Question 1: Mathematical Routines (MR) — 10 points

A **(i)** For sketching **one** of the following: **Point A1**

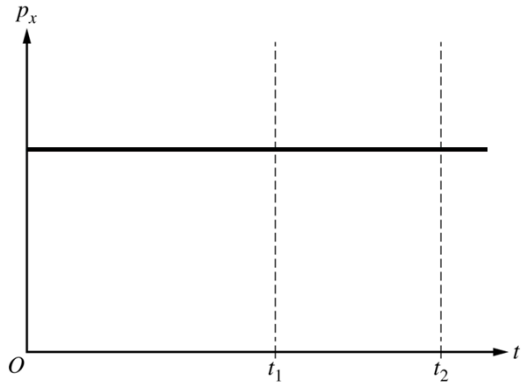
- A constant p_x for $t < t_1$
- A constant p_x for $t > t_1$

For sketching a line that demonstrates momentum is constant **Point A2**

Accept **one** of the following:

- A continuous, nonzero, horizontal line from $t = 0$ to $t = t_2$
- A continuous, nonzero, horizontal line from $t = 0$ to $t > t_2$

Example Response



(ii) For including a conservation of momentum equation **Point A3**

Scoring Note: Part A (ii) and part A (iii) may be scored together, if necessary.

For setting $m_c v_c$ equal to the momentum of the block-cart system after the collision **Point A4**

Scoring Note: A correct, isolated, final expression of $v_f = \frac{5}{6}v_c$ earns points A3 and A4.

Example Response

$p_i = p_f$

$m_c v_c = (m_c + m_b)v_f = \left(m_c + \frac{1}{5}m_c\right)v_f$

$v_f = \frac{5}{6}v_c$

(iii) For a multistep derivation that includes the correct relationship between kinetic energy, mass, and speed (i.e., $K = \frac{1}{2}mv^2$) **Point A5**

Scoring Note: The minimum requirement to earn this point is to show an expression of kinetic energy or change in energy that goes beyond the given equation on the reference information. For example, substituting quantities from the problem into $K = \frac{1}{2}mv^2$ or indicating the change in kinetic energy is $\Delta K = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$ earns the point.

For an indication that m_c and $\frac{6}{5}m_c$ are the initial and final masses, respectively, of the objects moving horizontally **Point A6**

For including an expression for v_f consistent with part A (ii) **Point A7**

Scoring Note: A correct, isolated, final expression of $\Delta K = -\frac{1}{12}m_c{v_c}^2$ earns points A3, A4, A6, and A7.

Example Response

$$\Delta K = K_f - K_0$$

$$K_0 = \frac{1}{2}m_c{v_c}^2$$

$$K_f = \frac{1}{2}\left(\frac{6}{5}m_c\right)\left(\frac{5}{6}v_c\right)^2 = \frac{5}{12}m_c{v_c}^2$$

$$\Delta K = -\frac{1}{12}m_c{v_c}^2$$

B

For indicating "Remains constant" **Point B1**

Scoring Note: This point is scored independently from the graph drawn in Figure 2 in part A (i).

For indicating **one** of the following: **Point B2**

- The frictional force exerted on the new block by the cart is equal in magnitude and opposite in direction to the frictional force exerted on the cart by the new block.
- The frictional force is internal to the new block-cart system.
- The net external force is still zero.
- The frictional force does not cause a net external force.

For indicating **one** of the following: **Point B3**

- The change in momentum of the new block is equal in magnitude and opposite in direction to the change in momentum of the cart.
- The impulse exerted on the cart and the impulse exerted on the new block are equal in magnitude and opposite in direction.
- The correct relationship between the change in the momentum of the block-cart system and the net external force.

Example Response

The momentum of the new block-cart system will remain constant because the frictional force exerted on the new block by the cart is internal to the system and only a net external force will cause a change in momentum of the system.