King Saud University
College of Science
Physics & Astronomy Dept.

PHYS 103 (GENERAL PHYSICS)

CHAPTER 6: Circular Motion and Other Applications of Newton's Laws

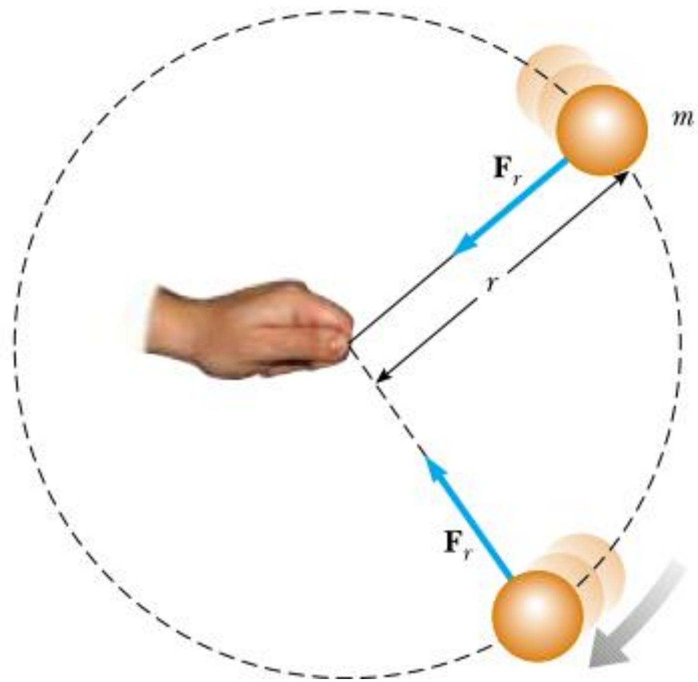
Presented by Nouf Saad Alkathran

6.1 Newton's Second Law Applied to Uniform Circular Motion

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

The acceleration is called centripetal acceleration because a_c is directed toward the center of the circle. Furthermore, a_c is always perpendicular to v.

Consider a ball of mass m that is tied to a string of length r and is being whirled at constant speed in a horizontal circular path. Why does the ball move in a circle?



- A radial force F r that makes it follow the circular path. This force is directed along the string toward the center of the circle.
- If we apply Newton's second law along the radial direction, we find that the net force causing the centripetal acceleration can be evaluated:

$$\sum F = ma_c = m\frac{v^2}{r}$$

- A force causing a centripetal acceleration acts toward the center of the circular path and causes a change in the direction of the velocity vector.
- If that force should vanish, the object would no longer move in its circular path; instead, it would move along a straight-line path tangent to the circle.

Quick Quiz 6.1 You are riding on a Ferris wheel (Fig. 6.3) that is rotating with constant speed. The car in which you are riding always maintains its correct upward orientation—it does not invert. What is the direction of your centripetal acceleration when you are at the *top* of the wheel? (a) upward (b) downward (c) impossible to determine. What is the direction of your centripetal acceleration when you are at the *bottom* of the wheel? (d) upward (e) downward (f) impossible to determine.

Quick Quiz 6.2 You are riding on the Ferris wheel of Quick Quiz 6.1. What is the direction of the normal force exerted by the seat on you when you are at the *top* of the wheel? (a) upward (b) downward (c) impossible to determine. What is the direction of the normal force exerted by the seat on you when you are at the *bottom* of the wheel? (d) upward (e) downward (f) impossible to determine.

Example 6.1 The Conical Pendulum AM

A small ball of mass m is suspended from a string of length L. The ball revolves with constant speed v in a horizontal circle of radius r as shown in Figure 6.3. (Because the string sweeps out the surface of a cone, the system is known as a *conical pendulum*.) Find an expression for v in terms of the geometry in Figure 6.3.

$$\sum F_y = T\cos\theta - mg = 0$$

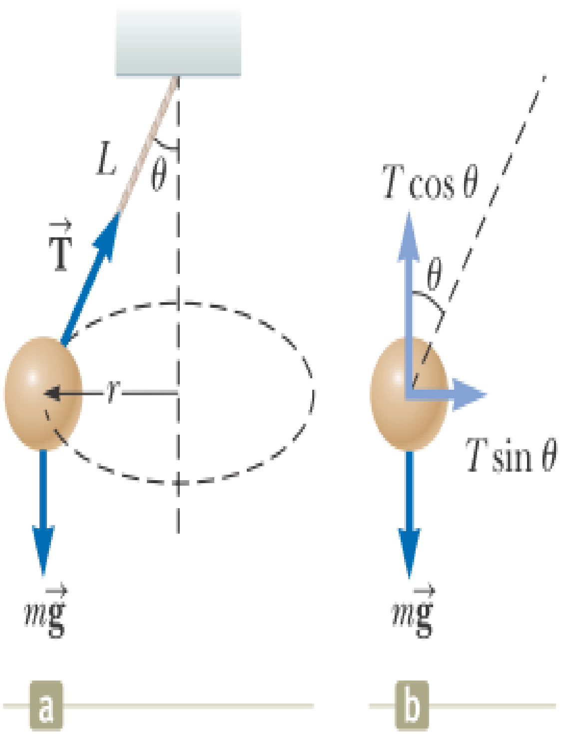
$$(1) \quad T\cos\theta = mg$$

$$(2) \quad \sum F_x = T\sin\theta = ma_c = \frac{mv^2}{r}$$

$$\tan\theta = \frac{v^2}{rg}$$

$$v = \sqrt{rg\tan\theta}$$

$$v = \boxed{\sqrt{Lg\sin\theta\tan\theta}}$$



Example 6.3 How Fast Can It Spin?

A ball of mass 0.500 kg is attached to the end of a cord 1.50 m long. The ball is whirled in a horizontal circle as shown in Figure 6.1. If the cord can withstand a maximum tension of 50.0 N, what is the maximum speed at which the ball can be whirled before the cord breaks? Assume that the string remains horizontal during the motion.

$$T = m\frac{v^2}{r}$$

$$(1) \quad v = \sqrt{\frac{Tr}{m}}$$

$$v_{\max} = \sqrt{\frac{T_{\max} r}{m}} = \sqrt{\frac{(50.0 \text{ N})(1.50 \text{ m})}{0.500 \text{ kg}}} = \boxed{12.2 \text{ m/s}}$$

What If? Suppose that the ball is whirled in a circle of larger radius at the same speed *v*. Is the cord more likely to break or less likely?

The larger radius means that the change in the direction of the velocity vector will be smaller for a given time interval. Thus, the acceleration is smaller and the required force from the string is smaller. As a result, the string is less likely to break when the ball travels in a circle of larger radius.

$$T_1 = \frac{mv^2}{r_1} \qquad T_2 = \frac{mv^2}{r_2} \qquad \frac{T_2}{T_1} = \frac{\left(\frac{mv^2}{r_2}\right)}{\left(\frac{mv^2}{r_1}\right)} = \frac{r_1}{r_2}$$

If we choose $r_2 > r_1$, we see that $T_2 < T_1$. Thus,

Example 6.4 What Is the Maximum Speed of the Car?

A 1 500-kg car moving on a flat, horizontal road negotiates a curve, as shown in Figure 6.5. If the radius of the curve is 35.0 m and the coefficient of static friction between the tires and dry pavement is 0.500, find the maximum speed the car can have and still make the turn successfully.

(1) $$f_s = m\frac{v^2}{r}$$

(2) $$v_{\max} = \sqrt{\frac{f_{s,\max}\, r}{m}} = \sqrt{\frac{\mu_s m g r}{m}} = \sqrt{\mu_s g r}$$

$$= \sqrt{(0.500)(9.80\ \mathrm{m/s^2})(35.0\ \mathrm{m})}$$

$$= 13.1\ \mathrm{m/s}$$

What If? Suppose that a car travels this curve on a wet day and begins to skid on the curve when its speed reaches only 8.00 m/s. What can we say about the coefficient of static friction in this case?

$$\mu_s = \frac{v_{\max}^2}{gr} = \frac{(8.00\ \mathrm{m/s})^2}{(9.80\ \mathrm{m/s^2})(35.0\ \mathrm{m})} = 0.187$$