Speed and Velocity

Read from **Lesson 1** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l1a.html

MOP Connection: Circular Motion and Gravitation: sublevel 1

Review:

1. A quantity that is fully described by magnitude alone is a ___________ quantity. A quantity that is fully described by both magnitude and direction is a ___________ quantity.
   a. scalar, vector b. vector, scalar

2. Speed is a ____________ quantity. Velocity is a ____________ quantity.
   a. scalar, vector b. vector, scalar c. scalar, scalar d. vector, vector

3. State the equation for calculating the average speed of an object:

Circular Motion:

4. An object which moves uniformly in a circle can have a constant ___________________ but a changing ___________________ .
   a. speed, velocity b. velocity, speed

5. The direction of a velocity vector is always ______. Circle all that apply.
   a. in the same direction as the net force that acts upon it
   b. in the opposite direction as the net force that acts upon it
   c. in the same direction as the object is moving
   d. in the opposite direction as the object is moving
   e. ... none of these!

6. **True** or **False**:

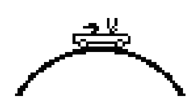
   The direction of the velocity vector of an object at a given instant in time depends on whether the object is speeding up or slowing down.

7. For an object moving in uniform circular motion, the velocity vector is directed _____.
   a. radially inwards towards the center of the circle
   b. radially outwards away from the center of the circle
   c. in the direction of the tangent line drawn to the circle at the object's location

8. Use your average speed equation to determine the speed of ... . (Given: Circumference = 2•PI•R)
   a. ... a rider on a carousel ride that makes a complete revolution around the circle (diameter = 21.2-meter) in 17.3 seconds. **PSYW**

   b. ... your clothes that are plastered to the wall of the washing machine during the *spin* cycle. The clothes make a complete revolution around a 61.9-cm diameter circle in 0.285 seconds. **PSYW**

9. A roller coaster car is traveling over the crest of a hill and is at the location shown. A side view is shown at the right. Draw an arrow on the diagram to indicate the direction of the velocity vector.



Acceleration and Circular Motion

Read from **Lesson 1** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l1b.html

MOP Connection: Circular Motion and Gravitation: sublevel 2

Review:

1. Accelerating objects are _____. Choose the one *most inclusive* answer.
   a. going fast
   b. speeding up (only)
   c. speeding up or slowing down
   d. changing their velocity

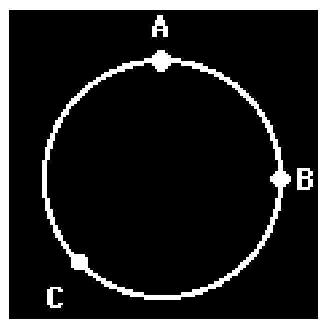
2. Identify the three controls on an automobile that are responsible for causing the car to accelerate.

Acceleration and Circular Motion:

3. A car that is moving in a circle at a constant speed of 30 mi/hr is _____.
   a. not accelerating since there is no change in velocity
   b. not accelerating despite the fact that there is a change in velocity
   c. accelerating since there is a change in velocity
   d. accelerating despite the fact there is no change in velocity.
   e. accelerating, but not for either reason mentioned above.

4. An object that is moving in a circle at a constant speed has a velocity vector that is directed ________and an acceleration vector that is directed ________.
   a. tangent to the circle, tangent to the circle
   b. tangent to the circle, outwards
   c. tangent to the circle, inwards
   d. inwards, tangent to the circle
   d. inwards, outwards
   f. outwards, tangent to the circle

5. An object moves in a clockwise direction along the circular path as shown in the diagram at the right. Three points along the path are labeled - A, B and C. For each location, **draw** a straight-line vector arrow in the direction of the velocity vector; label this vector as **v**. Then **draw** a straight-line vector arrow in the direction of the acceleration vector; label this vector as **a**.



6. An object that is moving in uniform circular motion will **definitely** have a large acceleration if it is _____.
   a. moving very fast
   b. moving along a sharp turn
   c. turning at a rapid rate

   Justify your answer:

> **Interesting Fact:**
> The moon orbits about the Earth with an average speed of just over 1000 m/s; yet its acceleration is less than 0.003 m/s^2. The moon is a fast-moving object with a low acceleration.

Uniform Circular Motion Simulation

Purpose:

The purpose of this activity is to explore the characteristics of the motion of an object in a circle at a constant speed.

Procedure and Questions:

1. Navigate to the **Uniform Circular Motion** page (in the **Shockwave Physics Studios** section of the web site) and experiment with the on-screen buttons in order to gain familiarity with the control of the animation. The object speed, radius of the circle, and object mass can be varied by using the sliders or the buttons. The vector nature of velocity and acceleration can be depicted on the screen. A trace of the object's motion can be turned on, turned off and erased. The acceleration of and the net force acting upon the object are displayed at the bottom of the screen. The animation can be started, paused, continued or rewound.

   After gaining familiarity with the program, use it to answer the following questions:

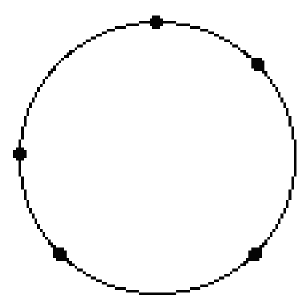
2. Velocity is a vector quantity that has both magnitude and direction. Using complete sentences, describe the object's velocity. Comment on both the magnitude and the direction.

3. **TRUE or FALSE?**

   If an object moves in a circle at a constant speed, its velocity vector will be constant.

   Explain your answer.

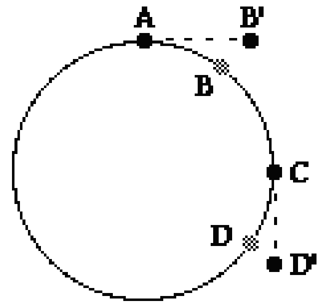
4. In the diagram at the right, a variety of positions about a circle are shown. Draw the velocity vector at the various positions; direct the **v** arrows in the proper direction and label them as **v**. Draw the acceleration vector at the various positions; direct the **a** arrows in the proper direction and label them as **a**.



5. Describe the relationship between the direction of the velocity vector and the direction of the acceleration for a body moving in a circle at constant speed.

6. **A Puzzling Question to Think About:** If an object is in uniform circular motion, then it is accelerating towards the center of the circle; yet the object never gets any closer to the center of the circle. It maintains a circular path at a constant radius from the circle's center. Suggest a reason as to how this can be. How can an object accelerate towards the center without ever getting any closer to the center?

7. **A "Thought Experiment":** Suppose that an object is moving in a clockwise circle (or at least trying to move in a circle).



Suppose that at point A the object traveled in a straight line at constant speed towards B'. In what direction must a force be applied to force the object back towards B? Draw an arrow on the diagram in the direction of the required force.

Repeat the above procedure for an object moving from C to D'. In what direction must a force be applied in order for the object to move back to point D along the path of the circle? Draw an arrow on the diagram.

If the acceleration of the body is towards the center, what is the direction of the unbalanced force? Using a complete sentence, describe the direction of the net force that causes the body to travel in a circle at constant speed.

8. **Thinking Mathematically:** Explore the quantitative dependencies of the acceleration upon the speed and the radius of curvature. Then answer the following questions.

a. For the same speed, the acceleration of the object varies ____________ (directly, inversely) with the radius of curvature.

b. For the same radius of curvature, the acceleration of the object varies ____________ (directly, inversely) with the speed of the object.

c. As the speed of an object is doubled, the acceleration is _________________ (one-fourth, one-half, two times, four times) the original value.

d. As the speed of an object is tripled, the acceleration is _________________ (one-third, one-ninth, three times, nine times) the original value.

e. As the radius of the circle is doubled, the acceleration is _________________ (one-fourth, one-half, two times, four times) the original value.

f. As the radius of the circle is tripled, the acceleration is _________________ (one-third, one-ninth, three times, nine times) the original value.

Conclusion:

Write a conclusion to this lab in which you completely and intelligently describe the characteristics of an object that is traveling in uniform circular motion. Give attention to the quantities speed, velocity, acceleration and net force.

Circular Motion and Inertia

Read from **Lesson 1** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l1c.html
http://www.physicsclassroom.com/Class/circles/u6l1d.html

MOP Connection: Circular Motion and Gravitation: sublevels 3 and 4

Review Questions:

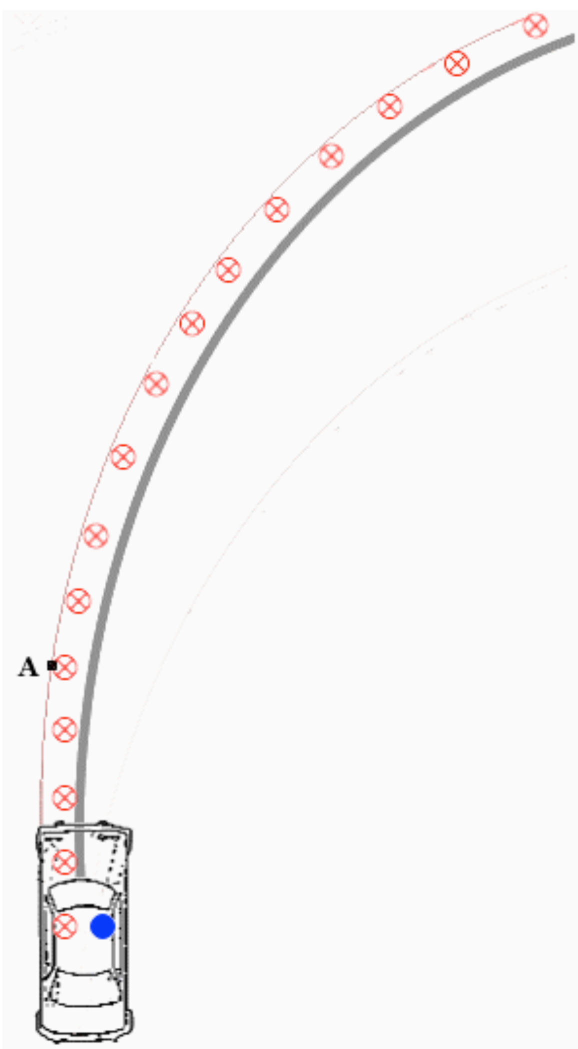
1. Newton's first law states: An object at rest will ________________________________.

   An object in motion will ____

   unless acted upon by ____.

2. Inertia is ...

Applications of Newton's First Law to Motion in Circles:
The diagram below depicts a car making a right hand turn. The driver of the car is represented by the *circled X*. The passenger is represented by the solid circle. The seats of the car are vinyl seats and have been greased down so as to be *smooth as silk*. As would be expected from Newton's law of inertia, the driver continues in a straight line from the start of the turn until point A. The path of the driver is shown. Once at point A, the door pushes the driver inward towards the center of the circle. With an inward force, the driver can make the circular turn.



3. On the same diagram, show the path of the passenger from the start of the turn until the passenger strikes the driver. Mark the passenger's position with a solid circle. Put a dot at the point where the driver and passenger *make contact*; label this as point B.

4. Describe the motion of the passenger from the start of the turn until point B.

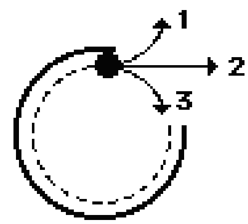
   Describe the motion of the passenger from point B for the rest of the turn.

5. From point B for the remainder of the turn, place arrows on the diagram to indicated the direction of the force of the driver pushing on the passenger. Label these arrows with an **F**.

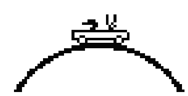
6. In this example, the collision between the passenger and the driver can be explained by exerting that _____ .
   a. an outward force pushed the passenger towards the driver.
   b. an outward force pulled the passenger towards the driver.
   c. the passenger traveled straight ahead and an inward force pushed the driver into the passenger.

7. Rex Things and Doris Locked are out on a date. Rex makes a rapid right-hand turn. Doris begins sliding across the vinyl seat (which Rex had waxed and polished beforehand) and collides with Rex. To break the awkwardness of the situation, Rex and Doris begin discussing the physics of the motion that was just experienced. Rex suggests that objects that move in a circle experience an outward force. Thus, as the turn was made, Doris experienced an outward force that pushed her towards Rex. Doris disagrees, arguing that objects that move in a circle experience an inward force. In this case, according to Doris, Rex traveled in a circle due to the force of his door pushing him inward. Doris did not travel in a circle since there was no force pushing her inward; she merely continued in a straight line until she collided with Rex. Who is correct? ________ Argue one of these two positions.

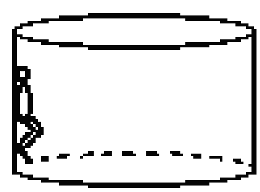
8. Noah Formula guides a golf ball around the outside rim of the green at the *Hole-In-One Putt-Putt Golf Course*. When the ball leaves the rim, which path (1, 2, or 3) will the golf ball follow? ___________ (Note that this diagram depicts the *God's eye* view.) Explain why.

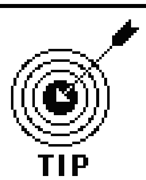


9. Suppose that you are a driver or passenger in a car and you travel over the top of a small hill in the road at a high speed. As you reach the crest of the hill, you feel your body still moving upward; your *gluts* might even be *pulled* off the car seat. It might even feel like there is an upward push on your body. This upward sensation is best explained by the ______.
a. tendency of your body to follow its original upward path
b. presence of an upward force on your body
c. presence of a centripetal force on your body
d. presence of a centrifugal force on your body



10. Darron Moore is on a *barrel ride* at an amusement park. He enters the barrel and stands on a platform next to the wall. The ride operator flips a switch and the barrel begins spinning at a high rate. Then the operator flips another switch and the platform drops out from under the feet of the riders. Darron is *plastered* to the wall of the barrel. This sticking to the wall phenomenon is explained by the fact that ________.
a. the ride exerts an outward force on Darron that pushes him outward against the wall
b. Darron has a natural tendency to move tangent to the circle but the wall pushes him inward
c. air pressure is reduced by the barrel's motion that causes a suction action toward the wall
d. the ride operator coats the wall with cotton candy that causes riders to stick to it





Learning to Learn Strategy

Always take time to reflect upon your own belief system that governs how you interpret the physical world. Be aware of your personal "mental model" which you use to explain why things happen. The idea of this physics course is **not** to acquire information through memorization but rather to analyze your own preconceived notions about the world and to dispel them for more intelligible beliefs. In this unit, you will be investigating a commonly held misconception about the world - that motion in a circle is caused by an outward (centrifugal) force. This misconception or wrong belief is not likely to be dispelled unless you devote some time to reflect on whether you believe it and whether it is intelligible. After considering more reasonable beliefs, you will be more likely to dispel the belief in a centrifugal force in favor of a belief in an inward or centripetal force.

The Centripetal Force Requirement

Read from **Lesson 1** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l1c.html

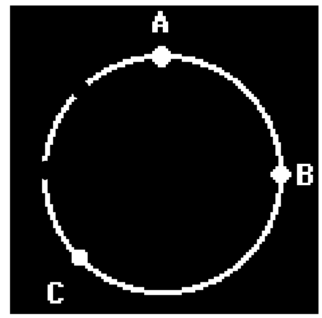
MOP Connection: Circular Motion and Gravitation: sublevels 2 and 4

Review Questions:

1. The net force acting upon an object is _________ as the direction of the object's acceleration.
   a. in the same direction b. in the opposite direction
   c. ... nonsense! There is no simple rule which relates the direction of the **a** and $\mathbf{F_{net}}$ vectors.

2. Consider the top view of the clockwise motion of an object shown at the right. Draw an arrow to indicate the direction of the ...
   a. acceleration vector at location A.
   b. velocity vector at location C.
   c. velocity vector at location D.

   Label your arrows with an **a** (for acceleration) and a **v** (for velocity).



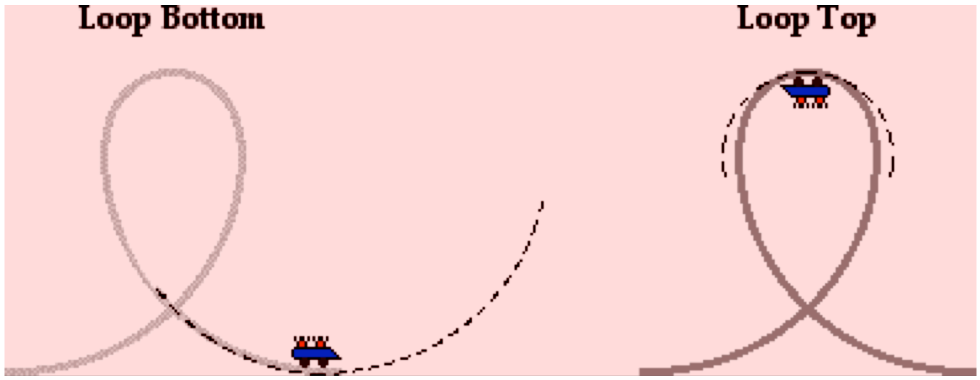
Force Analysis of Circular Motion:
Every instance of the motion of an object in a circle or along a circular turn involves some force that is directed inward or *centripetally*. The centripetal force is an adjective to describe the net force; it is not actually a new force to be added to an already lengthy list - including friction, gravity, applied, tension, normal, spring, air resistance, etc. Rather, the **centripetal force requirement** is a principle that states that in order to have the motion of an object in a circle, there must be an inward net force to sustain the inward acceleration.

3. In each of the following instances, identify the type of the force that fulfills the centripetal force requirement. That is, identify the inward force acting upon the **bold-faced object**.

Description of a Circular-Type Motion	Centripetal Force
a. A **planet** is orbiting the sun.	
b. A **bucket** (filled with water) is held by a string and whirled in a horizontal circle.	
c. **Passengers** on the CliffHanger amusement park ride (a barrel ride) are rotated rapidly in a circle.	
d. The **moon** is orbiting the Earth.	
e. A **car** is making a turn along a level roadway.	
f. A **car** is making a turn along a banked exit ramp.	
g. In football, a **halfback** leans in and rounds the corner to head up field.	
h. A **roller coaster car** is <u>at the top</u> of a circular loop (on the *inside* of the track).	
i. A **roller coaster car** is <u>at the bottom</u> of a circular loop (on the *inside* of the track).	
j. **Clothes** move in a circle during the spin cycle in a washing machine.	

4. Consider the diagram in question #2 on the front side. Draw an arrow on the diagram to indicate the direction of the net force vector at both locations B and E. Label the vector with an **F** (for force).

5. Consider a roller coaster car passing through a clothoid loop. Two strategic positions on the loop are the top and the bottom of the loop. In the diagrams below, draw force vectors on the riders to depict the direction and the magnitude of the two forces acting upon the riders. The size of the force should be approximately equal to the size of the vector arrow. Label the two arrows according to type - F_{grav} and F_{norm}.



6. When the roller coaster car is at the bottom of the loop, the direction of the acceleration and the net force is directed ____________ (up, down). When the roller coaster car is at the top of the loop, the direction of the acceleration and the net force is directed ____________ (up, down).

7. In order for the conditions described in question #6 above to be true, how does the magnitude of the normal force compare to the magnitude of the gravity force at the two locations. Put a greater than (>) or a less than (<) symbol in the blanks below.

   Loop Bottom: F_{norm} _____ F_{grav} Loop Top: F_{norm} _____ F_{grav}

8. A person's sensation of weight is due to the presence of a normal force upon their body. Usually, this normal force is of the same magnitude as the force of gravity. So a 600 Newton person typically feels 600 N of normal force to provide a sensation of how much they weigh. When the normal force becomes greater than or less than the force of gravity, a person has a sensation of feeling heavy or feeling light. Where on the roller coaster loop would a person most likely feel heavy - top or bottom? ____________ Explain your answer.

9. **TRUE** or **FALSE**:

   The centripetal force is a distinctly separate force. It can be added to the list of forces (along with tension, friction, normal, etc.) that might act upon an object.

Mathematics of Circular Motion

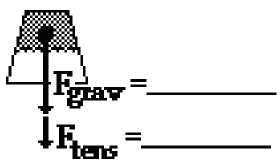
Read from **Lesson 2** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l2a.html
http://www.physicsclassroom.com/Class/circles/u6l2b.html
http://www.physicsclassroom.com/Class/circles/u6l2c.html

MOP Connection: Circular Motion and Gravitation: sublevel 5

1. The verbal descriptions of physical situations and the corresponding free-body diagrams are given below. Use your understanding of Newton's laws and centripetal force to fill in the blanks. **PSYW**

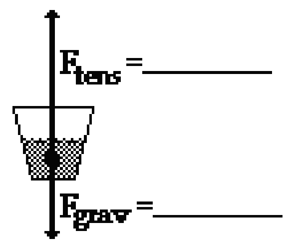
   a. A bucket of water (m=2.0 kg) is attached to a 0.80-m long string and spun in a vertical circle. The speed of the water at the top of the circular path is 3.0 m/s.



   a = ____________ m/s^2, __________ (dir'n)

   F_{net} = ____________ N, __________ (dir'n)

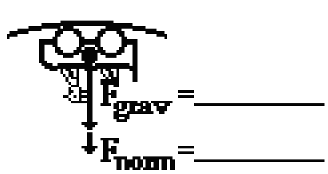
   b. A bucket of water (m=2.0 kg) is attached to a 0.80-m long string and spun in a vertical circle. The speed of the water at the bottom of the circular path is 6.0 m/s.



   a = ____________ m/s^2, __________ (dir'n)

   F_{net} = ____________ N, __________ (dir'n)

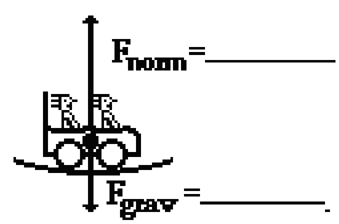
   c. A 500-kg roller coaster car is at the top of the loop on the Shockwave. The radius of the loop is 4.0 m and the speed is 8.0 m/s.



   a = ____________ m/s^2, __________ (dir'n)

   F_{net} = ____________ N, __________ (dir'n)

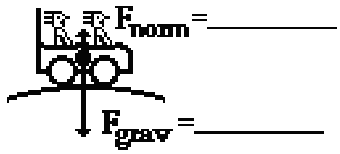
   d. A 500-kg roller coaster car is at the bottom of a loop on the Shockwave. The radius of the loop is 20 m and the speed is 24 m/s.



   a = ____________ m/s^2, __________ (dir'n)

   F_{net} = ____________ N, __________ (dir'n)

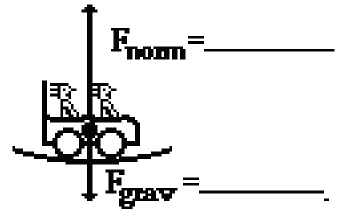
e. A 600-kg roller coaster car is at the top of a hill on the Viper. The radius of the curvature is 22 m and the speed is 14 m/s.



a = ____________m/s², _________ (dir'n)

F_{net} = ____________ N, _________ (dir'n)

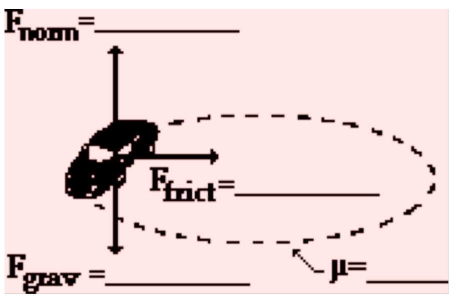
f. A 600-kg roller coaster car is at the bottom of a hill on the Viper. The radius of the curvature is 39 m and the speed is 30 m/s.



a = ____________m/s², _________ (dir'n)

F_{net} = ____________ N, _________ (dir'n)

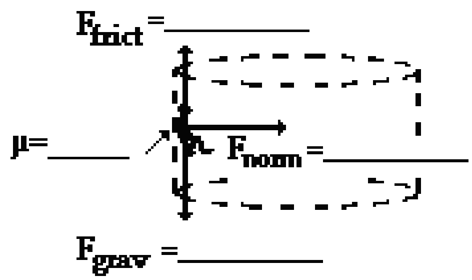
g. A 900-kg car makes a horizontal turn at 15.0 m/s around a curve with a 32.5-m radius of curvature.



a = ____________m/s², _________ (dir'n)

F_{net} = ____________ N, _________ (dir'n)

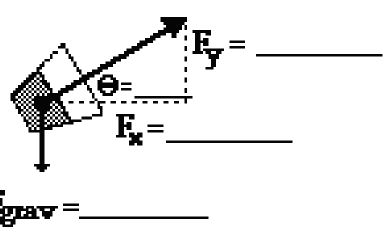
h. A 55-kg passenger on the CliffHanger barrel ride makes a turn at a speed of 6.0 m/s. The barrel radius is 3.0 meters.



a = ____________m/s², _________ (dir'n)

F_{net} = ____________ N, _________ (dir'n)

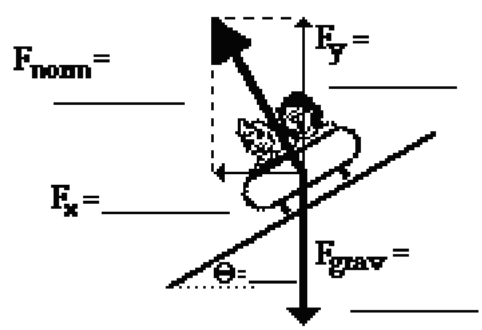
i. A 1.2-kg bucket of water is held by a string and spun in a horizontal circle with a 1.1-m radius. The speed of the bucket is 5.2 m/s.



a = ____________m/s², _________ (dir'n)

F_{net} = ____________ N, _________ (dir'n)

j. Thelma and Louise make a turn at 22.0 m/s in their 1200-kg car. The radius of curvature of the turn is 65.0 meters.

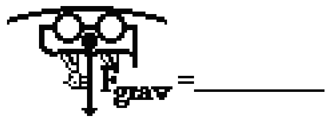


a = ____________m/s², _________ (dir'n)

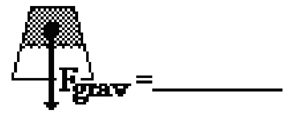
F_{net} = ____________ N, _________ (dir'n)

2. Determine the minimum speed at which .... . (HINT: at this speed, the object becomes a projectile.)

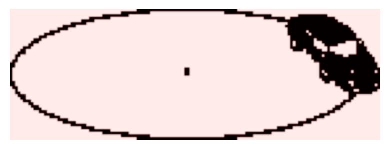
   a. ... the riders on a coaster car feel weightless at the top of a 4.0 m loop.

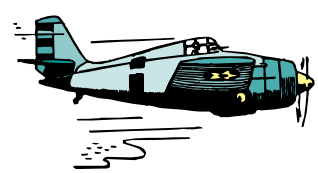
   b. ... the water remains in contact with the bucket bottom at the top of a 0.80-m circle.

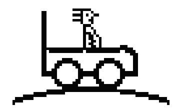
3. The coefficient of friction between an 1125-kg car and the roadway is 0.850. Determine the maximum speed at which the car can maneuver through a curve with a radius of curvature of 25.0 meters. Begin with a free-body diagram.



4. An air-show pilot makes a vertical loop with a radius of curvature of 84.0 m. Determine the normal force acting upon the 65.2-kg body at the bottom of the loop if the air speed is 62.0 m/s. Begin with a free-body diagram.

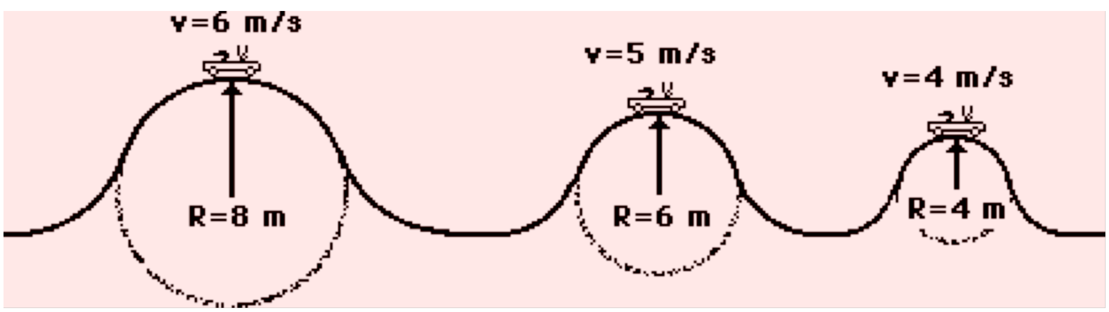


5. A 54.0-kg roller coaster passenger is moving so fast over the crest of a hill that she is lifted off her seat and the safety bar exerts a downward force upon the her body to keep her in the car. The speed of the car is 24.0 m/s and the radius of curvature is 30.0 meters. Determine the downward force applied by the safety bar. Begin with a free-body diagram.



6. The speeds of a 600-kg roller coaster car at the top of three consecutive hills are shown below. The *radii* of the hills are shown. Determine the acceleration of and net force and normal force experienced by the car at the top of each hill. **PSAYW**

Hill A **Hill B** **Hill C**



Universal Gravitation

Read from **Lesson 3** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l3a.html
http://www.physicsclassroom.com/Class/circles/u6l3b.html
http://www.physicsclassroom.com/Class/circles/u6l3c.html

MOP Connection: Circular Motion and Gravitation: sublevels 6 and 7

1. The evidence that stimulated Newton to propose the law of universal gravitation emerged from a study of ____.
   a. the motion of the moon and other celestial or heavenly bodies
   b. the fall of an apple to the Earth
   c. the gravitational interaction of smaller objects upon the Earth
   d. ...nonsense! There was no evidence; it was just proposed as a theory.

2. The *universal* of Newton's law of universal gravitation is a common source of confusion. The *universal* means that _____.
   a. the amount of gravitational forces is the same for all objects.
   b. the acceleration caused by gravity is the same for all objects.
   c. the force of gravity acts between all objects - not just between the Earth and an object, but also between two people. All objects with mass attract.

3. According to Newton's gravitation law, the force of gravitational attraction between a planet and an object located upon the planet's surface depends upon _____. Choose all that apply.
   a. the radius of the planet b. the mass of the planet
   c. the mass of the object d. the volume of the object
   e. … nonsense! None of these variables affect the force of gravity.

4. The more massive that an object is, the ______ (more, less) that the object will be attracted to Earth.

5. The more massive the Earth is, the ______ (more, less) that another object will be attracted to Earth.

6. The greater that Earth's radius is, the ______ (more, less) that another object will be attracted to Earth.

7. In the mathematical form of Newton's law of universal gravitation (see equation at right), the symbol **G** stands for _____.

$$F_{grav} = \frac{G \cdot m_1 \cdot m_2}{d^2}$$

   a. gravity b. the acceleration of gravity c. the gravitational constant

8. **TRUE** or **FALSE**:
   The value of **G** (in the equation above) is an enormously large number; that explains why (at least in part) the force of gravitational attraction between the Sun and the very distant Earth is such a large number.

9. **TRUE** or **FALSE**:
   Two lab partners attract each other with a gravitational force. However, it is impossible to calculate such a force since it is only an unproven theory.

10. **TRUE** or **FALSE**:
    The notion that any two objects attract each other gravitationally is a theory. There is no empirical evidence for such a notion.

11. Orbiting astronauts on the space shuttle do not have weight in space because _____.
    a. there is no gravity in space b. there is no air resistance in space
    c. there are no scales in space d. the food is terrible and they work all the time
    e. ... nonsense! The astronauts do have weight in space.

12. Use the gravitational force equation to fill in the following table ($G = 6.673 \times 10^{-11}\ N \bullet m^2/kg^2$).

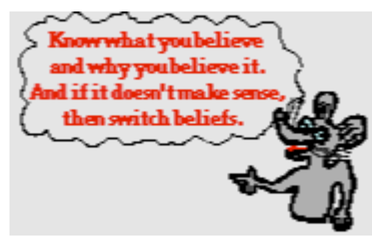
Mass of Object 1 (kg)	Mass of Object 2 (kg)	Distance of Separation* (m)	F_{grav} (N)	Significance of Numbers
60.0	60.0	1.0		Two typical students in physics class
60.0	5.98×10^{24}	6.37×10^{6}		A typical student on the surface of the Earth
60.0	11.96×10^{24}	6.37×10^{6}		A typical student on *an Earth* with twice the mass
60.0	5.98×10^{24}	3.18×10^{6}		A typical student on *an Earth* with half the radius
60.0	5.98×10^{24}	6.47×10^{6}		A *typical* student in orbit 60 miles above the Earth
60.0	1.2×10^{22}	1.15×10^{6}		A *typical* student on the surface of the Pluto
60.0	1.901×10^{27}	6.98×10^{7}		A *typical* student on the "surface" of the Jupiter

*The distance of separation means the distance between the centers of the two masses (NOT the distance between the two objects' edges.)

13. Use the gravitational acceleration equation to fill in the following table ($G = 6.673 \times 10^{-11}\ N \bullet m^2/kg^2$).

Mass of Object Creating the Field (kg)	Distance of Separation* (m)	g (m/s^2)	Significance of Numbers
5.98×10^{24}	6.37×10^{6}		On earth's surface
5.98×10^{24}	6.48×10^{6}		60 miles above earth's surface
5.98×10^{24}	42.3×10^{6}		Above earth's surface in a geosynchronous orbit
1.2×10^{22}	1.15×10^{6}		On Pluto's surface
1.901×10^{27}	6.98×10^{7}		On Jupiter's "surface"

*The distance of separation means the distance between the centers of the two masses (NOT the distance between the two objects' edges.)



Identify the following statements as being **True** or **False**.

______ 14. Astronauts on the space station do not weigh anything.

______ 15. There is no gravity on the space station.

______ 16. There is no gravity anywhere in space.

______ 17. There is no gravity in a vacuum.

______ 18. Orbiting astronauts are not accelerating.

______ 19. If the Earth were not spinning, then there would be insufficient gravity to hold us on its surface.

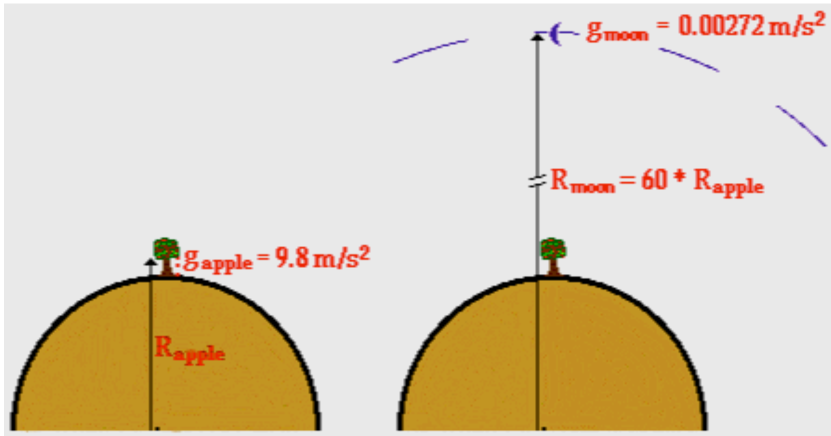
______ 20. The gravitational acceleration of a free-falling object depends upon its mass.

The Inverse Square Law of Universal Gravitation

Read from **Lesson 3** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l3b.html
http://www.physicsclassroom.com/Class/circles/u6l3c.html

MOP Connection: Circular Motion and Gravitation: sublevels 6 and 7



1. Isaac Newton compared the acceleration of a falling apple to the acceleration of the *falling* moon. In his comparison, he proved that the moon accelerates at a rate that is 1/3600-th of the apple's rate; he also showed that the separation distance (center to center) between the moon and the Earth was 60 times the separation distance between the apple and the Earth. This is evidence that the acceleration caused by gravity is ___________________ (directly, inversely) dependent upon the _______________________ (square, square root, cube, cubed root, etc.) of the separation distance.

Use Newton's gravitational law in a conceptual manner in order to fill in the following blanks.

2. Two objects gravitationally attract with a force of 18.0 N. If the distance between the two objects' centers is doubled, then the new force of attraction is ______ N.

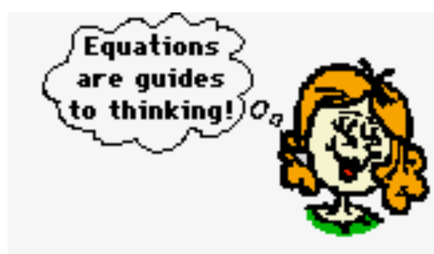
3. Two objects gravitationally attract with a force of 18.0 N. If the distance between the two objects' centers is tripled, then the new force of attraction is ______ N.

4. Two objects gravitationally attract with a force of 18.0 N. If the distance between the two objects' centers is halved, then the new force of attraction is ______ N.

5. Two objects gravitationally attract with a force of 18.0 N. If the distance between the two objects' centers is decreased by a factor of three, then the new force of attraction is ______ N.

6. Two objects gravitationally attract with a force of 18.0 N. If the distance between their centers is decreased by a factor of four, then the new force of attraction is ___ N.

7. Two objects gravitationally attract with a force of 18.0 N. If the **mass** of one of the objects is doubled and the **distance** between their centers is doubled, then the new force of attraction is ______ N.



8. Two objects gravitationally attract with a force of 18.0 N. If the **mass**es of both of the objects are doubled and the **distance** between their centers is doubled, then the new force of attraction is ______ N.

9. Two objects gravitationally attract with a force of 18.0 N. If the **mass**es of both of the objects are tripled and the **distance** between the two objects' centers is doubled, then the new force of attraction is ______ N.

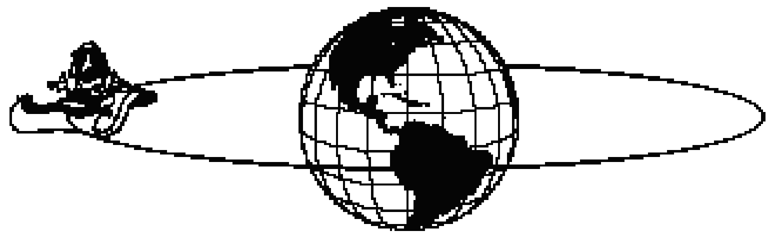
Satellite Motion

Read from **Lesson 4** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l4b.html
http://www.physicsclassroom.com/Class/circles/u6l4c.html

MOP Connection: Circular Motion and Gravitation: sublevel 8

1. Consider the rather strange-looking orbiting satellite shown in the diagram at the right. Draw a free-body diagram showing the type and direction of the forces acting upon the satellite.



2. For any satellite, the net force is equal to $m_{sat} \bullet a$ or $m_{sat} \bullet \frac{v^2}{R}$. Since this net centripetal force is supplied by the force of gravity, the force of gravity expression can be set equal to the net centripetal force expression:

$$\frac{G \bullet m_{sat} \bullet M_{earth}}{R^2} = m_{sat} \bullet \frac{v^2}{R}$$

Algebraically manipulate this equation in order to derive an expression for the speed (**v**) of an orbiting satellite. **PSAYW**

3. Use your equation in #2 above to answer the following questions:
   - If the radius of orbit of a satellite is increased, then the orbital speed would ______ .
   - If mass of the earth is increased, then the orbital speed would ______ .
   - If the radius of the earth is increased, then the orbital speed would ______ .
   - If the mass of the satellite is increased, then the orbital speed would ______ .
   - If the radius of orbit of a satellite is increased by a factor of 2 (i.e., doubled), then the orbital speed would ______ (increase, decrease) by a factor of _______.
   - If the mass of the earth is increased by a factor of 2 (i.e., doubled), then the orbital speed would ______ (increase, decrease) by a factor of _______.

4. Use the equation in derived #2 to calculate the orbital speed of ... . ($M_{earth} = 5.98 \times 10^{24}$ kg)

Object	**Orbital Radius (m)**	**Orbital Speed (m/s)**
a. ... the moon	4×10^8	
b. ... a geosynchronous satellite	4.15×10^7	
c. ... the space shuttle	6.55×10^6	

5. The speed of a satellite is also found from its orbital period (**T**) and the radius of orbit (**R**):

$$v = \frac{2 \bullet \pi \bullet R}{T}$$

Set the expression for orbital speed (**v**) above to the expression for orbital speed from question #2. Algebraically manipulate the equation to obtain an equation relating orbital period (**T**) to the radius and mass of the earth.

Analyze the following trip knowing the concepts and equations utilized in this unit. Insert your answers to the following questions in the table below.

6. Suppose that the man pictured on the front side is orbiting the earth (mass = 5.98×10^{24} kg) at a distance of 310 miles (1600 meters = 1 mile) above the surface of the earth (radius = 4000 miles).
   a. What acceleration does he experience due to the earth's pull?
   b. What tangential velocity must he possess in order to orbit safely (in m/s)?
   c. What is his period (in hours)?

7. Now suppose that the man is orbiting the earth at 22,500 miles above its surface.
   a. What is the acceleration?
   b. What is the tangential velocity (in m/h) at this location?
   c. What is his period (in hours)?

8. Finally suppose that the man lands on the moon ($R_{earth\text{-}moon} = 4 \times 10^8$ meters).
   a. What is the moon's and its inhabitants acceleration (in m/s^2) around the earth?
   b. What is the tangential velocity (in m/s) around the earth?
   c. What is the moon's period (in days)?

Object	Radius (m)	Accel'n (m/s/s)	vel. (m/s)	T (hrs or days)
Man - 310 mi				
Man - 22 500 mi				
Moon				

9. Explain why the man would want to orbit at 22 500 miles above the surface of the Earth.

Weightlessness

Read from **Lesson 4** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l4d.html

MOP Connection: Circular Motion and Gravitation: sublevel 9

1. Analyze the following logical argument. At what step (i through iv) does a logical fallacy occur?

   i. The weight of an object is equal to the force of gravity acting upon that object.
   ii. Orbiting astronauts feel weightless as they orbit the Earth.
   iii. A person who feels weightless is not acted upon by the force of gravity.
   iv. There is no force of gravity acting upon orbiting astronauts.

   Explain your answer.

2. When you stand on a bathroom scale, the scale does **not** measure the force of gravity (i.e., weight) acting upon your mass. What does the scale measure? ____________________ If a scale does not technically measure your weight, then why is it often used to measure your weight? Express your understanding of forces, Newton's second law of motion, and bathroom scales by discussing these questions.

Otis L. Evaderz is conducting his famous elevator experiments. Otis stands on a bathroom scale and reads the scale while ascending and descending the John Hancock building. Otis weighs 750 N, but notices that the scale readings depend on what the elevator is doing. Use a free-body diagram and Newton's second law of motion to solve the following problems.

3. What is the scale reading when Otis accelerates upwards at +0.50 m/s^2? **PSYW**

4. What is the scale reading when Otis is traveling upward at a constant velocity of at 2 m/s? **PSYW**

5. As Otis approaches the top of the building, the elevator slows down at a rate of 0.50 m/s^2. Be cautious of the sign on acceleration. What does the scale read? **PSYW**

6. Otis stops at the top floor and then accelerates at a rate of -0.50 m/s^2. What does the scale read? **PSYW**

7. As Otis approaches the ground floor, the elevator <u>slows down</u> at a rate of +0.50 m/s^2. Be cautious of the sign on acceleration. What does the scale read? **PSYW**

Otis L. Evaderz desired to conduct the following experiment. Otis wanted the building engineers to allow the elevator to free fall from the top floor for fifty floors. Otis would observe the scale reading. Then the engineers would activate the safety system and slow the elevator down with an acceleration value of +15.0 m/s^2.

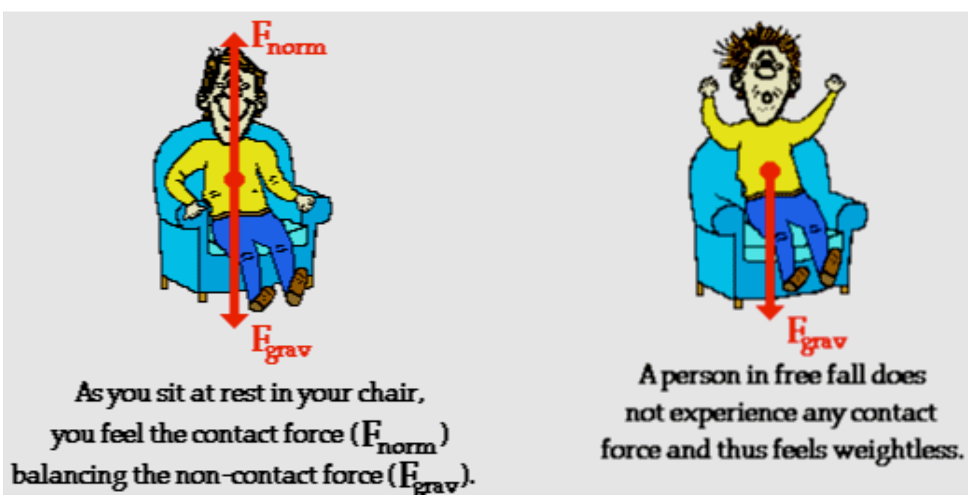
8. What would the scale read during the free fall stage of the experiment? **PSYW**

9. What would the scale read during the slowing down stage of the experiment? **PSYW**

10. In questions #3-9, is Otis' weight changing? ___________

 Is Otis' sensation of weight changing? ___________ Explain why or why not.

11. Earth-orbiting astronauts feel weightless in space because _____. Choose all that apply.
 a. They are in free-fall motion.
 b. There is an absence of contact forces acting upon their bodies.
 c. The weight of objects diminish to close to 0 N at these distances from Earth's center.
 d. There is no gravity in space.
 e. Gravity is the only force acting upon their bodies.
 f. There is no air resistance in space.
 g. They haven't eaten for days.
 h. The rotation rate of the Earth upon its axis is so rapid it gives a sensation of weightlessness.
 i. They are not experiencing any support forces.
 j. Their surroundings are accelerating to the earth at the same rate they are.
 k. The acceleration of gravity (**g**) at these distances is close to 0 m/s/s.



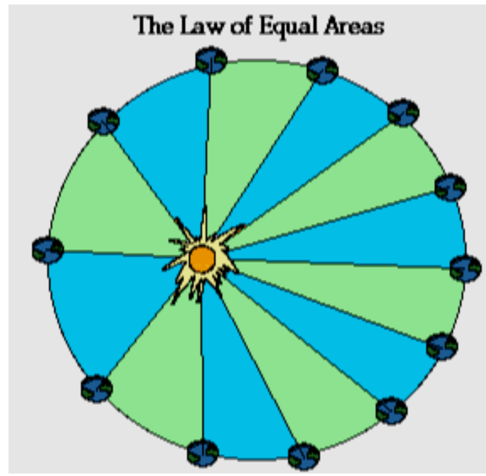
Kepler's Laws and Planetary Motion

Read from **Lesson 4** of the **Circular and Satellite Motion** chapter at **The Physics Classroom**:

http://www.physicsclassroom.com/Class/circles/u6l4a.html

MOP Connection: Circular Motion and Gravitation: sublevel 10

1. Kepler's first law of planetary motion states that ____. Choose one.
   a. the Sun is at the center of the solar system
   b. planets orbit the Sun in elliptical orbits, with the Sun located at one focus
   c. planets orbit the Sun in circular orbits, with the Sun located at the center
   d. gravity provides the force that holds the planets in orbit about the Sun



2. Kepler's second law of planetary motion states that a line connecting a planet to the Sun ____. Choose one.
   a. is longest in winter and shortest in summer
   b. sweeps out more area during a winter month than during the summer month
   c. sweeps out the same amount of area in any two equal periods of time
   d. sweeps out the same amount of area regardless of the planet.

3. A planet would move ____.
   a. at the same speed at all times during its orbit about the Sun
   b. at faster speeds when positioned closer to the Sun during its orbit
   c. at slower speeds when positioned closer to the Sun during its orbit

4. Kepler's third law of planetary motion states that the ratio of ____.
   a. the orbital period to the orbital radius is the same for all planets
   b. the orbital periods of any two planets equals the ratio of the orbital radii
   c. all planets would orbit with the same orbital period
   d. the period squared to the radius cubed is the same ratio for all planets

5. A planet that is further from the Sun would take _____ time to orbit the Sun compared to planets that are closer to the Sun.
   a. more b. less c. the same amount of

6. Planetary data for the nine planets are shown below. Radius and period data are expressed relative to the Earth's radius and period.

Planet	Period (Earth years)	Ave. Radius (astron. units)
Mercury	0.241	0.39
Venus	0.615	0.72
Earth	1.00	1.00
Mars	1.88	1.52
Jupiter	11.8	5.20
Saturn	29.5	9.54
Uranus	84.0	19.18
Neptune	165	30.06
Pluto	248	39.44

Taking two planets at a time, compare the ratio of the square of the period to the ratio of the cube of their radius.

$(T_{Mars} / T_{Earth})^2 =$	____________	$(R_{Mars} / R_{Earth})^3 =$	____________
$(T_{Jupiter} / T_{Earth})^2 =$	____________	$(R_{Jupiter} / R_{Earth})^3 =$	____________
$(T_{Neptune} / T_{Uranus})^2 =$	____________	$(R_{Neptune} / R_{Uranus})^3 =$	____________
$(T_{Pluto} / T_{Uranus})^2 =$	____________	$(R_{Pluto} / R_{Uranus})^3 =$	____________
(T______ / T______)^2 =	____________	(R______ / R______)^3 =	____________
(T______ / T______)^2 =	____________	(R______ / R______)^3 =	____________
(T______ / T______)^2 =	____________	(R______ / R______)^3 =	____________

7. Complete the following statements.

   a. If planet A is twice as far from the Sun as planet B, then the period of its orbit will be _____ times as long.

   b. If planet A is three times as far from the Sun as planet C, then the period of its orbit will be _____ times as long.

   c. If planet A is four times as far from the Sun as planet C, then the period of its orbit will be _____ times as long.

   d. If planet A is five times as far from the Sun as planet C, then the period of its orbit will be _____ times as long.

8. If a small planet were located eight times as far from the sun as the Earth's distance from the sun, how many years would it take the planet to orbit the sun. **PSYW**