بسم الله الرحمن الرحيم

King Saud University
College of Science
Physics & Astronomy Dept.

PHYS 103 (GENERAL PHYSICS)

CHAPTER 9: LINEAR MOMENTUM

LECTURE NO. 13

THIS PRESENTATION HAS BEEN PREPARED BY: *DR. NASSR S. ALZAYED*

Lecture Outline

- Here is a quick list of the subjects that we will cover in this presentation. It is based on Serway, Ed. 6
- *Introduction*
- *9.1 Linear Momentum and Its Conservation*
- *9.2 Impulse and Momentum*
- *Interactive Quiz 9.1+9.2*
- *Interactive Quiz 9.3+9.4*
- *Interactive Quiz 9.5+9.6*
- *Example 9.4 How Good Are the Bumpers?*
- *Linear Momentum Conservation (Interactive Flash)*
- *Lecture Summary*
- *End of Presentation*

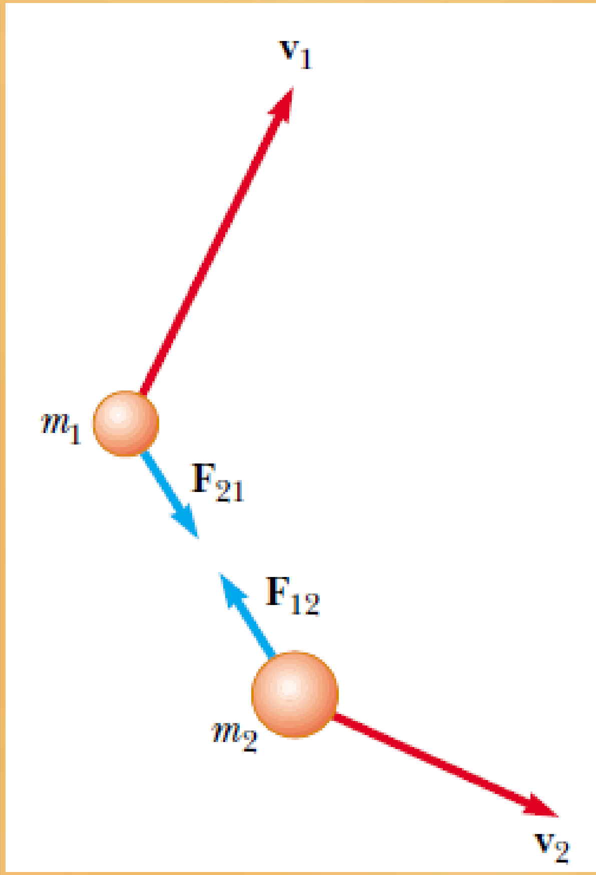
Intruduction

Consider what happens when a bowling ball strikes a pin, as in the opening photograph. The pin is given a large velocity as a result of the collision; consequently, it flies away and hits other pins or is projected toward the backstop. Because the average force exerted on the pin during the collision is large, the pin achieves the large velocity very rapidly and experiences the force for a very short time interval. According to Newton's third law, the pin exerts a reaction force on the ball that is equal in magnitude and opposite in direction to the force exerted by the ball on the pin. This reaction force causes the ball to accelerate, but because the ball is so much more massive than the pin, the ball's acceleration is much less than the pin's acceleration.

9.1 Linear Momentum and Its Conservation

- Consider two particles m_1 and m_2 with v_1 and v_2 collide as in figuer:
- If a force from particle 1 acts on particle 2, then there must be a second force—equal in magnitude but opposite in direction—that particle 2 exerts on particle 1. That is, they form a Newton's third law action–reaction pair, so that F_{12}=-F_{21}. We can express this condition as:
- $\mathbf{F}_{21} + \mathbf{F}_{12} = 0$
- Using Newton's 2nd law:
- $m_1\mathbf{a}_1 + m_2\mathbf{a}_2 = 0$

$$\Rightarrow m_1 \frac{dv_1}{dt} + m_2 \frac{dv_2}{dt} = 0$$



9.1 Linear Mom. and Its Cons. (Continued)

- If the masses m_1 and m_2 are constant, we can bring them into the derivatives, which gives:

$$\Rightarrow \frac{d\,(m_1 v_1)}{dt} + \frac{d\,(m_2 v_2)}{dt} = 0$$

$$\therefore \frac{d}{dt}\left(m_1 v_1 + m_2 v_2\right) = 0 \qquad (9.1)$$

- To finalize this discussion, note that the derivative of the sum ($m_1 v_1$ + $m_2 v_2$) with respect to time is zero. Consequently, this sum must be constant. We learn from this discussion that the quantity mv for a particle is important, in that the sum of these quantities for an isolated system is conserved. We call this quantity linear momentum
- linear momentum of a particle or an object is defind as:
- $\mathbf{p} = m\mathbf{v}$ (9.2)

9.1 Linear Mom. and Its Cons. (Continued)

- If a particle is moving in 3-D then:
- $p_x = mv_x$ $\quad$ $p_y = mv_y$ $\quad$ $p_z = mv_z$
- Using Newton's second law of motion, we can relate the linear momentum of a particle to the resultant force acting on the particle:

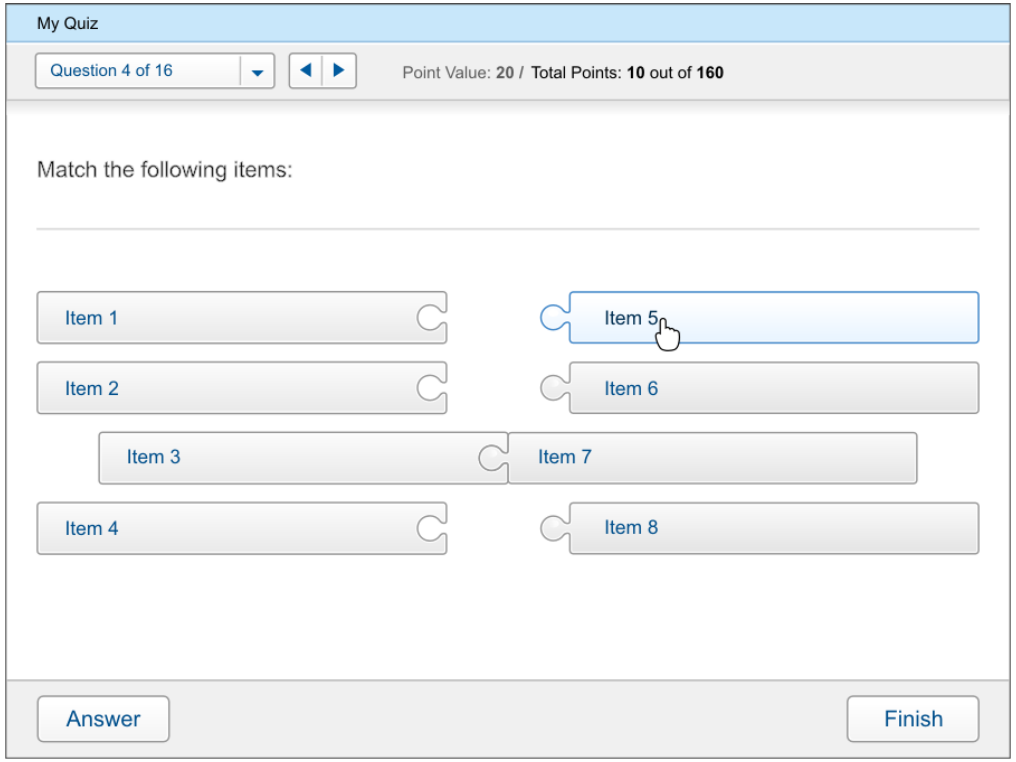
$$\sum F_x = ma = m\frac{dv}{dt}$$

- In Newton's second law, the mass m is assumed to be constant. Thus, we can bring m inside the derivative notation to give us:

$$\sum F_x = \frac{d(mv)}{dt} = \frac{dp}{dt} \qquad (9.3)$$

- *This shows that the time rate of change of the linear momentum of a particle is equal to the net force acting on the particle.*

Quiz 9.1+9.2



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9.1 Linear Mom. and Its Cons. (Continued)

- Using the definition of momentum, Equation 9.1 can be written:

$$\frac{d}{dt}(p_1 + p_2) = 0$$

$$\because \frac{d}{dt} p_{tot} = \frac{d}{dt}(p_1 + p_2) = 0$$

$$\therefore p_{tot} = p_1 + p_2 = \text{constant} \qquad (9.4)$$

$$\Rightarrow p_{1i} + p_{2i} = p_{1f} + p_{2f} \qquad (9.5)$$

- *Whenever two or more particles in an isolated system interact, the total momentum of the system remains constant.*
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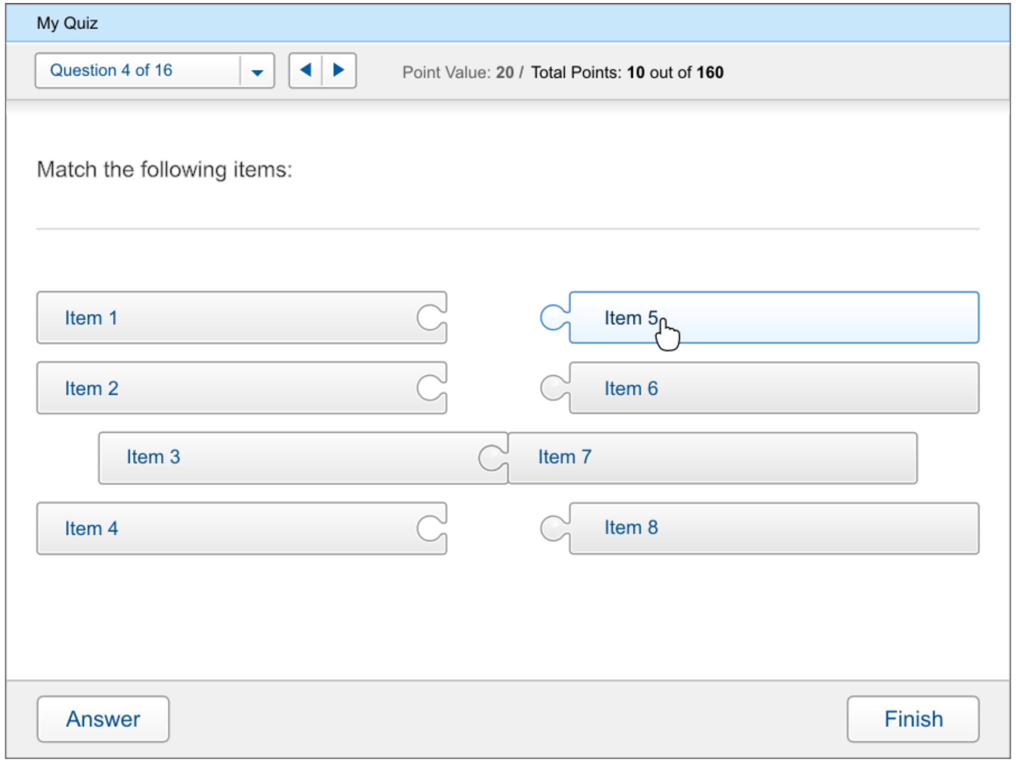
- This law tells us that the total momentum of an isolated system at all times equals its initial momentum.

Quiz 9.3+9.4



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9.2 Impulse and Momentum

- To build a better, let us assume that a single force **F** acts on a particle and that this force may vary with time. According to Newton's second law:

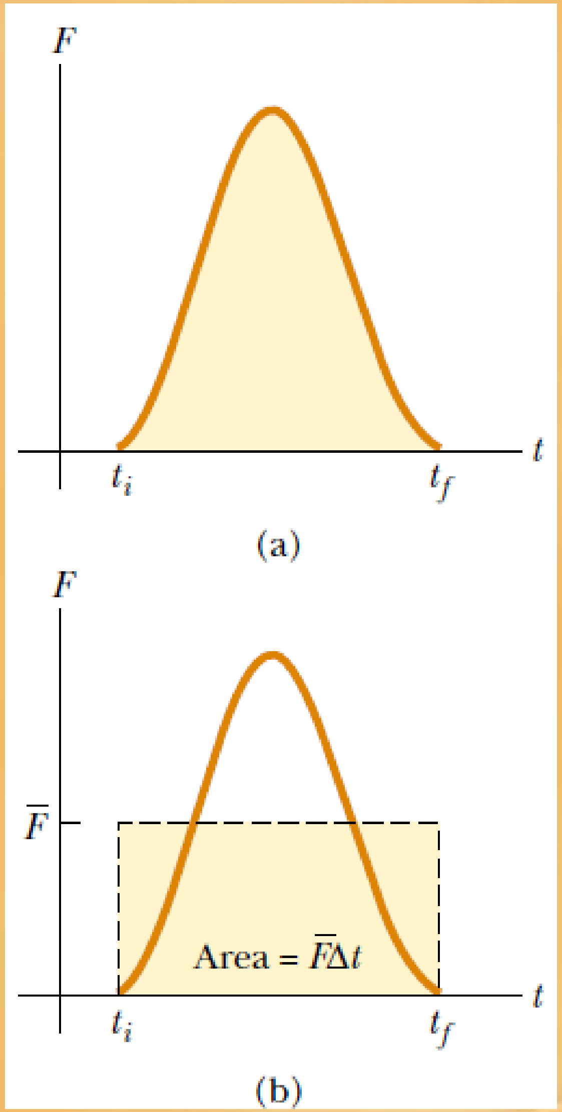
$$F = \frac{dp}{dt}$$

$$\Rightarrow dp = F dt \qquad (9.7)$$

- Inegrating for time t_i to t_f :

$$\Delta p = p_f - p_i = \int_{t_i}^{t_f} F dt \qquad (9.8)$$

OR: $$I = \int_{t_i}^{t_f} F dt \qquad (9.9)$$



9.2 Impulse and Momentum (continued)

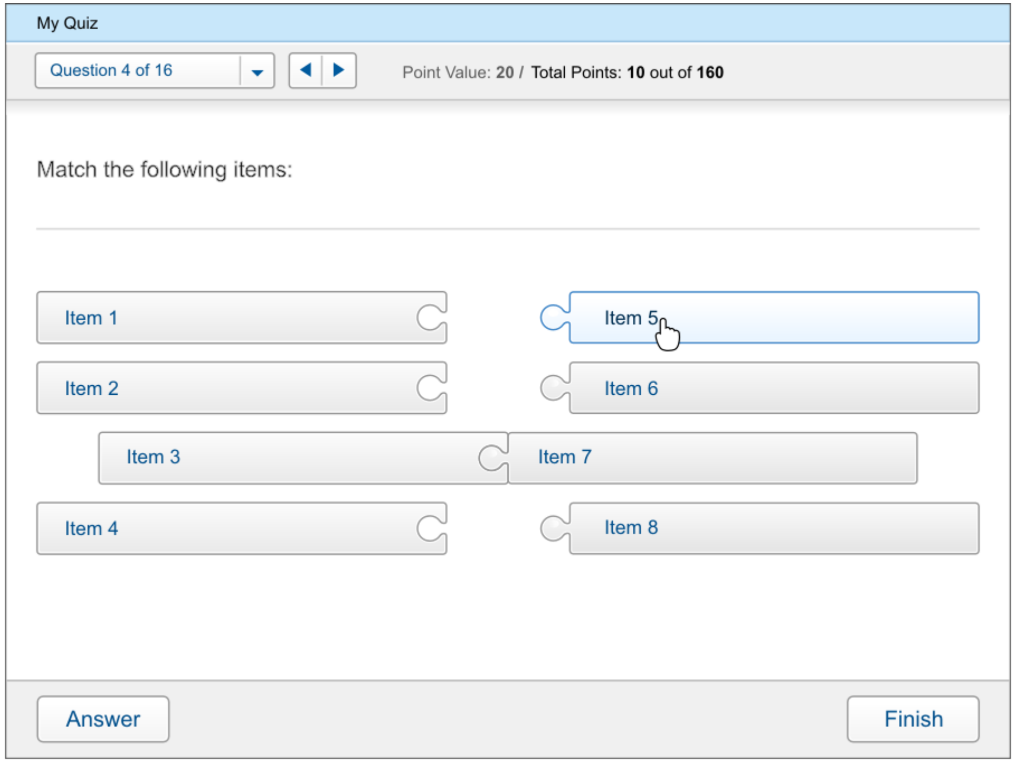
- The quantity in (9.9) is called: Impulse. (9.8) is called: **Impulse-Momentum Theorm**.
- The impulse of the force **F** acting on a particle equals the change in the momentum of the particle.
- Because the force imparting an impulse can generally vary in time, it is convenient to define a time-averaged force:

$$\bar{F} = \frac{1}{\Delta t}\int_{t_i}^{t_f} F dt \qquad (9.10)$$

OR: $$I = \bar{F}\Delta t \qquad (9.11)$$

- In principle, if **F** is known as a function of time, the impulse can be calculated from Equation 9.9. The calculation becomes especially simple if the force acting on the particle is constant. In this case Equation 9.11 becomes: **I** = **F**Δt

Quiz 9.5 + 9.6



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Example 9.4 How Good Are the Bumpers?

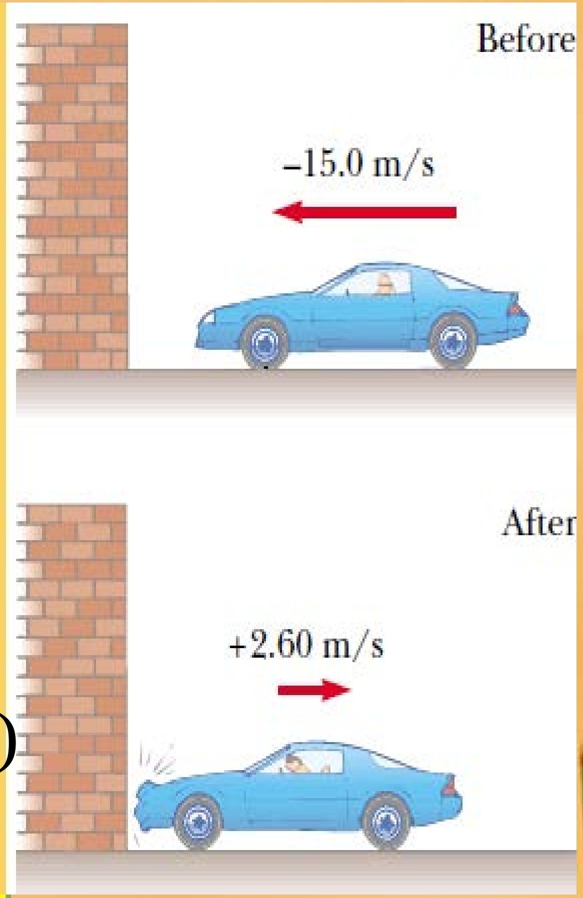
- In a particular crash test, a car of mass 1 500 kg collides with a wall, as shown in Figure 9.6. The initial and final velocities of the car are v_i = -15 m/s and v_f = 2.6 m/s , respectively. If the collision lasts for 0.150 s, *find the impulse caused by the collision and the average force exerted on the car.*
- ***Solution:***

$$\because I = \Delta p = p_f - p_i$$

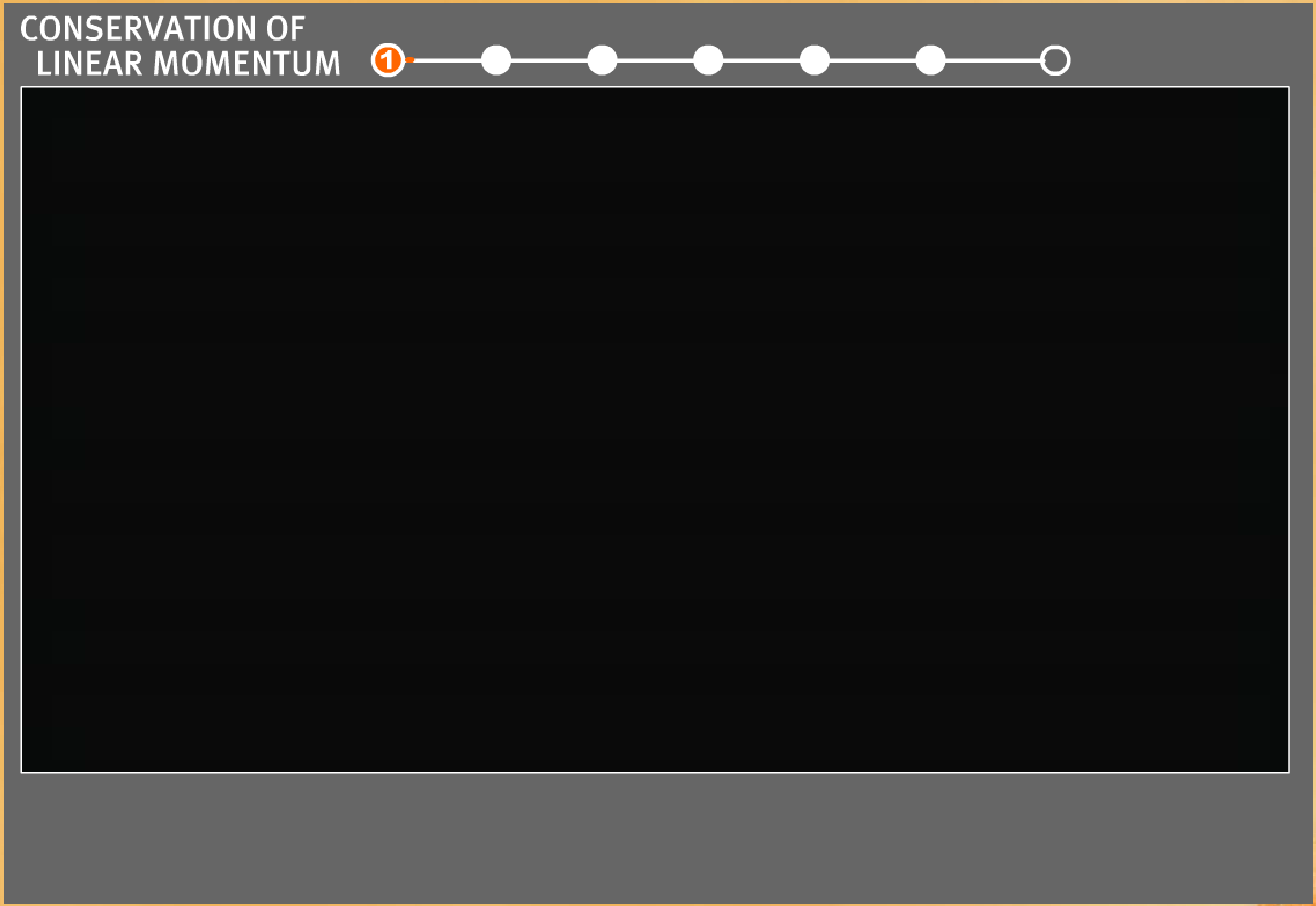
$$= mv_f - mv_i = (1500)(2.6\hat{i}) - (1500)(-15\hat{i})$$

$$= 2.64\times10^4\,\hat{i}\ \mathrm{kg.m/s}$$

$$\because \overline{\mathrm{F}} = \frac{\Delta p}{\Delta t} = \frac{2.64\times10^4}{0.15} = 1.76\times10^5\ N$$



Linear Momentum Conservation



Lecture Summary

- The linear momentum **p** of a particle , m moving with a velocity **v** is:
- **p** = m**v** (9.2)
- The law of conservation of linear momentum indicates that the total momentum of an isolated system is conserved. If two particles form an isolated system, the momentum of the system is conserved regardless of the nature of the force between them. Therefore, the total momentum of the system at all times equals its initial total momentum, or

$$p_{1i} + p_{2i} = p_{1f} + p_{2f} \qquad (9.5)$$

- The impulse imparted to a particle by a force **F is equal to the change in the momentum** of the particle:

$$\mathrm{I} = \int_{t_i}^{t_f} F dt = \Delta p \qquad (9.9)$$

- This is known as the impulse–momentum theorem.


THE END!