Problem on

Conservation of linear momentum

Question:

A trolley of mass 200 kg moves with a uniform speed of 36 km/h on a frictionless track. A child of mass 20 kg runs on the trolley from one end to other (10 m away) with a speed of 4 m/s relative to the trolley in direction opposite to the trolley's motion and jumps out of the trolley. What is the final speed of the trolley? How much has the trolley moved from the child begins to run?

Let us understand

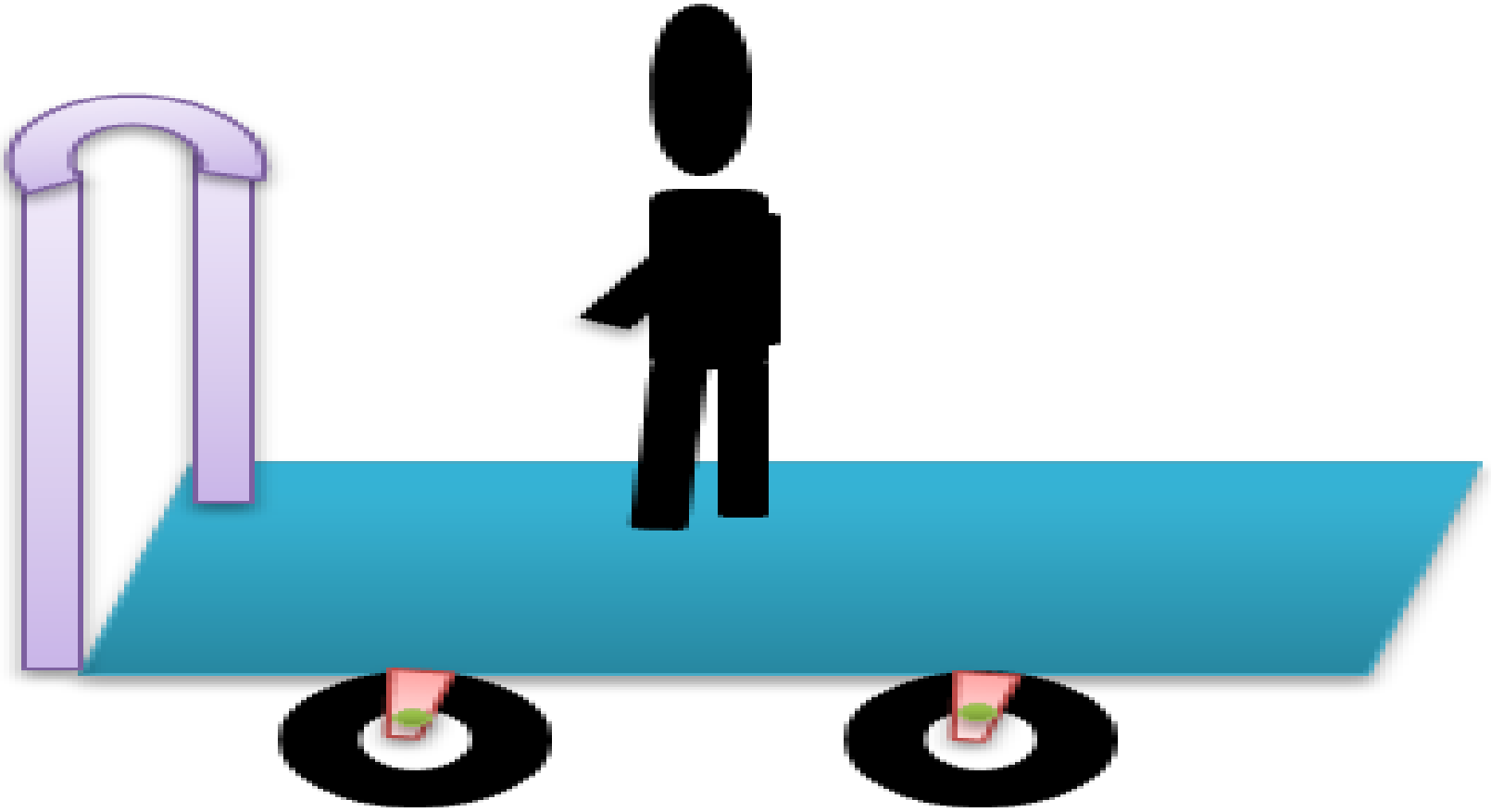
We have,

Uniform speed of the trolley and child, before the child starts

running,

$$\mathbf{u} = \mathbf{36\ km}\ h^{-1} = \frac{36 \times 1{,}000}{60 \times 60}$$

$$= 10\ m\ s^{-1};$$



Mass of the child, M_1= 20 kg

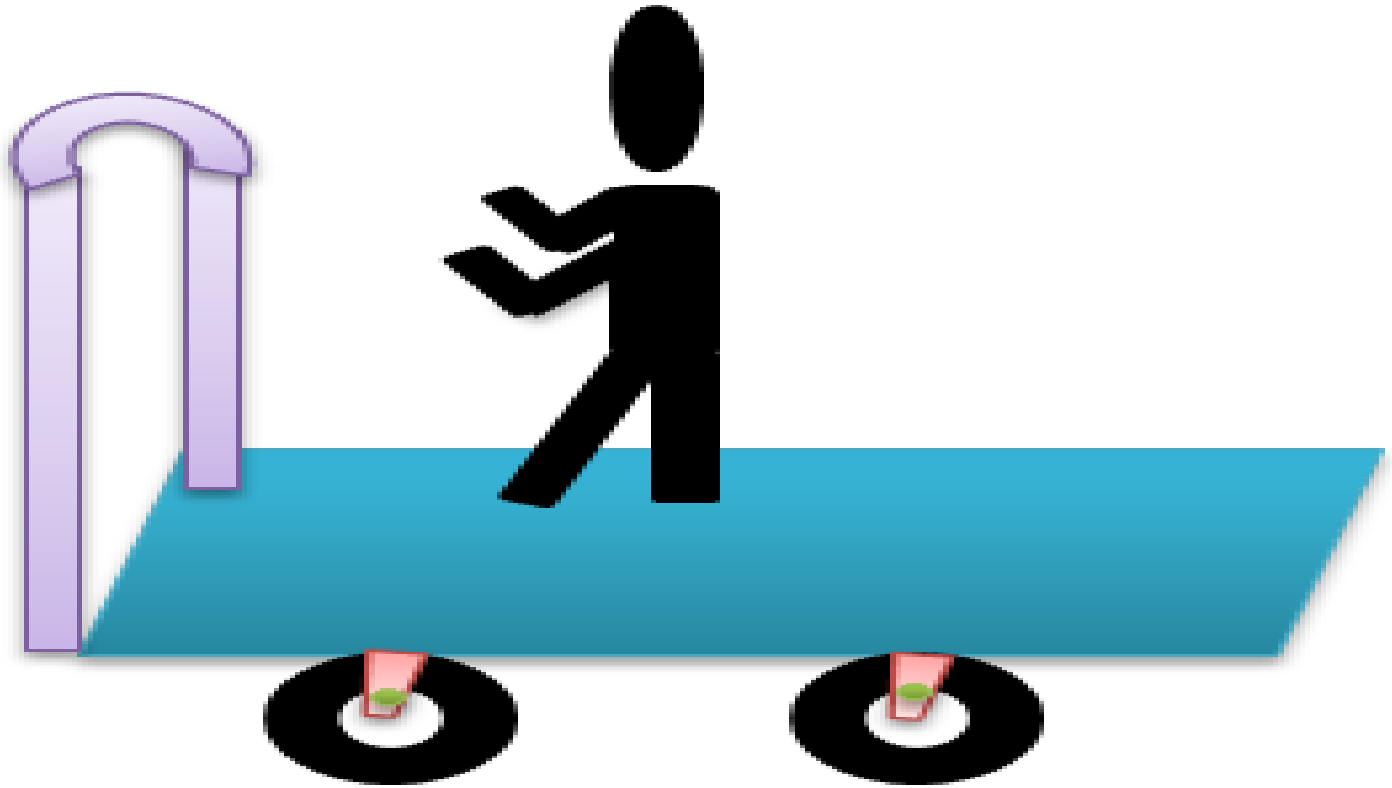
Mass of the trolley, M_2 = 200 kg

Linear momentum (p_i) of the child and the trolley, before the child starts running,

$$(M_1 + M_2)u = (20 + 200) \times 10$$

$$p_i = 2{,}200 \text{ kg m } s^{-1}$$

As child starts running from one end of the trolley to other and jumps out of the trolley, the velocity of the trolley will change.



As the child jumps out of the trolley with a velocity v_1 and as a result, the velocity of the trolley becomes v_2.

The relative velocity of the child w.r.t. the trolley is given by

$$\vec{v}_{12} = \vec{v}_1 - \vec{v}_2$$

As the child runs in backward direction,

$$\vec{v}_{12} = -4ms^{-1}$$

Further, as the child jumps out in backward direction,

$$\vec{v}_1 = -v_1$$

Finally, as the trolley is moving in forward direction,

$$\vec{v}_2 = v_2$$

After substituting the values, we get the equation,

$$-4 = (-v_1) - v_2$$

$v_1 = 4 - v_2$ **(in forward direction)**

Therefore, linear momentum (p_f) of the child and the trolley, after the child, jumps out of the trolley,

$$= M_1\vec{v}_1 + M_2\vec{v}_2 = -M_1v_1 + M_2v_2$$

$$= -20(4 - v_2) + 200v_2$$

$$p_f = -80 + 220v_2$$

By conservation of linear momentum,

$$p_i = p_f$$

$$-80 + 200v_2 = 2,200$$

$$200v_2 = 2,200 + 80$$

$$v_2 = \frac{2,280}{220} = 10.36\ ms^{-1}$$

The time in which the child will cover the distance of 10 m on the trolley before jumping,

$$\mathbf{t} = \frac{\mathbf{10}}{\mathbf{4}} = \mathbf{2.5}\ \boldsymbol{s}$$

Therefore, distance moved by the trolley from the time the child begins to run,

$$\boldsymbol{v_2 t} = \mathbf{10.36} \times \mathbf{2.5}$$

$$= \mathbf{25.9}\ \boldsymbol{m}$$

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