part a to determine the magnitude and direction of the velocity of glider D relative to the track after the collision. Explain.
Consider reference frame R, moving to the left with constant speed 0.2 m/s relative to the track.

c. Apply the Galilean transformation of velocities to draw the velocity vectors of gliders C and D in reference frame R before and after the collision.

Use the velocity vectors above to draw the momentum vectors of glider C, glider D, and system S in reference frame R before and after the collision. Explain.

d. Use your results from part c above to answer the following:

i. In reference frame R, is the momentum of system S before the collision the same as it is after the collision?

ii. Recall the definition of conserved from part D of section II of the tutorial:

“When the momentum of an object or system of objects does not change with time, the momentum of the object or system is said to be conserved.”

In reference frame R, is the momentum of system S conserved? Explain.

e. Use your results from parts a and c above to answer the following:

Before the collision, does the momentum of system S have the same value in reference frame R as it does in the reference frame of the track? Explain.

f. Consider the following dialogue.

Student 1: “The momentum of system S is conserved. That means it must have the same value in reference frame R as it does in the frame of the track.”

Student 2: “I disagree. Even when momentum is conserved, it could have a different value in one reference frame than it does in another. It must have the same value before and after the collision no matter which reference frame is used.”

With which student, if either, do you agree? Explain.
1. Two objects are arranged on a level, frictionless table as shown. Two experiments are conducted in which object A is launched toward the stationary block B. The initial speed of object A is the same in both experiments; the direction is not. The initial and final velocities of object A in each experiment are shown.

The mass of block B is four times that of object A \( (m_B = 4m_A) \).

![Diagrams showing experiment 1 and 2 before and after collision]

a. In the space provided, draw separate arrows representing the direction of the change in momentum vector of object A in the two experiments.

Is the magnitude of the change in momentum of object A in experiment 1 greater than, less than, or equal to that in experiment 2? Explain.

![Diagram showing direction of \( \Delta p_A \) for experiment 1 and 2]

b. In the space provided, draw separate arrows representing the direction of the change in momentum vector of block B in the two experiments.

After the collisions, is the magnitude of the momentum of block B in experiment 1 greater than, less than, or equal to that in experiment 2? If the momentum of block B is zero in either case, state that explicitly. Explain.

![Diagram showing direction of \( \Delta p_B \) for experiment 1 and 2]
2. Two objects collide on a level, frictionless table. The mass of object A is 5.0 kg; the mass of object B is 3.0 kg. The objects stick together after the collision. The initial velocity of object A and the final velocity of both objects are shown.

<table>
<thead>
<tr>
<th>Before collision</th>
<th>After collision</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\vec{v}_{A_1}$</td>
<td>$(\vec{v}<em>{A_f} = \vec{v}</em>{B_f})$</td>
</tr>
</tbody>
</table>

(One side of a square represents 0.1 m/s)

a. In the space provided, draw separate arrows for object A and for object B representing the direction of the change in momentum vector of the object.

Is the magnitude of the change in momentum of object A greater than, less than, or equal to that of object B? Explain your reasoning.

b. System C is the system of both objects A and B combined. How does the momentum of system C before the collision compare to the momentum of system C after the collision? Discuss both magnitude and direction.

Construct and label a vector showing the momentum of system C at an instant before the collision. Show your work clearly.

c. Construct and label a vector showing the initial velocity of object B. Show your work clearly.
3. a. Object A collides on a horizontal frictionless surface with an initially stationary target, object X. The initial and final velocities of object A are shown. The final velocity of object X is not given.

i. At an instant during the collision, is the net force on object A zero or non-zero?

ii. During the collision, is the momentum of object A conserved? Explain.

Is the momentum of the system consisting of objects A and X conserved? Explain.

b. On the same horizontal surface, object C collides with an initially stationary target, object Z. The initial speeds of objects C and A are the same, and \( m_A = m_Z > m_C = m_C \).

After the collisions, object C moves in the direction shown and has the same final speed as object A.

i. In the space below, copy the vectors \( \vec{v}_{ci} \) and \( \vec{v}_{cf} \) with their tails together. Use these vectors to draw the change in velocity vector \( \Delta \vec{v} \) for glider C.

ii. Is the magnitude of the change in velocity vector of object A greater than, less than, or equal to the magnitude of the change in velocity vector of object C? Explain.

iii. Is the magnitude of the change in momentum vector of object A greater than, less than, or equal to the magnitude of the change in momentum vector of object C? Explain.

iv. Is the final speed of object X greater than, less than, or equal to the final speed of object Z? Explain.

c. Consider the following incorrect statement:

"Gliders A and C have the same change in momentum. They have the same mass, and because they have the same initial speed and same final speed, \( \Delta v \) is the same for each of them."

Discuss the error(s) in the reasoning.