

Portland State University
 General Physics Workshop
 Problem Set 4

Circular Motion

Equations and Relations:

Newton's Laws:

- 1st: An object will stay at rest or in motion with constant velocity unless acted on by a net force.
- 2nd: $\Sigma F_x = ma_x$, $\Sigma F_y = ma_y$
- 3rd: Forces come in pairs. If A exerts a force on B, then B exerts a force on A with the same magnitude but in the opposite direction.

Motion with Constant Acceleration:

$$v = v_0 + at$$

$$x = x_0 + v_0t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$\bar{v} = (v + v_0) / 2$$

$$g = 9.80m / s^2 \approx 10m / s^2$$

Friction: $f_s \leq \mu_s N$, $f_k = \mu_k N$

Weight: $F_g = mg$

Angular velocity:

$$\omega_{av} = \frac{\Delta\theta}{\Delta t}$$

$$v = \omega r$$

$$s = \theta r$$

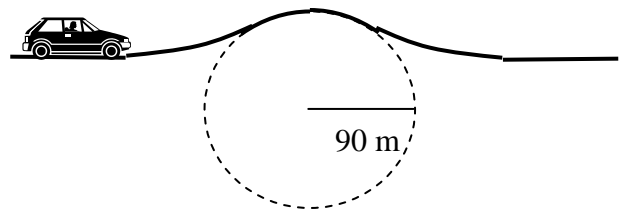
Uniform Circular Motion: $a_c = v^2 / r$

Kepler's 3rd law: $T = \left(\frac{2\pi}{\sqrt{GM_s}} \right) r^{3/2}$

- 1) It is desired that the outer edge of a grinding wheel 10 cm in radius move at a rate of 5.0 m/s.
 - (a) Determine the angular speed of the wheel.
 - (b) What length of thread could be wound on the rim of the wheel in 5.0 sec when it is turning at this rate?

- 2) A jetliner traveling at 500 km/h is turning in a circle of radius 5 km. What is its centripetal acceleration?

- 3) A car of mass 1000 kg is driving along the highway at a constant speed of 30 m/s when it encounters a small hill in the road. The hill has a radius of curvature of 90 meters, as shown in the sketch to the right. The car maintains a constant speed of 30 m/s as it drives over the bump.



- a) Make a FBD for the car when it is at the exact top of the hill.

- b) Write out Newton's 2nd Law in the vertical direction. (Hint: At the top of the hill, what is the car's acceleration?) Then determine the normal force acting on the car when it is at the top of the hill, assuming that $g = 10 \text{ m/s}^2$. Describe in words what has happened to this car.
- c) Is it safe to assume that the normal force on an object is always equal to its weight? What is the best way to determine the normal force acting on something?
- d) Now make a FBD for the car at some arbitrary point along its motion on the curved hill. Using Newton's 2nd Law, determine the conditions under which the car will leave the road. Is the top of the hill the most likely place for this to happen?

Check Point

- Which force or forces are acting as the "centripetal force" in this problem? Is the centripetal force always a single force, or can it be a combination of forces?
- Suppose the car was going faster than 30 m/s when it encountered the hill. What does your expression for the normal force indicate in that case? Can a normal force be negative in magnitude?
- How much force, as a function of angle, must friction supply to the car if it is to maintain constant speed on the hill?

- 4) You are driving your car (of mass M) at constant speed around a curve on a horizontal road.
 - a) Make a FBD for the car, and then write out Newton's 2nd Law in both the horizontal and the vertical direction.
 - b) Determine the normal force acting on the car, in terms of symbols.
 - c) If the radius of curvature of the road is 40 meters and the road is dry concrete, find the maximum speed the car can go without skidding. You can take $g = 10 \text{ m/s}^2$. (Hint: the coefficient of static friction between rubber and dry concrete is approximately 1.0.)
 - d) Repeat part d) but assume that the road is wet concrete. The coefficient of static friction between rubber and wet concrete is approximately 0.7.

Check Point

- Can you summarize the circumstances under which the normal force on an object is equal to the object's weight?
- How can static friction (as opposed to kinetic friction) apply to the case of a moving car?
- Why are the coefficients of friction given as approximate, rather than exact values?

- 5) A ball of mass M is attached to a string, and you swing the ball in a vertical circle of radius R at constant speed v .
 - a) Where in the motion of the ball do you expect to feel the greatest tension in the string?
 - b) Find the tension in the string at 3 different places: the top of the circle, the bottom of the circle, and the side of the circle. Your answers should be symbolic.

- c) After you've solved the problem symbolically, you can substitute $M = \frac{1}{2} \text{ kg}$, $R = 1 \text{ m}$ and $v = 6 \text{ m/s}$ to get numerical answers.

**Check
Point**

- *What force or forces are acting as the centripetal force in each case?*
- *About how many revolutions per second is the ball making, given the numerical values from part (c)?*

- 6) In each case below make a sketch, indicating with arrows the direction of the *acceleration* of the object. Then make a separate free-body diagram (FBD) for the object. Ignore air resistance.

a) A beer glass is on top of a record turntable, near the edge. The turntable is rotating, and the glass is moving along with the rotating turntable at constant speed, without slipping.

b) A car is moving at a constant speed around a curve on a horizontal road.

c) The Earth is orbiting the Sun in an approximately circular orbit with constant speed.

**Check
Point**

- *What is the direction of the net force in each of your free-body diagrams*
- *Which force or forces are supplying the net force in each case? Can a net force ever consist of a combination of forces? Try to think of an example where this is the case.*

- 7) a) Determine the mass of the sun assuming the distance from the earth to the sun to be $1.5 \times 10^{11} \text{ m}$.

b) A geo-synchronous satellite is one that stays above the same point on the equator of the earth. Such satellites are used for purposes as cable TV transmission, for weather forecasting, and as communication relays. What is the height above the earth's surface such a satellite must orbit?

**Check
Point**

- *Do lower orbit satellites move faster or slower?*

Additional Questions

- 1) When you go around a curve in your car, you feel "thrown" to the outside of the car. What is causing this feeling?
- 2) A washing machine uses a spin cycle to rapidly remove large quantities of water from wet clothes. Give a physics description (i.e. in terms of forces, acceleration and Newton's Laws) of how this works.
- 3) Is it possible to whirl a ball (attached to a string) in a circle in the air with the string *horizontal*? If you're not sure, try making a FBD.