

# PHYSICS 1: Physics Fundamental 1

## CIRCULAR MOTION

After studying this chapter, you should be able to:

1. Define period and frequency
2. Describe motion of an object moving in a curved path in terms of period or frequency
3. Identify the forces acting on an object moving in a circular path
4. Define centripetal acceleration, centripetal force and centrifugal force
5. Derive the equation for centripetal force from Newton's second law of motion
6. Give applications of centripetal force
7. Explain why some curved roadways are tilted from the horizontal

**PERIOD** = is the time required for an object to make one complete revolution.

**FREQUENCY** = the number of revolutions completed by the object in a given time.

- Using the terms **frequency** and **period**, you can describe the motion of a bicycle wheel. Suppose the rear wheel makes 5 revolutions in 1 minute. Therefore frequency  $f = 5$  revolutions per minute or **5rpm**.
- Period may be expressed in seconds, minutes, hours or years. Correspondingly the frequency may be expressed as rev/s, rev/min, rev/hr, rev/year etc.

$$f = \frac{1}{T}$$

A

**Circular Motion** is the motion of a body along a circle. If an object moves in a circular path at constant speed, its motion is said to be uniform. **Uniform Circular Motion** is the simplest kind of circular motion.

Consider a ball whirled about on a string, the ball moves at constant speed. The speed of the ball may be computed if you know the ball's frequency and the radius is equal to the length of the string.



Recall that the speed is defined as the total distance traveled divided by the elapsed time. In symbol:

$$V_s = \frac{d}{t}$$

Use the equation to define the speed of the ball

The distance traveled by the ball in one revolution is equal to the circumference of the circle that represents its path: that is  $c = 2\pi r$ . The elapsed time is equivalent to the period  $T$ .

By substitution of these quantities into the equation  $v = d/t$ , the speed of any particle in uniform circular motion is expressed as

$$v = \frac{2\pi r}{T}$$

B

Or in terms of frequency (see ex. B)

$$v = \frac{2\pi r}{1/f}$$

$$\text{Or } v = 2\pi r f$$

The speed computed using equation B and C is both the instantaneous and average speeds since the motion of the object is uniform. If motion is nonuniform, the calculated speed represents only the average speed of the object.

C

For an object in **CIRCULAR MOTION** the **speed is constant**, but this not necessarily mean that **velocity is also constant**. The **velocity is continuously changing** because the direction of motion is also continuously changing. At any point in the curved path, the direction of the velocity is **tangent** to the circular path. Since the **velocity is changing**, the object is **accelerating**.



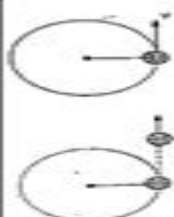
### IN WHAT DIRECTION IS THIS FORCE ACTING ON THE BALL?

Try whirling a ball a release the string while the ball is moving. You will find out that it will go flying off in the direction of the velocity it had, at the instant the string was released.

You will feel that the string prevents the ball from moving in a straight-line path by exerting a force on the ball that makes it follow a circular path. This force known as **centripetal force** ( $F_c$ ) is directed toward the center of the circular path.

To keep the speed of the object constant, the magnitude of this force must also be constant. If you release the string while the ball is in motion, you will observe the ball flying tangentially to the circle. When the string is released the centripetal force is removed.

According to Newton's second law of motion, force and acceleration are in the same direction.



But what are the magnitudes of the acceleration and the force?

The centripetal acceleration is

$$a_c = \frac{v^2}{r}$$

Applying Newton's second law  $F = ma$ , the centripetal force is expressed as

$$F_c = ma_c$$

$$F_c = \frac{mv^2}{r}$$

**FIGURE 1** shows that there are two equal but opposite forces acting on the ball and the string. The exerted by the string on the ball is directed toward the center of the circle and is the centripetal force  $F_c$ . Based on Newton's third law, you know that there must be an opposite but equal force. As a reaction to centripetal force, the ball exerts an equal but opposite force on the string. It is directed away from the center and is called the **Centrifugal force**.



Outside the car, the road exerts an inward pull (centripetal force) on the car. This force is supplied by the friction force of tires and the road.

$$F_c = f = \mu F_N$$

Eq. 1

This equation shows that the maximum possible value of the frictional force is proportional to the normal force  $F_N$  pushing the surfaces together. This normal force is related to the mass and weight of the car. That is,

$$F_N = W = mg$$

Equation 1 may now be expressed,

$$F_c = f = \mu W = \mu mg$$

You can say that

$$\mu F_N = \frac{mv^2}{r}$$

A **Centrifuge** is another application of centripetal and centrifugal forces. It is a device which separates the lighter and heavier substances in a mixture. This is usually used in laboratories for chemical analysis. Milk, for example, can be separated into cream and skim milk in a cream separator rotates, the denser watery substance moves toward the outside, leaving the less dense (lighter) cream nearer the center.

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**David Halliday, Robert Resnick, Jearl Walker**



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## **Table of Contents Physics Fundamental 20gpbworksheet**

1. Understanding the eBook Physics Fundamental 20gpbworksheet
  - The Rise of Digital Reading Physics Fundamental 20gpbworksheet
  - Advantages of eBooks Over Traditional Books
2. Identifying Physics Fundamental 20gpbworksheet
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Physics Fundamental 20gpbworksheet
  - User-Friendly Interface
4. Exploring eBook Recommendations from Physics Fundamental 20gpbworksheet
  - Personalized Recommendations
  - Physics Fundamental 20gpbworksheet User Reviews and Ratings

- Physics Fundamental 20gpbworksheet and Bestseller Lists
- 5. Accessing Physics Fundamental 20gpbworksheet Free and Paid eBooks
  - Physics Fundamental 20gpbworksheet Public Domain eBooks
  - Physics Fundamental 20gpbworksheet eBook Subscription Services
  - Physics Fundamental 20gpbworksheet Budget-Friendly Options
- 6. Navigating Physics Fundamental 20gpbworksheet eBook Formats
  - ePub, PDF, MOBI, and More
  - Physics Fundamental 20gpbworksheet Compatibility with Devices
  - Physics Fundamental 20gpbworksheet Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Physics Fundamental 20gpbworksheet
  - Highlighting and Note-Taking Physics Fundamental 20gpbworksheet
  - Interactive Elements Physics Fundamental 20gpbworksheet
- 8. Staying Engaged with Physics Fundamental 20gpbworksheet
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Physics Fundamental 20gpbworksheet
- 9. Balancing eBooks and Physical Books Physics Fundamental 20gpbworksheet
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Physics Fundamental 20gpbworksheet
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Physics Fundamental 20gpbworksheet
  - Setting Reading Goals Physics Fundamental 20gpbworksheet
  - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Physics Fundamental 20gpbworksheet
  - Fact-Checking eBook Content of Physics Fundamental 20gpbworksheet
  - Distinguishing Credible Sources

13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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