

# Circular Motion and Gravity

IB 11

## Uniform Circular Motion:

Cycle:

Period:

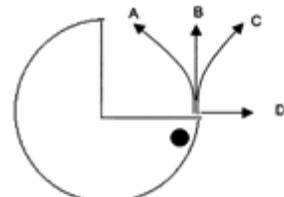
Symbol:

Formula for Period:

Units:

Average Speed

Which path will the marble take? Why? Explain using one of Newton's Laws.

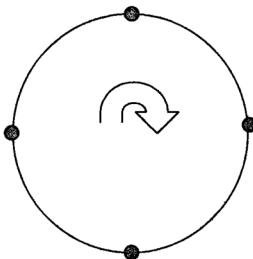


## Instantaneous Velocity (linear velocity, tangential velocity)

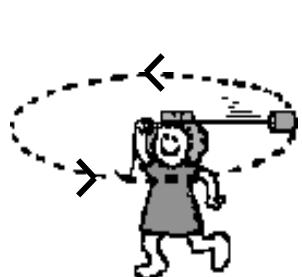
Magnitude:

Sketch the instantaneous velocity vectors for the marble at each location shown at right.

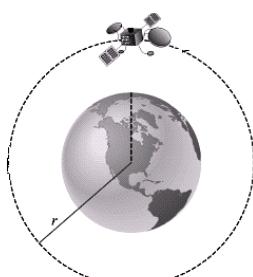
Direction:



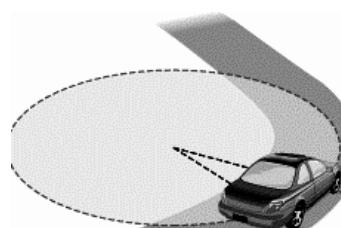
Draw and label the force causing the circular motion in each case below.



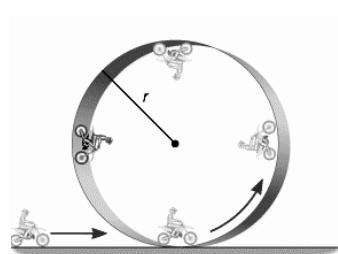
a) rubber stopper on a string



b) satellite circling Earth



c) car rounding a curve



d) motorcycle stunt

1. In each case, what is the direction of the force causing the circular motion?
2. Are these objects accelerating, even if they are moving at a constant speed?
3. In which direction are they accelerating?
4. Are objects moving in circular motion ever in equilibrium? Explain.

## Centripetal Force:

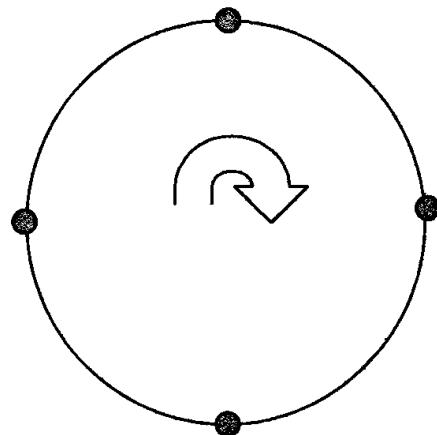
Symbol:

## Centripetal Acceleration:

Symbol:

Sketch and label the instantaneous velocity, force, and acceleration for the marble at each location in the diagram.

Compare the directions of the instantaneous velocity, force, and acceleration for an object in uniform circular motion.



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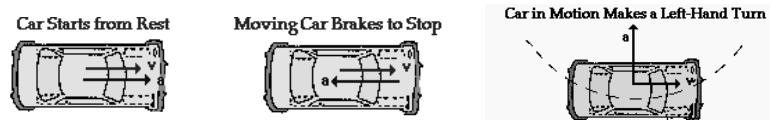
**NOTE:** The phrase “centripetal force” does not denote a new and separate force of nature. The phrase is merely another name for the net force pointing toward the center of the circular path. The centripetal force always has another name, such as  $F_g$ ,  $F_N$ ,  $F_T$ ,  $F_f$ , or any combination of these.

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Centripetal force:

How is the acceleration of a car related to the forces you feel as a rider in the car?

Centrifugal force:



A car traveling down the road makes a quick left-hand turn. Explain, using Newton's laws and a different frame of reference, how any “centrifugal” force you feel can be explained as a centripetal force.



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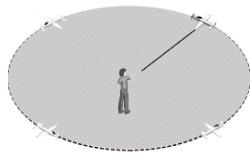
Centripetal Acceleration

Centripetal Force

Centripetal Force is the Net Force!

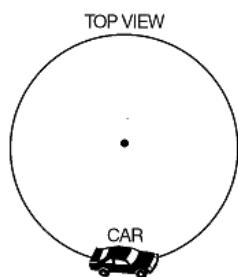
1. A boy flies a 0.750-kg motorized plane on a 2.3 m string in a circular path. The plane goes around 8.0 times in 12.0 seconds. Determine the following:

  - a) the period of revolution
  - b) the speed of the plane
  - c) the acceleration of the plane
  - d) the tension in the string



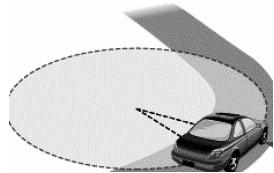
2. A 1.5 kilogram toy car moves on a circular track of 1.3 meter radius at a constant speed of 2.0 meters per second. Determine the following:

  - a) the time it takes to go around the track once
  - b) the centripetal acceleration of the cart
  - c) the centripetal force acting on the cart
  - d) What is causing this force?



3. A 2000. kg car attempts to turn a corner going at a speed of 25 m/s. The radius of the turn is 15 meters.

a) How much friction is needed to negotiate this turn successfully?



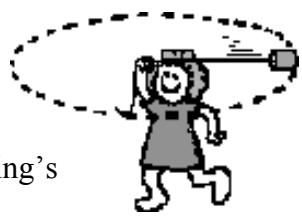
b) If the pavement is dry asphalt, will the car be able to safely turn? Justify your answer.

c) Derive an expression for the maximum speed with which a car of mass  $m$  can safely make a turn around a curve of radius  $r$ .

4. At amusement parks, there is a popular ride where the floor of a rotating cylindrical room falls away, leaving the backs of the riders “plastered” against the wall. What is the minimum coefficient of static friction that must exist between a rider's back and the wall, if the rider is to remain in place when the floor drops away?



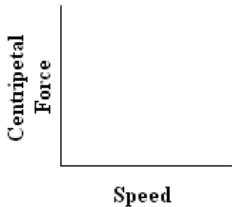
1. A student swings a rubber stopper around on a string at a constant speed with a centripetal acceleration of  $6.0 \text{ m/s}^2$ , as shown. What would happen to the acceleration if:



- a) the speed is doubled?
- b) the speed is halved?
- c) the string's length is tripled?
- d) the speed is doubled and the string's length is halved?
- e) the mass of the stopper is doubled?
- f) What would happen to the tension in the string if the mass is doubled and the speed is halved?

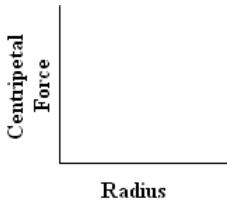
## Graphical Relationships

2. What is the relationship between centripetal force and speed?



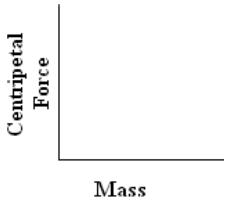
Control:

3. What is the relationship between centripetal force and radius?



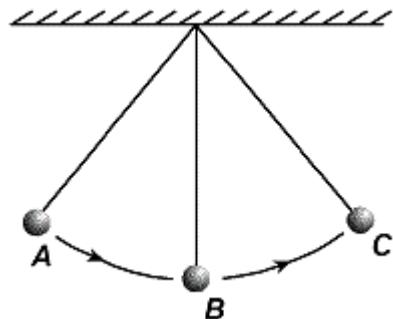
Control:

4. What is the relationship between centripetal force and mass?



Control:

1. Is a swinging pendulum in equilibrium? Explain.



2. Is a swinging pendulum in uniform circular motion? Justify your answer.

3. Compare the tension in the pendulum's string as it swings.

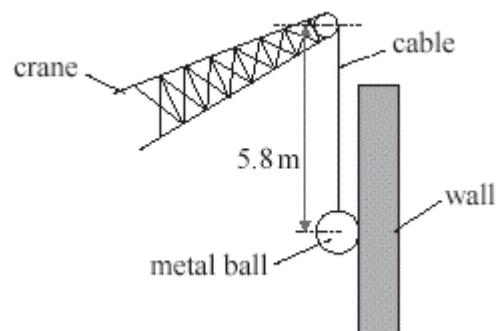
4. Compare the tension in a swinging pendulum to one that is hanging motionless. Sketch appropriate diagrams to aid your explanation.

**Hanging**

**Swinging**

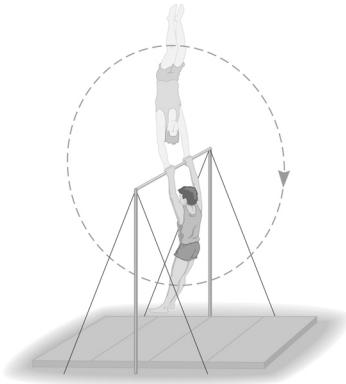
5. A 2100-kg demolition ball is attached to the end of a 5.8-m cable.

- a) Determine the tension in the cable as the ball hangs motionless.

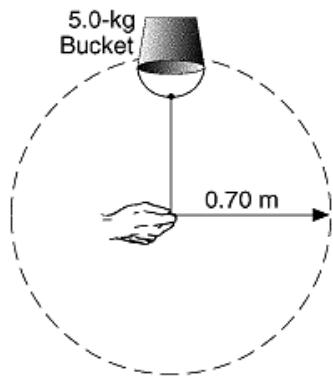


- b) The ball is pulled back and released. At the lowest point of the swing, the ball is moving at a speed of 7.6 m/s. Determine the tension in the cable upon impact with the wall.

6. How much force does this 55 kilogram gymnast need to hold onto the bar as they swing through the bottom of their swing at 3.4 meters per second? Assume their center of mass is approximately 0.80 meter from their outstretched hands.



7. a) What is the maximum speed that this bucket can have at the bottom of its swing if the breaking strength of the rope is 100. newtons?

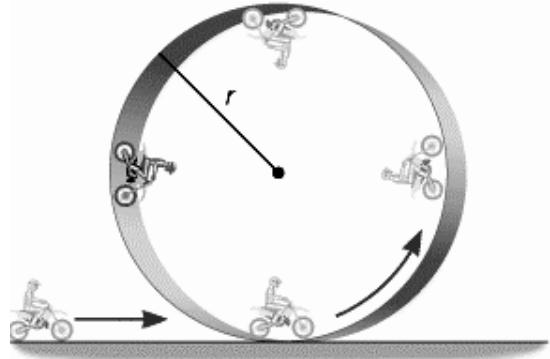


- b) What is the minimum speed the bucket must have at the top of its swing to make it around without the water falling out?

8. a) Compare the force exerted by the track on the cyclist at the top and the bottom.

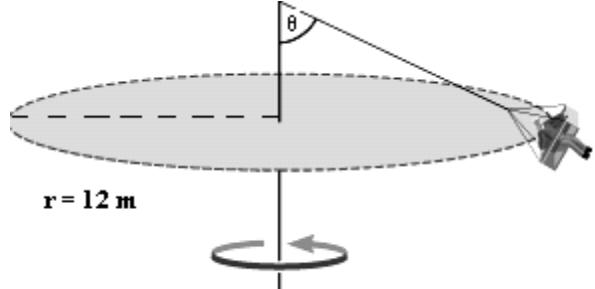
Bottom:

Top:



- b) Derive an expression for the minimum speed the cyclist must have at the top to successfully make it around the track without falling.

9. A student decides to go on the chair swing ride at an amusement park. Together the student and the chair have a combined mass of 80. kilograms and the chain makes an angle of  $25^\circ$  with the vertical as shown. Determine the tension in the chain and the speed of rotation of the ride.



Law of Universal Gravitation:

Published in:

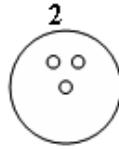
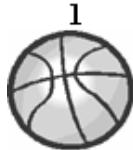
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Two identical basketballs are floating in deep space.



- a) What will happen?
- b) If basketball #1 pulls on basketball #2 with a force of 10. N, how strongly does basketball #2 pull on basketball #1?
- c) Explain this behavior using one of Newton's laws of motion.
- d) Compare the accelerations of the two basketballs.

Basketball #2 is now replaced with a bowling ball.



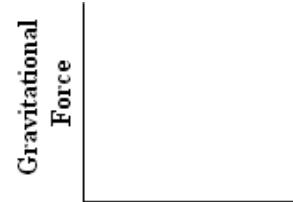
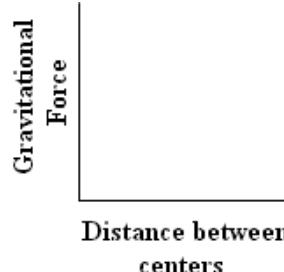
- e) If the mass of the bowling ball is approximately 20 times the mass of the basketball, how strong is the new force pulling on basketball #1?
- f) How much force does the basketball exert on the bowling ball?
- g) Compare the accelerations of the two balls.

## Calculating the Force of Gravity

IB 11

Variable	$F_g$	$G$	$m$	$r$
Quantity				
Units				
Type				

Graphical relationships



Formula

inverse square law:

1. Calculate the gravitational force of attraction between a basketball and a bowling ball that are 1.50 meters apart.
2. Calculate the force holding the Moon in orbit around the Earth.

3. a) Calculate the gravitational force of attraction between you and the Earth.



- b) For an object on or near the surface of a planet . . .
- c) What is another name for this force? Demonstrate this.

- 
4. a) What is the gravitational force of attraction between a 60. kilogram student and the Earth if the student is in a plane at an altitude of  $6.37 \times 10^6$  m?



- b) When an object is above the surface of a planet . . .
- c) How could your answer to (a) be arrived at by proportional reasoning?

Gravitational field:

Sketch the gravitational field of the Earth



**Gravitational Force**

**Gravitational Field Strength**



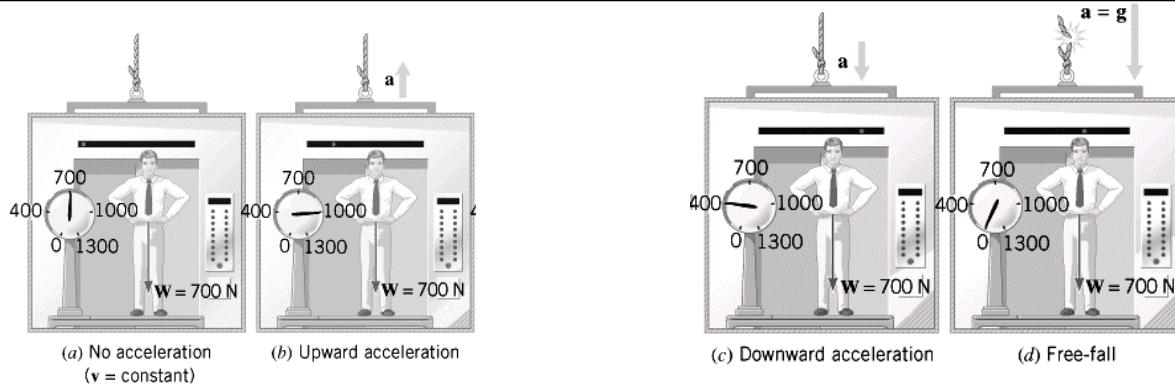
Variable	<b>Fg</b>	<b>G</b>	<b>g</b>
Quantity			
Units			
Type			
Property			

1. Calculate the Earth's gravitational field strength:

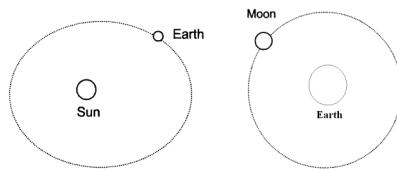
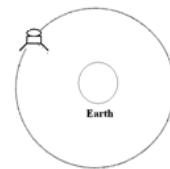
- a) at the surface of Earth.      b) at an altitude equal to one Earth radius.

2. The International Space Station (ISS) orbits at an average altitude of 340 kilometers. How strong is the Earth's gravitational field at this altitude?
3. Planet X has the same mass as Earth but only half the diameter. What is the gravitational field strength on the surface of this planet?

### Weight and Weightlessness - Riding in an Elevator



1. When does the scale read the normal weight of the person?
2. When does the scale read higher than the normal weight of the person?
3. When does the scale read less than the normal weight of the person?
4. What does a scale reading actually measure?
5. Determine the acceleration of the elevator in cases (b) and (c).

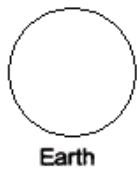
**Satellite:**
**Natural Satellites**

**Artificial Satellites**


- How can an object become a satellite?

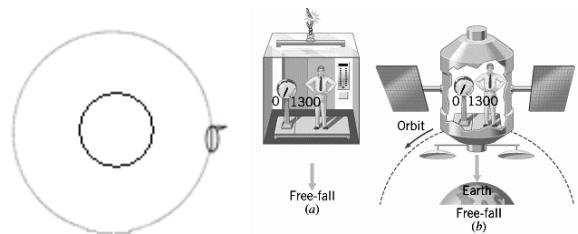


- What keeps a satellite up?

- Why doesn't the Moon fall into the Earth as an apple does?

**Real weightlessness**


**Apollo 13**


**Apparent weightlessness**


- Why did the Apollo astronauts feel weightless?

- Why do the space shuttle astronauts feel weightless?

**Artificial Gravity**

- How can gravity be simulated in a space station?

- How fast would this 20. meter diameter space station have to spin to simulate Earth's gravity?

