Circular Motion

Answer all questions in standard SI units.

Frequency and Period Problems

1. A turntable rotates an album at 33 revolution per minute, RPM. What frequency is this?

2. A car's engine spins at 1500 RPM. What is the frequency of the rotating engine?

3. Little Bobby Bolo noticed his bolo swung around his head 3 times every 1.40 seconds. What is the period and frequency is of the rotating bolo?

4. A baton twirler spins her baton 12 times in a second when it is tossed into the air. What is the period and frequency of the rotating baton?

5. Middle "c" on the musical scale has a frequency of 256 Hz. How many times a seconds is the sound wave vibrating?

6. Little Ms. Watchful noticed that some kids rotated on a carousel with a frequency of 0.66 Hz. How many times a second did the carousel rotate?

Discussion Problems

DIRECTIONS: Pair up with a partner if possible and discuss the following situations in terms of ideas related to centripetal force and circular motion: Identify the direction of the centripetal force and the source of the centripetal force. Write down your conclusions for each problem on a separate sheet of paper.

7. Turns on a race track are banked inward.
8. An earth satellite will stay in orbit at some distance from the earth only if it going at the right speed.
9. If a satellite is going faster than the required speed, it will leave its orbit.
10. If a satellite slows down, it will fall to the earth.
11. It is difficult to make a sharp turn if a car is going very fast.
12. A small sports car can negotiate a winding road easier than a large car.
13. A centrifuge is used as a separator in lab.
14. A spin dry washing machine in operation.
15. A scale attached with a string to a mass shows a greater reading when the mass is swinging than when it is stationary.

16. A small bucket full of water can be swung in a vertical circle without the water spilling out.
17. Astronauts could experience variable g forces in a human centrifuge before manned rocket launches were tried.

18. Riding a bike without a rear fender through a puddle produces a spray of water down the rider's back.

Circular Motion

General Problems

19. A children's carousel rotates 3 times every 2 seconds. The diameter of the carousel is 3.0 meters.

- What is the period of motion?
- What is the tangential velocity of the carousel?
- What is the centripetal acceleration of the rider at the edge of the carousel?

20. When traveling down the road at a constant speed of 55 mph, 24.6 m/s, the tangential velocity of the wheels is also 55 mph. If a car tire is 65.0 cm in diameter, then;

- What is the period and frequency of the spinning car tire?
- What is the centripetal acceleration of a rock stuck in the tire's tread?

21. Given that the Earth is 1.49x1011 m from the Sun. And the earth's period of motion is 365.25 days. Calculate how fast it is revolving around the Sun. Put your answer in m/s.

22. Do the same thing for the Moon: Given it is 3.8x108 m from the Earth and revolves around the Earth every 27.31 days. Put your answer in m/s.

23. Given the Earth has a mass of 5.98x1024 kg and the Moon has a mass of 7.34x1022 kg, what centripetal force is necessary to keep each in orbit.

24. A bicycle wheel of radius 0.325 m rotates at a speed of 10.0 m/s (22.4 mph).

a. If a person is riding the bike, how fast are they traveling?
b. What is the frequency and period of rotation of the bicycle's wheel?

25. The time shaft ride at King's Dominion has a radius of 5.0 m and spins with a period of 1.3 seconds (only a guess).

a. What is the tangential velocity of the ride?
b. What is the centripetal acceleration of the ride?
c. How many g's is this?

26. An upright clothes washer spins clothes around 50 times in 20 seconds. Its radius is 0.30 m.

a. What is the period and frequency of the clothes dryer?
b. What is the tangential velocity of the clothes in the washer?
c. What is the centripetal acceleration of the clothes in the washer?

27. A car is traveling at 24.6 m/s (55 mph). The radius of the tire is 0.40 m. a rock is stuck in the tire.

a. What is the tangential velocity of the rock?
b. What is the centripetal acceleration of the rock?
c. What is the frequency and period of motion?
d. If the rock flies off the tire, how fast will it be traveling and how will its path of motion be related to the radius vector?
e. If the rock's mass is 0.0010 kg, what force holds the rock in the tread of the tire?

28. While playing with a HOT WHEELS race set, a child puts together 2 pieces of track on the loop-the-loop. Normally the loop-the-loop is made with only one piece of track. So now the circumference of the track is doubled.

a. How is the radius affected?

b. A car that supplies its own velocity runs along the loop-the-loop. If the same car is used on each size loop-the-loops, then;

- How do the periods compare?
- How do the centripetal accelerations compare?
- How do the centripetal forces compare?

29. While playing Bolo-Master of the world, the radius the rock is twirled around with is held constant and the velocity is doubled a moment later.

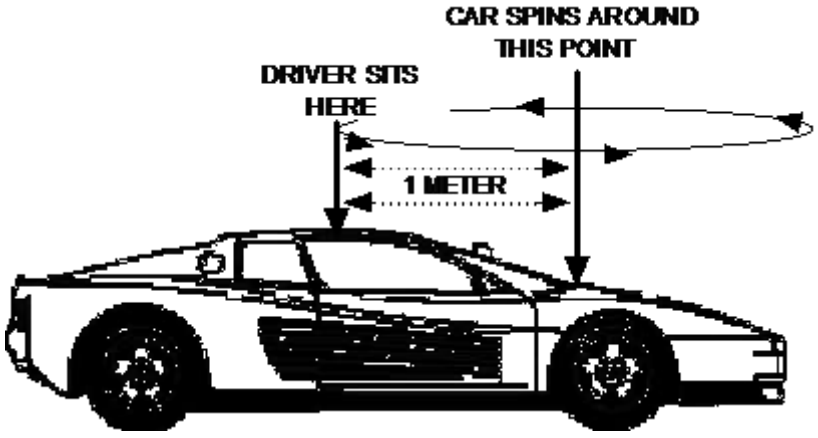
a. How do the centripetal accelerations compare?

b. How do the periods of motion compare?

30. As a car goes around a flat curve, what supplies the centripetal force necessary for the car to go in a curved path?

31. A car spins out on an ice covered road. The car's length is 4 meters. The driver is 1 meter from the car's spin center. The car spins 4 times around in 3 seconds.

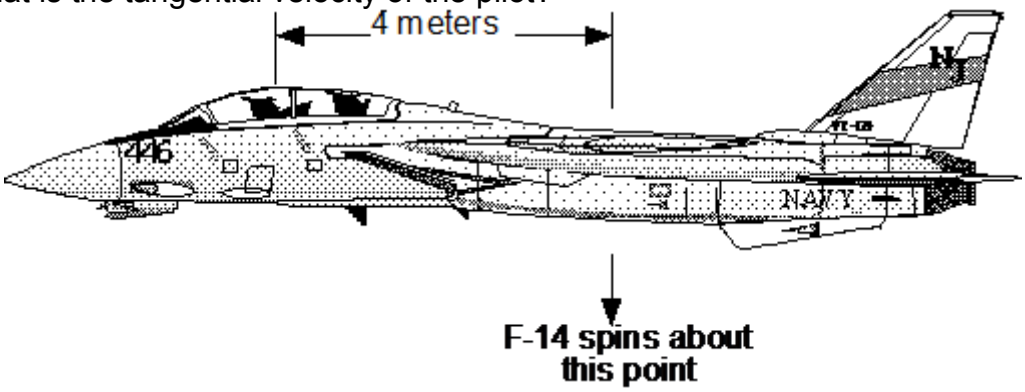
- What is the period and frequency of the spinning car?
- What is the period and frequency of the driver in the car?
- What is the tangential velocity of the driver?
- What is the centripetal acceleration of the driver?
- What is the centripetal acceleration in g's?



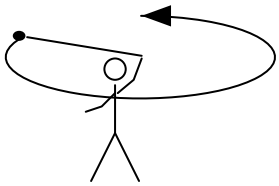
Circular Motion

32. In the movie Top Gun, an F-14 fighter jet gets stuck in a flat spin. The jet rotates such that the pilot, 4 meters from the planes spin center, feels a centripetal force of 6 g's. There the pilot's hand weighs 6 times as much as normal.

- What is the centripetal acceleration of the pilot in m/s^2.
- What is the period of motion of the pilot?
- What is the tangential velocity of the pilot?



33. For every problem that describes a person's motion, calculate the centripetal force felt on each rider if their mass is 60 kg.



34. While playing "Bolo Master of the World" little Lisa was spinning a rock around her head on a string 1.32 m long. The rock travels around once every 1.43 seconds.

(A) What is the speed of the rock?
(B) What is the centripetal acceleration of the rock?
(C) If the rock has a mass of 0.15 kg then, what is the centripetal force acting on the rock?

35. A race car is traveling around a race at an average speed of 65.625 m/s (147 mph). The race car takes 2 minutes and 44 seconds to go around the track once.

(A) What is the centripetal acceleration of the car?
(B) Is the car WEIGHS 7840 N, then what is the centripetal force acting on the car?
(C) What do you think supplies the centripetal force to turn the car?

36. An ice skater spins with her hands stretched out from her body. Her hand is 1.12 meters from the axis the is spinning along. Her hands are spinning at 5.74 m/s.

(A) What is the centripetal acceleration of her hand?
(B) How many g's is your answer in (A)?
(C) If her hand has a mass of 0.2 kg then what is the centripetal force acting on her hand?
(D) How long does it take for her to spin around once?

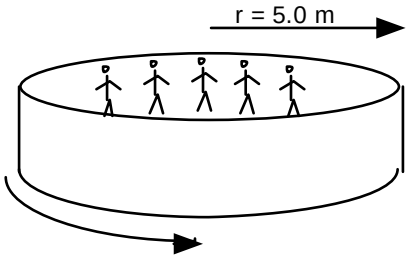
37.A dog is chasing his tail. The radius of the circle that dog makes is 0.62 meters. The dog runs in a circle 10 times in 7.2 seconds.

a) What is the period of motion of the dog?
b) What is the speed of the dog?
c) What us the centripetal acceleration of the dog?
d) If the dog has a bandanna tied to his neck, mass is 0.024 kg, then what is the centripetal force acting on the bandanna?

38 A merry-go-round travels with a tangential speed of 3.5 m/s. Its diameter is 34 m across?
a) What is the centripetal acceleration of the merry-go-round?
b) How long does the merry-go-round take to go around once?

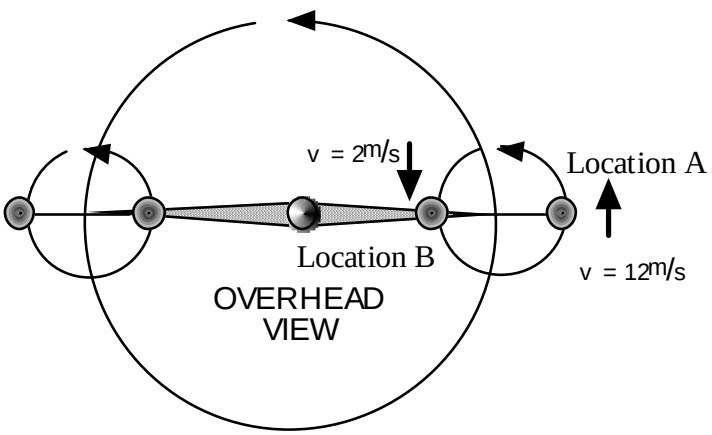
c) What is the centripetal force acting on a 45 kg rider 15 meters from the center of merry-go-round?

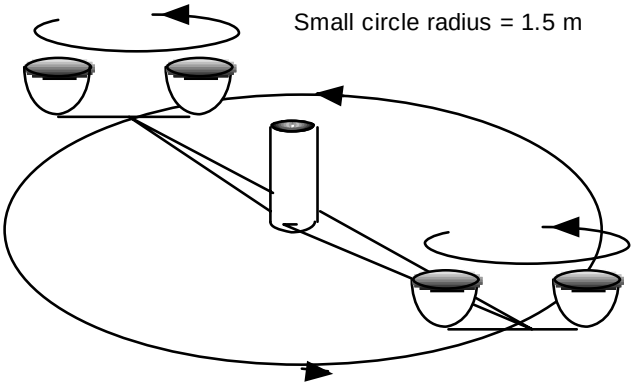
39 In an amusement park, there is a ride called the "Mexican Hat." The ride is basically a big barrel that spins very rapidly. The rides rest standing up against the barrel's wall. While spinning, the floor drops down while inertia holds the passengers in place.



a. A rider feels a force associated with 2 g's of centripetal acceleration when riding this ride. How fast is the ride spinning?
b. How long does it take to complete one cycle of motion?
c. How many times does the ride go around in 1 minute?

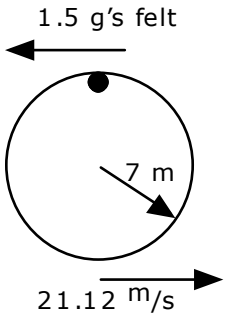
40. In an amusement park, there is a ride called the "Mad Hatter's Teas Party." The ride is basically a pair of tea cups that spin very rapidly. The pair itself spin on a larger circle.



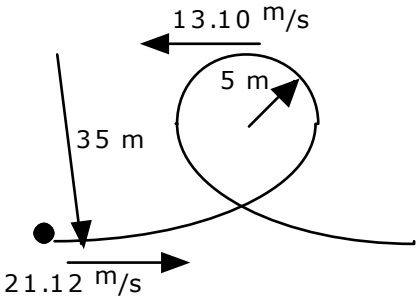


a How many g's of centripetal acceleration does the rider feel at the outer most edge of the circle? (The radius at this point is the large radius plus the small circle's radius.)
b How many g's of centripetal acceleration does the rider feel at the inner most edge of the circle? (The radius at this point is the large radius minus the small circle's radius.)
c Use an average velocity between the inner and outer most point to determine the time it takes for the passenger to spin around once in the <u>smaller</u> circle of motion.

Circular Motion



Circular Loop



Spiral of Archimedes Loop

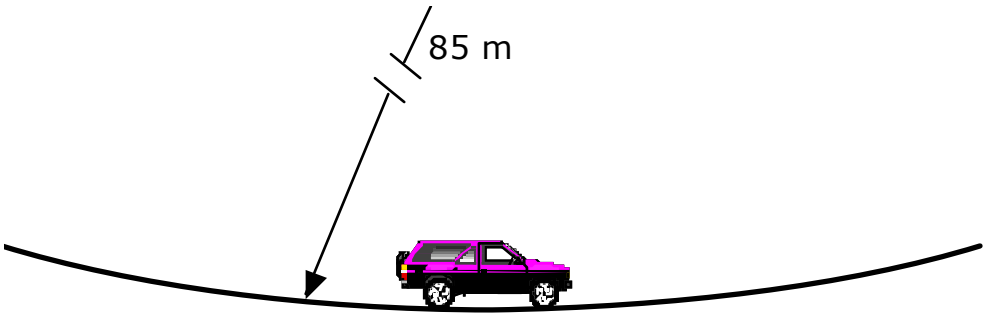
41. For the circular loop, how many g's are felt by the rider at the bottom of the loop as they enter the loop? (7.5 g's)

43. For the circular loop, how fast is the roller coaster car traveling at the top of the loop? (12.10 m/s)

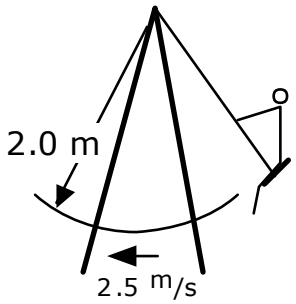
44. For the Spiral of Archimedes loop, how many g's are felt by the rider at the top of the loop as they enter the loop? (2.5 g's)

45. For the Spiral of Archimedes loop, how many g's are felt by the rider at the bottom of the loop as they enter the loop? (2.3 g's)

46. How fast is the car traveling if the passenger's feel 1.5 g's at the bottom of the road's dip. (20.41 m/s)

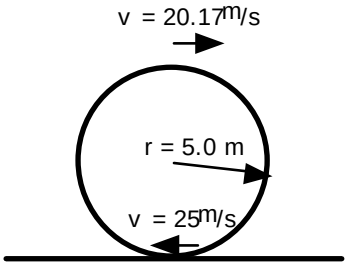


47. How many g's does the child on the swing feel if they are traveling as shown at the right. (1.32 g's)



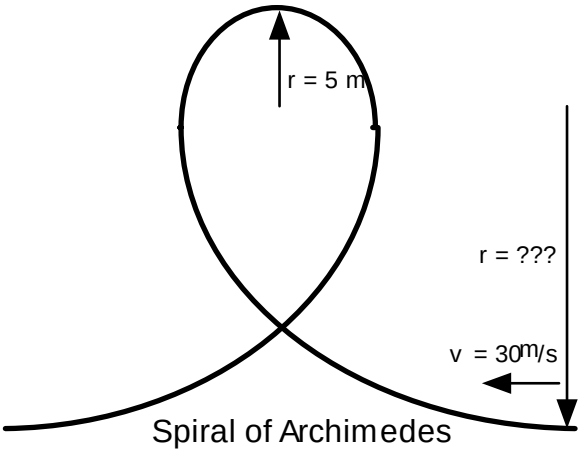
Circular Motion

48. A roller coaster travels in a circular loop of radius 5.0 m. At the bottom of the loop the roller coaster car is traveling 25.00 m/s. At the top of the loop the roller coaster car is traveling 20.17 m/s.



a What is the centripetal acceleration exerted by the track at the top and the bottom of the loop in g's.
b How many g's are **felt** by the rider at the top and the bottom of the loop?

49. A roller coaster travels in a loop whose shape is irregular. The shape is called the spiral of Archimedes or Clothoid. The spiral of Archimedes is a circular shape whose radius changes as its height increases. This spiral has a radius of 5 m at the top.

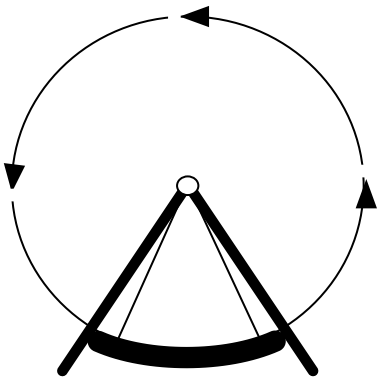


Spiral of Archimedes

a What is the centripetal acceleration exerted on the rider by the track at the top of the loop if the rider is traveling 20 m/s at the top in m/s2.
b How many g's are FELT by the rider at the top of the loop?
c If the track is to be designed so that the same number of g's are to be FELT by the rider at the bottom of the track, what must the radius be?
d If the rider's mass is 70 kg, What centripetal force is exerted on the rider at the bottom?

49. T H E B E R S E R K E R

The Berserker is a ride where the passengers are fastened into a "boat." The boat swings back and forth like a swing. Finally, it swings with so much speed that it makes a complete revolution. This ride is not a true example of the type of circular motion that we are studying because its tangential velocity decreases and increases as the ride swings up and down. However, we can still analyze parts of its motion if we ignore the period of motion and remember that it does travel in a circle. (Assume a “Dr. Suess” world of physics)



The diameter of the Berserker is 25.1 m. When the Berserker reaches the bottom of the ride it is traveling with a speed of 22.2 m/s.

(a) What is the centripetal acceleration of the ride?

(b) How many g's is this ride?

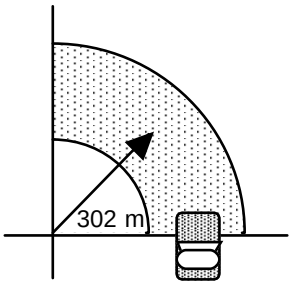
VEHICULAR APPLICATIONS

50. A 1000 kg car travels around a turn whose radius is 302 m at 20 m/s.

a What is the centripetal acceleration of the car?

b What is the centripetal force applied to the car?

c How much time does it take for the car to travel around the curve if the curve is 90°?

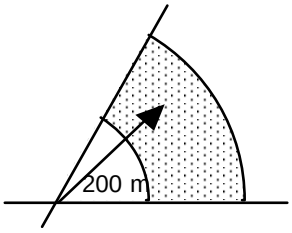


51. A 500 kg car travels around a curve with a centripetal force of 2500 N. The curve’s radius is 200 m.

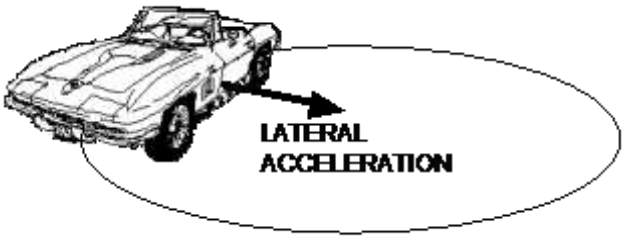
a What is the velocity of the car?

b What is the centripetal acceleration of the car?

c How much time does it take to complete the curve if the curve travels around 60°?

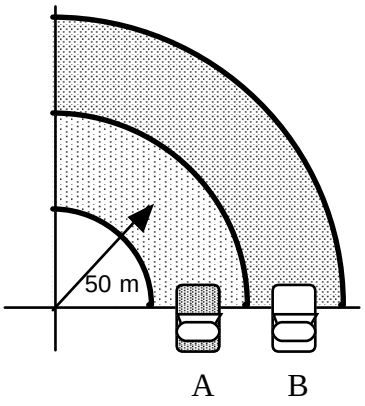


52. A 1500 kg car can travel around in a circle of radius 30 m at a maximum speed of 12.124 m/s.



a What is the car's centripetal acceleration in m/s2? (This is the maximum centripetal acceleration.)
b What is the car's lateral acceleration in m/s2?
c What is the car's centripetal acceleration in g's?
d The maximum centripetal acceleration for a car will remain the same for the car no matter what size circle it travels in. What is the maximum velocity this car could travel around a curve of radius 300 m?
e What is the quickest time this car could travel around a curve with a radius of 200 m and 45°?

53. Two cars are traveling around a two lane curve as shown. the cars stay side by side around the turn. Therefore the take the same amount of time to finish the 90° curve. The radius of curve "A" is 50 m. Curve "B" is 3.5 m longer. Car "A" is traveling at a constant velocity of 10 m/s. Car "A" has a mass of 1200 kg.



a How much time does it take for car "A" to finish the curve?
b How fast must car "B" travel to keep up with car "A?"
c What centripetal force must car "A" exert to make it around the curve without slipping?
d If car "B" is to exert the same centripetal force as car "A," then what must car "B's" mass be to make it around the curve in the same amount of time as car "A?"

CAR'S AND CORNERING PROBLEMS

Use your car's acceleration chart to solve the following.

55. What is the maximum velocity that a Lamborghini Diablo can go around a curve if it the curve has a radius of 50 m?

56. What is the maximum velocity that a Range Rover can go around a curve if it the curve has a radius of 50 m?

57. a How much centripetal acceleration is needed so a car can go around a curve at 21 $^{m}/_{s}$ if the curve's radius is 50 m? (Answer in g's and $^{m}/_{s^2}$)
b Which cars can navigate the curve without slipping?

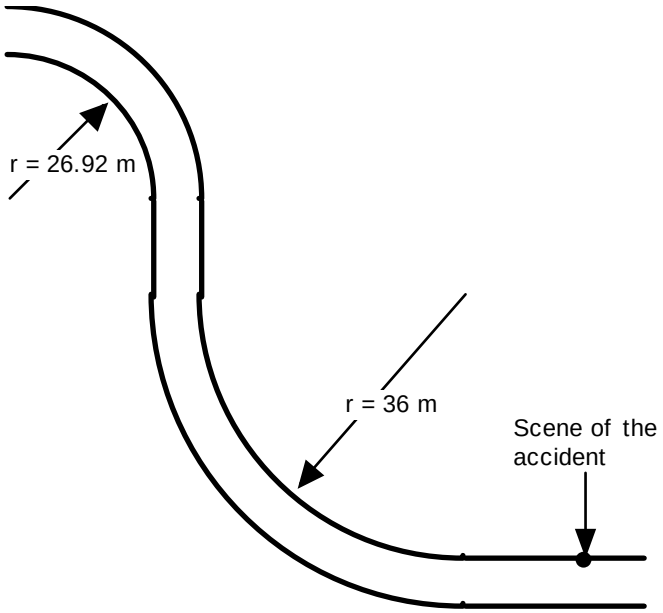
58. What is the smallest radius curve that a "Nissan 300ZX" can travel around at 25 m/s.

59. How fast could a "Geo Metro LSI" take the same curve as the Nissan in #58?

60. Detective Columbo was looking at an accident when he noticed something. He saw that the car traveled around a curve of radius 30 m at 15.43 m/s, 34.6 mph, before the car began to slip to the outside. Columbo sends this information to you in the crime lab.

It is up to you to send him a list of possible cars that the perpetrator may have been driving. Using physics, which possible cars could the suspect have been driving?

61. In a court trial a suspect is accused of fleeing the scene of an accident. The suspect's car is a dark green "Toyota 4Runner 4WD" . A witness testified that they saw a dark green vehicle traveling about 30 mph around the nearby corners. Could he have been at the scene of the crime?



62. A 1000 kg car can travel around in a circle with a centripetal acceleration of 0.7 g's without slipping. When the car loses traction on a road, it exerts a centripetal acceleration of 0.3 g's.
   a What is the car's centripetal acceleration in m/s2 when it is not slipping?
   b What is the car's centripetal acceleration in m/s2 when it is slipping?
   c How big of a turn could the car turn at a constant velocity of 20 m/s without slipping?
   d How big of a turn could the car turn at a constant velocity of 20 m/s when it begins to slip on a road?
   e Here is the scenario. A car is going around a turn without slipping. Suddenly the tires begin to slip thereby reducing the centripetal acceleration. Assuming the curve has a radius equal to that in problem "c," what velocity does the car need to travel at in order to safely navigate the same curve.
   f In each problem (c,d) how much time does it take to complete a turn of 180°?

Circular Motion

RATIO'S

Note: The mass does not change.

Describe the how the first variable is affected assuming the changes mentioned in the other variables.

63. a_C: The velocity is constant while the radius is tripled
64. T: The velocity is constant while the radius is tripled
65. v_t: The acceleration is constant, the radius is halved
66. T: The acceleration is constant, the radius is halved
67. F_C: The velocity doubles and the period remains constant
68. v_t: The radius is doubled and the period is tripled
69. R: The force is changed by a factor of 5/8 and the period is changed by a factor of 3/2
70. T: The force changes by 3/7 and the velocity changes by 3.
71. R: The force changes by 3/7 and the velocity changes by 3.
72. F_C: The radius is tripled and the period changes a factor of 2/3
73. a_C: The velocity changes by a factor of 7/8 and the radius changes by 6
74. T: The radius is quadrupled and the force is tripled
75. v_t: The radius is quadrupled and the force is tripled
76. r: The acceleration changes by 1/4 and the period changes by 5/6
77. r: a_C triples, v remains constant
78. T: v changes by a factor of 3/8, R changes by a factor of 5/2
79. F_c: The radius triples, the velocity remains constant
80. v: a_C remains constant, the time to go around once triples
81. a_C: the velocity changes by a factor of 4/6, the radius is halved
82. T: the velocity changes by a factor of 2/3, the centripetal acceleration changes by a factor of 5/4
83. r: Centripetal force doubles, velocity triples
84. v: Centripetal acceleration changes by a factor of 1/3, period changes by a factor of 4/3

Circular Motion

Givens: (Do not memorize.)

$G = 6.673 \times 10^{-11} (N \cdot m^2)/kg^2$

Earth's Radius: 6.37×10^6 m	Earth's Mass: 5.98×10^{24} kg	Orbit: 1.50×10^{11} m
Moon's Radius: 1.74×10^6 m	Moon's Mass: 7.35×10^{22} kg	Orbit: 3.85×10^8 m
Sun's Radius: 6.96×10^8 m	Mass: 1.99×10^{30} kg	

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1 What is the force of attraction between a 60.0 kg student in the senior parking lot and the school? The distance between the two is 100.000 m and the mass of the school 65,000,000 kg.

2 You're on a date with "the significant other." You are getting close. Your center of masses are 0.50 meters apart. If you have a mass's of 50.00 kg and 70.00 kg then what is the actual scientific force of attraction between the two of you?

3 Two asteroids, ($m_1 = 1.00 \times 10^{12}$ kg and $m_2 = 5 \times 10^{12}$ kg), are floating in space. The force of attraction between them is 10.000 N. How far apart are their centers of mass?

4 In a car race, the force of attraction between the 1st and 2nd place cars is 3.0349×10^{-7}N. If the 1st place car has a mass of 700 kg and the 2nd place car has a mass of 650 kg, then what is the distance between the two cars?

5 While on the surface of the Earth a student has a weight of 450 N. If she is moved twice as far from the center of the Earth, then how does hew new weight compare to her old?

6 How many Earth Radii distances could fit between the center of the Earth and the Center of the moon when it is in orbit around the Earth? If the same 50 kg student in problem #5 is moved out from the surface of the Earth to this distance away from the center of the Earth, then how does her new weight compare to her old?

7 An alien spacecraft is out in space leaving an unknown planet. It detects the pull of gravity due to this unknown planet to be 100 N. Later the alien rechecks the pull on their spacecraft when it is 9 times farther away from the surface. By what factor has their force of attraction changed since they left the unknown planet?

8 The space shuttle travels at 17,000 mph, 7,589.288 m/s while in orbit. How far away from the SURFACE OF THE EARTH is the shuttle?

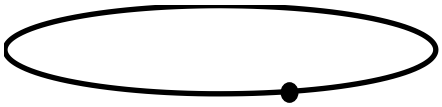
9 How fast is the moon traveling as it orbits the Earth?

10 A geosynchronous orbit is one where a satellite orbits the Earth with the SAME period of motion as the Earth on it own axis. How far from the center of the Earth is the Satellites orbit?

11 Using Kepler's 3rd Law of Planetary motion, determine the distance between the center of the Earth and the center of the Moon.

12 Using Kepler's 3rd Law of Planetary motion, determine the distance between the center of the Earth and the center of the Sun.

13 A planet is in orbit as shown below. Where are the two possible locations for a Sun?



14 The moon Io revolves around Jupiter in 0.0048 sidereal years. Io has a mean orbital radius of 0.0028 Au's. If another Jupiter moon, Europa, has a period of rotation of 0.0097 sidereal years, then how far away is Europa from the center of Jupiter?

15 The planet Mercury takes 0.24 sidereal years to go around the sun. What is the distance from the center of Mercury to the center of the sun?

16 The moon takes 27.32 days to revolve around the Earth once. The moon is 242,000 mi from the center of the Earth. The International Space Station orbits in the same orbit as the space shuttle. The International Space Station makes an orbit around the Earth in 90 minutes, then how high up is the International Space Station from the center of the Earth and the surface of the Earth? (The radius of the Earth is 3950 miles.) Why is this answer different from question #8?

17 The Planet Jupiter's mean orbital radius is 5.2025 Au's. What is the period of Jupiter in sidereal years?

18 The planet Pluto is 39.5 Au's from the Sun. How long does is taking to go around the Sun once?

19 There is belt of asteroids between Mars and Jupiter. This belt circles the "inside" of our solar system and is called the Asteroid belt. This belt has a mean radius from the Sun of 2.6 Au's. How long does it take for 1 asteroid to in the belt to travel around the Sun once?

ORBITAL VELOCITY

20 A satellite is placed in an orbit 16,090,000 meters above the Earth's Surface. How fast is the satellite traveling to remain in orbit?

21 A space ship is to orbit a planet with a mass of 8×10^{20} kg. How far, from the plant's center, must the ship travel if it is to travel with a velocity 10,000 m/s?

22 A spacecraft is to orbit an asteroid of mass 5.00 X 1015 kg at a distance of 55,555 m from the asteroid's center. What is the spacecraft's period of motion and orbital velocity?

23 The Hubble Telescope orbits the Earth 596,000 m ABOVE THE SURFACE of the earth. What is the Telescope's Period and tangential velocity?

24 A spaceship is traveling to a planet called Orphius. The astronauts aboard the ship have a weight of 250 N at one point in their flight. Later they are 5 times closer than when they made the first weight measurement. What will be the new weight at this closer distance?

25 On the Surface of the Earth a test pilot has a weight of 965 N. In an effort to earn her astronaut wings, our pilot travels the necessary distance of 1 000 000 ft above the Earth's surface to be recognized for astronaut wings.

   a. What is the ratio of the two radii?

   b. What was her weight at this altitude?

26 Calculate the value of "g" using the Earth's radius and its mass.

27 The Hubble Telescope orbits the Earth 598 km above the surface. How fast is it traveling to stay in its stable orbit?

28 At one time an infamous computer company had an idea to put its own satellite in a low orbit about 25 km above the Earth's Surface. How fast would these satellites travel?

29 A communications satellite stays in the same spot in the sky above the Earth's surface. It also takes 24 hours to complete a single orbit -just like the Earth's rotation. This orbit is unique and called a "geosynchronous orbit." How high above the Earth's surface is the satellite orbiting?

Circular Motion

Answers

1. 2.6023 X 10-5N
2. 9.3416 X 10-7 N
3. 5,774,945.887 m
4. 10.0 m
5. 1/4 the weight, therefore 112.5 N
6. 60; New =(1/60^2)OLD
7. 1/81 times the 100N
8. 54,7771.53 m (340 mi)
9. 1018.05 m/s
10. 42255942.3 m

11., 12., 13., 19. 4.192 sidereal years

14. 0.00447 Au's
15. 5.76 X 1010m
16. 437.65 miles
17. 11.87 Au's
18. 248 sidereal years
20. 4979.89 m/s

21 5, 338,072