American University Of The Middle East

Modern mechanics - PHYS 172

Fall 2021

Chapter 2: The Momentum Principle

Week 3 – LECTURE 2

Outline:

2.1 THE MOMENTUM PRINCIPLE P.45

CH. 2 – The Momentum Principle

Concepts, Definitions, and Formulas:

- **System and Surroundings (Definition): Sec. 2.1, P. 45**
- **The Momentum principle (Statement + Formula): Sec. 2.1, P. 46**
- **Change of momentum: Sec. 2.1, P. 46**
- **Definition of net force: Sec. 2.1, P. 47**
- **Duration of Interaction (Definition): Sec. 2.1, P. 48**

Problem Solving:

- **Examples – From the Textbook (1): Collision with a Wall and Constant Checkpoints – From the Textbook (1): 1**
- **Problems (3):**

– **Problem 9: P. 82**
– **Problem 10: P. 82**
– **Problem 11: P. 82**

One or more objects can be considered to be a ‘**system**’.

Everything that is not included in the system is part of the ‘**surroundings**’.

The Momentum Principle relates **the change in momentum of a system to the amount of interaction with its surroundings**.

No matter what system we choose, the Momentum Principle will correctly predict the behavior of the system.

The Momentum Principle applies to any system, no matter how complex.

The **Momentum Principle** (**Newton's 2nd Law**) restates and extends Newton's first law of motion in a quantitative, causal form that can be used to predict the behavior of objects.

It can be applied to **every possible system**, no matter how large or small (from clusters of galaxies to subatomic particles), and no matter how fast it is moving.

$$\boldsymbol{\Delta\vec{p} = \vec{F}_{net}\Delta t}$$

'$\vec{F}_{net}\Delta t$' is often referred to as an **Impulse**: $\vec{J} = \vec{F}_{net}\Delta t$ or : $\vec{I} = \vec{F}_{net}\Delta t$

The change of momentum $\boldsymbol{\Delta\vec{p}}$ of a system (**an effect**) is equal to the net force acting on the system times the duration of the interaction (**the cause**). The time interval Δt must be small enough that the net force is nearly constant during this time interval.

It is true for every kind of interaction (electric, gravitational, etc.). It is a summary of the way interactions affect motion in the real world.

$$\boxed{\Delta\vec{p} = \vec{F}_{net}\Delta t}$$

The **change in momentum** $\Delta\vec{p}$ of a system can involve:

- a change in the magnitude of momentum.
- a change in the direction of momentum.
- a change in both magnitude and direction.

$$\boxed{\Delta\vec{p} = \vec{F}_{net}\Delta t}$$

The 'net' forces part ($\vec{F}_{net}$) indicates that we must count up all **of the forces acting on the system (external forces $\vec{F}_i$).**

A **<u>Free-Body Diagram</u>** will help us to identify these forces.

Remember that we are concerned only with the forces **<u>acting on the system of interest</u>**, not forces the system exerts on its surroundings.

There may be forces internal to the system, exerted by one object in the system on another object in the system, but such internal forces cannot change the momentum of the system.

$$\boxed{\Delta\vec{p} = \vec{F}_{net}\Delta t}$$

The length of time during which $\vec{F}_{net}$ acts on an object, affects the change of momentum of the object

The magnitude of the change in momentum is directly proportional to the length of time $\Delta t = t_2 - t_1$ during which the force acts on the object.

EXAMPLE **Collision with a Wall**

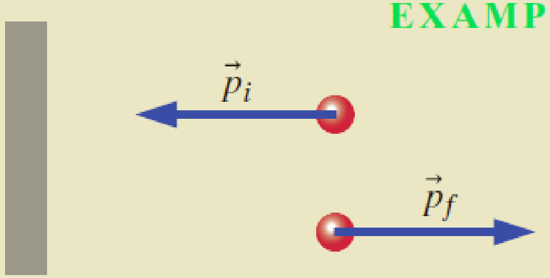

Figure 2.6 A ball hits a wall and rebounds.

A tennis ball traveling in the $-x$ direction with magnitude of momentum 2.8 kg·m/s hits a wall and rebounds (Figure 2.6). After the collision the magnitude of the ball's momentum is nearly the same, but the ball is traveling in the $+x$ direction. What was the impulse applied to the ball by the wall?

Solution Although the magnitude of the ball's momentum did not change significantly, its direction did change, so the impulse is not zero.

$$\Delta\vec{p} = \vec{F}_{\text{net}}\,\Delta t$$

$$(\langle 2.8, 0, 0\rangle\ \text{kg}\cdot\text{m/s} - \langle -2.8, 0, 0\rangle\ \text{kg}\cdot\text{m/s}) = \vec{F}_{\text{net}}\,\Delta t$$

$$\langle 5.6, 0, 0\rangle\ \text{kg}\cdot\text{m/s} = \vec{F}_{\text{net}}\,\Delta t$$

Checkpoint 1 (1) Two external forces, $\langle 40, -70, 0 \rangle$ N and $\langle 20, 10, 0 \rangle$ N, act on a system. What is the net force acting on the system? (2) A hockey puck initially has momentum $\langle 0, 2, 0 \rangle$ kg·m/s. It slides along the ice, gradually slowing down, until it comes to a stop. **(a)** What was the impulse applied by the ice and the air to the hockey puck? **(b)** It took 3 seconds for the puck to come to a stop. During this time interval, what was the net force on the puck by the ice and the air (assuming that this force was constant)?

•**P9** A truck driver slams on the brakes and the momentum of the truck changes from $\langle 65{,}000, 0, 0\rangle$ kg·m/s to $\langle 26{,}000, 0, 0\rangle$ kg·m/s in 4.1 s due to a constant force of the road on the wheels of the truck. As a vector, write the net force exerted on the truck by the surroundings.

Solution:

The system is the truck.

$$
\begin{aligned}
\vec{p}_{\mathrm{i}} &= \langle 65000, 0, 0\rangle \ \mathrm{kg\cdot m/s} \\
\vec{p}_{\mathrm{f}} &= \langle 26000, 0, 0\rangle \ \mathrm{kg\cdot m/s} \\
\Delta t &= 4.1\ \mathrm{s} \\
\vec{F}_{\mathrm{net}} &= \frac{\Delta \vec{p}}{\Delta t} \\
&= \frac{\vec{p}_{\mathrm{f}} - \vec{p}_{\mathrm{i}}}{\Delta t} \\
&= \frac{\langle 26000, 0, 0\rangle \ \mathrm{kg\cdot m/s} - \langle 65000, 0, 0\rangle \ \mathrm{kg\cdot m/s}}{4.1\ \mathrm{s}} \\
&= \frac{\langle -39000, 0, 0\rangle \ \mathrm{kg\cdot m/s}}{4.1\ \mathrm{s}} \\
&= \langle -9510, 0, 0\rangle \ \mathrm{N}
\end{aligned}
$$

•P10 At a certain instant a particle is moving in the $+x$ direction with momentum $+8\ \text{kg}\cdot\text{m/s}$. During the next 0.13 s a constant force acts on the particle, with $F_x = -7$ N and $F_y = +5$ N. What is the *magnitude* of the momentum of the particle at the end of this 0.13 s interval?

Solution:

$$\vec{p}_{\text{i}} = \langle 8, 0, 0\rangle\,\text{kg}\cdot\text{m/s}$$

$$\Delta t = 0.13\,\text{s}$$

$$\vec{p}_{\text{f}} = ?$$

$$\vec{F}_{\text{net}} = \langle -7, 5, 0\rangle\,\text{N}$$

$$\begin{aligned}
\vec{p}_{\text{f}} &= \vec{p}_{\text{i}} + \vec{F}_{\text{net}}\Delta t \\
&= \langle 8, 0, 0\rangle\,\text{kg}\cdot\text{m/s} + (\langle -7, 5, 0\rangle\,\text{N})\,(0.13\,\text{s}) \\
&= \langle 7.09, 0.65, 0\rangle\,\text{kg}\cdot\text{m/s}
\end{aligned}$$

$$\begin{aligned}
|\vec{p}_{\text{f}}| &= \sqrt{(7.09)^2 + (0.65)^2 + (0)^2}\,\text{kg}\cdot\text{m/s} \\
&= 7.12\,\text{kg}\cdot\text{m/s}
\end{aligned}$$

•P11 At $t = 16.0$ s an object with mass 4 kg was observed to have a velocity of $\langle 9, 29, -10\rangle$ m/s. At $t = 16.2$ s its velocity was $\langle 18, 20, 25\rangle$ m/s. What was the average net force acting on the object?

Solution:

$$
\begin{aligned}
t_i &= 16\,\mathrm{s}\\
t_f &= 16.2\,\mathrm{s}\\
m &= 4\,\mathrm{kg}\\
\vec{v}_i &= \langle 9, 29, -10\rangle\,\mathrm{m/s}\\
\vec{v}_f &= \langle 18, 20, 25\rangle\,\mathrm{m/s}\\
\vec{F}_{net} &= ?
\end{aligned}
$$

$$
\begin{aligned}
\vec{F}_{net} &= \frac{\Delta\vec{p}}{\Delta t}\\
&= \frac{m\Delta\vec{v}}{\Delta t}\\
&= \frac{m\left(\vec{v}_f - \vec{v}_i\right)}{\Delta t}\\
&= \frac{(4\,\mathrm{kg})\left(\langle 18, 20, 25\rangle\,\mathrm{m/s} - \langle 9, 29, -10\rangle\,\mathrm{m/s}\right)}{(16.2\,\mathrm{s} - 16.0\,\mathrm{s})}\\
&= \frac{(4\,\mathrm{kg})\left(\langle 9, -9, 35\rangle\,\mathrm{m/s}\right)}{0.2\,\mathrm{s}}\\
&= \langle 180, -180, 700\rangle\,\mathrm{N}
\end{aligned}
$$