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| **CirMot: Quantitatively analyze objects undergoing circular motion.** | | |
| Be able to define, explain, identify, compare or provide examples of each of the following: | | |
| * Centripetal Acceleration * Frequency | * Centripetal Force * Banked/Unbanked | * Period * Vertical Circles |

**Horizontal, Uniform Circular Motion**

1. A plane flying at a constant speed in a circular path of radius 5500 m completes one revolution every 485 s. Calculate the centripetal acceleration of the plane. {ac = 0.922 m/s2}
2. A 1.2 kg stone attached to a 2.0 m long string is whirled in a horizontal circle. At what speed must the stone move for its centripetal acceleration to equal 9.81 m/s2. {v = 4.4 m/s}
3. A mass of 0.50 kg is tied to one end of a rope and is swung in a circle of radius 1.0 m. The speed is 4.0 m/s. Calculate centripetal force. {Fc = 8.0 N}
4. A communications satellite has a period of 5600 s and an orbital radius of 6.8 x 106 m. If the mass is 2000 kg, calculate the centripetal force keeping the satellite in orbit. {Fc = 17 000 N}
5. A 1.5 kg ball on a string is swung in a horizontal circle. The string will break under a tension of 350 N. Calculate the maximum velocity of the ball if the string is
   1. 0.5 m long {v = 10.8 m/s}
   2. 1.5 m long {v = 18.7 m/s}
6. A 50.0 kg satellite that is 7.00 x 106 m from the center of the Earth is orbiting at a speed of 1000 m/s. Calculate:
   1. The time it takes to orbit the Earth once. {T = 44 000 s}
   2. The centripetal acceleration of the satellite. {ac = 0.143 m/s2}
   3. The centripetal force keeping the satellite in orbit. {Fc = 7.14 N}
7. A boy holds a 0.25 kg toy 6.00 m from the center of a merry-go-round by means of a string. The toy has a tangential velocity of 3.0 m/s.
   1. How long does it take the merry-go-round to make one revolution? {T = 12.6 s}
   2. Calculate the tension in the string. {FT = 0.375 N}
8. The Moon has a mass of 7.4 x 1022 kg. It is 4.0 x 108 m from the center of the Earth and orbits the Earth every 2.4 x 106 seconds. Calculate:
   1. The velocity of the Moon. {v = 1050 m/s}
   2. The force needed to keep the Moon in orbit. {Fc = 2.03 x 1020 N}
9. A 1200 kg is traveling through a 90o corner with a radius of 15.9 m. It takes the car 2.50 seconds to make the turn. Calculate:
   1. The velocity of the car. {v = 10.0 m/s}
   2. The centripetal acceleration of the car. {ac = 6.28 m/s2}
   3. The centripetal force acting on the car. {Fc = 7500 N}
   4. The maximum speed the car could make the corner at if the maximum force available between the tires and the pavement is 5000 N due to ice. {v = 8.14 m/s}
10. A 25 kg object is moving along a circular path at a constant speed of 4.0 m/s completes one trip around the circle in 5.0 s. The coefficient of static friction is 0.75.
    1. Calculate the radius of the circle. {r = 3.2 m}
    2. Calculate the acceleration of the object. {ac = 5.0 m/s2}
    3. Calculate the centripetal force and the force of static friction. {Fc = 125 N; Ff = 184 N}
    4. Calculate the farthest position the object can be placed and still keep the circular motion {r = 4.7 m}
11. A 1750 kg truck is traveling through a 90o corner with a radius 24.8 m. It takes the car 3.17 seconds to make the turn driving at its maximum safe velocity. Calculate the coefficient of static friction between the tires and the road. {μs=0.62}
12. An amusement park ride consists of a large cylinder that rotates around a vertical axis. People stand on a ledge inside. When the rotational speed is high enough, the ledge drops away and people “stick” to the wall. If the period of rotation is 2.5 seconds and the radius is 3.5 m, calculate the minimum coefficient of friction required to keep the riders from sliding. {μs = 0.44}
13. A circular platform is designed to spin horizontally (around a vertical axis) with a period of 1.6 seconds. How far from the center should a mass be placed to not fly off if the coefficient of static friction is 0.57? {r = 0.36 m}
14. A mass is to be placed 1.75 m from the center of a spinning platform. The coefficient of static friction is 0.41. Calculate the maximum frequency of the spinning platform such that the mass would not move. {f = 0.24 Hz}
15. A car rounds a 92 m radius corner without losing traction at a speed of 26 m/s. Calculate the coefficient of static friction between the tires and the road? {μs = 0.75}
16. The maximum speed a car can have to safely take a turn is 30 m/s. On a cold morning ice has reduced the coefficient of static friction by a factor of three. Calculate the new maximum speed for the car to safely navigate the same turn under icy conditions. {v = 17 m/s}

**Banked Curves**

1. Without relying on friction, calculate the maximum speed a car can travel around a 120 m curve and banked at 18o. {v = 20 m/s}
2. Without relying on friction, calculate the angle necessary to bank a curve of 150 m such that cars can safely navigate it traveling 25 m/s. {θ = 23o}
3. A turn is to be banked at 25o for vehicles to navigate, without relying on friction, at 30 m/s. Calculate the required radius of the turn. {r = 197 m}
4. A 1575 kg airplane makes a 1325 m radius turn at 125 m/s.
   1. Calculate the bank-angle the airplane makes with the horizontal. {θ = 50o}
   2. Calculate the centripetal force acting on the airplane. {Fc = 18 573 N}
   3. Calculate the lift (the upward force perpendicular to the wings) on the airplane. {Flift = 24 245 N}
5. For comfort, a passenger airplane keeps a low bank-angle of 12o. A 737 plane is traveling 225 m/s and needs to adjust course.
   1. Calculate the turning radius required. {r = 24 278 m}
   2. Calculate the centripetal force necessary for a 60 500 kg 737 plane to make that turn. {Fc = 126 156 N}
   3. Calculate the centripetal force experienced by a 75 kg passenger. {Fc = 156 N}
   4. Calculate the lift acting on the wings. {Flift = 606 777 N}
   5. During the turn, does the airplane descend, ascend or stay about the same altitude?
6. A 125 m turn is to be constructed on Earth and on Mars. The maximum velocity for each turn is 15 m/s.
   1. Calculate, for each planet, the angles the turn needs to be banked at for vehicles to navigate the turn without relying on friction. {θEarth = 10o, θMars = 26o}
   2. Why is a larger angle required for a banked turn on a planet with a lower acceleration due to gravity?
7. A 75 m turn is banked at 20o. The coefficient of static friction between the tires and road is 0.55. Calculate the maximum velocity to safely navigate the turn. {v = 29 m/s}
8. Vehicles will be taking a banked turn at 28 m/s. The bank will be made at an angle of 15o with the ground. With a coefficient of static of 0.65, calculate the required radius of the turn. {r = 72 m}
9. Calculate the minimum coefficient of static friction necessary for a truck to safely navigate an 87 m radius turn that is banked at 18o while driving 32 m/s. (μ = 0.63}
10. ***Math Challenge***: A race car track needs to build banked turns. The cars will have a maximum speed of 56 m/s and a coefficient of static friction of 0.74 between the tires and the ground. The radius of curvature for the turns is 120 m. Calculate the bank-angle necessary for the cars to safely navigate the corners. {θ = 18o}

**Vertical Circular Motion**

1. A rope has a length of 1.2 m. At the end of the rope is a 10.5 kg mass.
   1. Calculate the minimum velocity to swing the mass in a complete vertical circle. {v = 3.4 m/s}
   2. If the rope breaks under a tension of 750 N, calculate the maximum velocity. {v = 8.6 m/s}
2. The fastest a 350 kg motorcycle can travel is 35 m/s. Calculate the radius of the largest vertical circle that the motorcycle can safely travel around. {r = 125 m}
3. A rope will break under a tension of 1250 N. The desired speed of a 7.25 kg mass at the bottom of a vertical circle is 16 m/s. A piece of rope 1.2 m long is used. With support from calculations, will the rope break before the mass reaches 16 m/s?
4. When a person is traveling in a vertical circle, they experience an *apparent weight*. Mathematically, this is the normal force acting on an object. Calculate the apparent weight of a 58 kg person at the top and bottom of a vertical loop. The circular speed is a constant 14 m/s and the loop has a radius of 12 m. {FNtop = 378 N; FNbot = 1516 N}