Circular Motion
Physics - Mr. Jones
Circular Motion

Describes a revolving or rotating object

- Revolution: an object following a circular path
- Rotation: a solid object spinning around its center of mass
Rotational speed

• How many times the object revolves or rotates per unit of time

• Measured in revolutions per minute (RPM), rotations per second, etc

• a.k.a. frequency
Period

- Duration of time for one revolution/rotation/cycle of object

\[
\text{period} = \frac{1}{\text{frequency}} \quad T = \frac{1}{f}
\]

- Units: seconds, minutes, etc
Example

- The earth requires 24 hours (period of rotation) to rotate once on its axis. What is the frequency of rotation for the earth:

  a) in rotations per hour?

  b) in rotations per minute?

  a) in rotations per second?
Example #2

- A race car travels around an elliptical track 45 times per hour. On average, how much time does it take for the car to make one lap?
Tangential speed

- a.k.a. linear speed

\[ v = \frac{2\pi r}{T} \]

- Units: m/s, mph, etc
- Varies directly with the radius, r
Is the object accelerating?

- It is continuously changing direction
- Centripetal acceleration
  - “center seeking”
- $a_c$ is toward the center of revolution
- Varies directly with radius
- Units: m/s²

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

- Toward the center of revolution
- A force must cause an object to follow a circular path
  \[ F_c = \frac{mv^2}{r} \]
- Units: Newton
- Varies directly with radius
What about **centrifugal** force?

- An object’s inertia tends to make it move in a straight line (Newton’s 1st Law)
- You feel like you are being “pulled outward”
- It’s a false force!
The Centripetal Force

- $F_c$ is a “job” not a new type of force
The Centripetal Force

- It makes an object travel in a circle (revolve)

What fundamental type of force is it?

What does the force do to an object?
The Centripetal Force

- The object accelerates!

What fundamental type of force is it?

F_c

How does the object respond?

What does the force do to an object?

What fundamental type of force is it?
What force? The centripetal force

- Any type of force can act as the centripetal force
  - push, tension, gravity, etc

- $F_c$ is toward the center of revolution

- Examples:
  - Spin cycle
  - Twirling ball
  - Amusement park ride
  - Curved road
Experiencing centripetal force

• When you round a curve in your car, do you feel a force?
  – What direction is that force?
  – Centrifugal versus centripetal force

• Ever ride a spinning amusement ride?
  – What’s your favorite?
Example

- A ball is twirled on a string such that the ball makes 50 revolutions per minute. What is the ball’s tangential velocity and centripetal acceleration if the string is:
  
  a) 1.0 m long
  
  b) 2.0 m long
Example

• A 200-kg satellite is 1000 kilometers above the surface of the earth. The satellite’s orbit is designed such that the satellite remains above Brazil at every moment.
  a) What is the period of the satellite’s orbit?
  b) What is the tangential speed of the satellite in kilometers per hour?
  c) What is the centripetal acceleration of the satellite in m/s²?
  d) What is the centripetal force on the satellite in Newtons?
  e) What fundamental force is responsible for this?
Conceptual review questions

Circular Motion
Questions

• Distinguish between tangential speed and rotational speed

• At a given distance from the axis, how does tangential (or linear) speed change as the frequency changes?
  - In other words, if rotational speed doubles, what happens to tangential speed?
Sample answers

• Distinguish between tangential speed and rotational speed
  – Tangential speed is the distance per time (e.g. m/s) traveled by an object as it revolves in a circular path. Rotational speed is the number of revolutions or rotations per unit of time, measured in units such as RPM.

• At a given distance from the axis, how does tangential (or linear) speed change as the rotational speed changes?
  – In other words, if rotational speed doubles, what happens to tangential speed?
    • The tangential speed is directly related to the rotational speed. If the rotational speed doubles, the tangential speed also doubles.
Questions

• At a given rotational speed, how does tangential speed change as the distance from the axis (radius) changes?
  – In other words, if the radius doubles, what happens to the tangential speed?

• When you whirl an object (e.g. toy plane) at the end of a string in a circular path, what is the direction of the force that acts on the object?

• Does an inward force or an outward force act on the clothes during the spin cycle of a clothes washer?
Sample answers

• At a given rotational speed, how does tangential speed change as the distance from the axis (radius) changes?
  – In other words, if the radius doubles, what happens to the tangential speed?
    • The tangential speed is directly related to the radius. If the radius doubles, the tangential speed also doubles.

• When you whirl an object (e.g. toy plane) at the end of a string in a circular path, what is the direction of the force that acts on the object?
  – The force acts toward the center of the path.

• Does an inward force or an outward force act on the clothes during the spin cycle of a clothes washer?
  – An inward force acts on the clothes. It is supplied by the walls of the washer.
Questions

• If you lose your grip on a rapidly spinning merry-go-round and fall off, in which direction will you fly?

• A ladybug sits halfway between the axis and edge of a rotating turntable (record player). What will happen to the ladybug’s tangential speed if:
  a) the RPM rate is doubled?
  b) the ladybug moves and now sits at the edge?
  c) both a) and b) occur?
Sample answers

• If you lose your grip on a rapidly spinning merry-go-round and fall off, in which direction will you fly?
  – You will fly in a straight line that is tangent to your original circular path.

• A ladybug sits halfway between the axis and edge of a rotating turntable (record player). What will happen to the ladybug’s tangential speed if:
  a) the RPM rate is doubled?
    – The tangential speed will double.
  b) the ladybug moves and now sits at the edge?
    – The radius doubles, so the tangential speed will double.
  c) both a) and b) occur?
    – The tangential speed will quadruple (2 x 2).
Questions

• When a car makes a turn, do seat belts provide you with a centripetal force or centrifugal force?

• If the string that holds a whirling toy in its circular path breaks, what causes the can to move in a straight-line path -- centripetal force, centrifugal force, or a lack of force?
  – What law of physics supports your answer?
Sample answers

• When a car makes a turn, do seat belts provide you with a centripetal force or centrifugal force?
  – Seatbelts provide a centripetal force that makes your body travel in a circular path

• If the string that holds a whirling toy in its circular path breaks, what causes the can to move in a straight-line path -- centripetal force, centrifugal force, or a lack of force?
  – What law of physics supports your answer?
    • A lack of force causes the toy to move in a straight line. According to Newton’s 1st law, the toy moves in a straight line due to inertia.
Questions

• Which state in the United States has the greatest tangential speed as the earth rotates on its axis?

• The speedometer in a car is driven by a cable connected to the shaft that turns the car’s wheels. Will speedometer readings be more or less than the actual speed if the car’s wheels are replaced with smaller ones?
Sample answers

• Which state in the United States has the greatest tangential speed as the earth rotates on its axis?
  – In the continental U.S., Florida has the greatest tangential speed because it is farthest from the axis of the earth’s rotation (the southern tip of Florida, at least). All states have the same rotational speed or frequency of rotation.

• The speedometer in a car is driven by a cable connected to the shaft that turns the car’s wheels. Will speedometer readings be more or less than the actual speed if the car’s wheels are replaced with smaller ones?
  – The speedometer readings will be more than the actual speed because the speedometer is calibrated for a certain distance traveled for each rotation of a specific size tire.
Questions

• When a soaring hawk turns during its flight, what is the source of the centripetal force acting on it?

• Does centripetal force do work on a revolving object?
  – Hint: Consider the direction of centripetal force and the direction of motion.
  – Hint #2: Are they perpendicular or parallel?
Sample answers

• When a soaring hawk turns during its flight, what is the source of the centripetal force acting on it?
  – A force caused by air moving past its wings acts as the centripetal force. (We will learn more about this when we study Bernoulli’s force in the near future!)

• Does centripetal force do work on a revolving object?
  – Hint: Consider the direction of centripetal force and the direction of motion.
  – Hint #2: Are they perpendicular or parallel?
    • Centripetal force does no work on a revolving object because this force is perpendicular to the direction of motion or displacement. Only a force (or component of a force) that is parallel to an object’s motion does work on the object.