Module 3: Motion in Two Dimensions
Topic 4 Content: Circular Motion Practice Solutions

Click next to begin your practice problems concerning circular motion.

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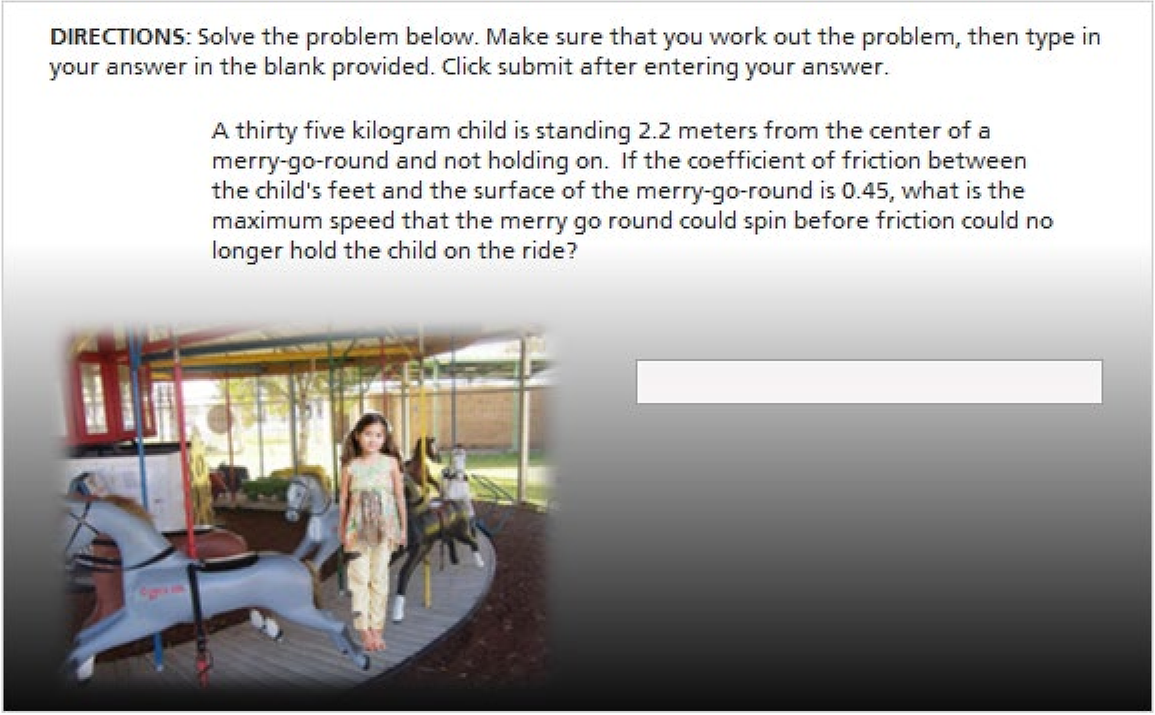
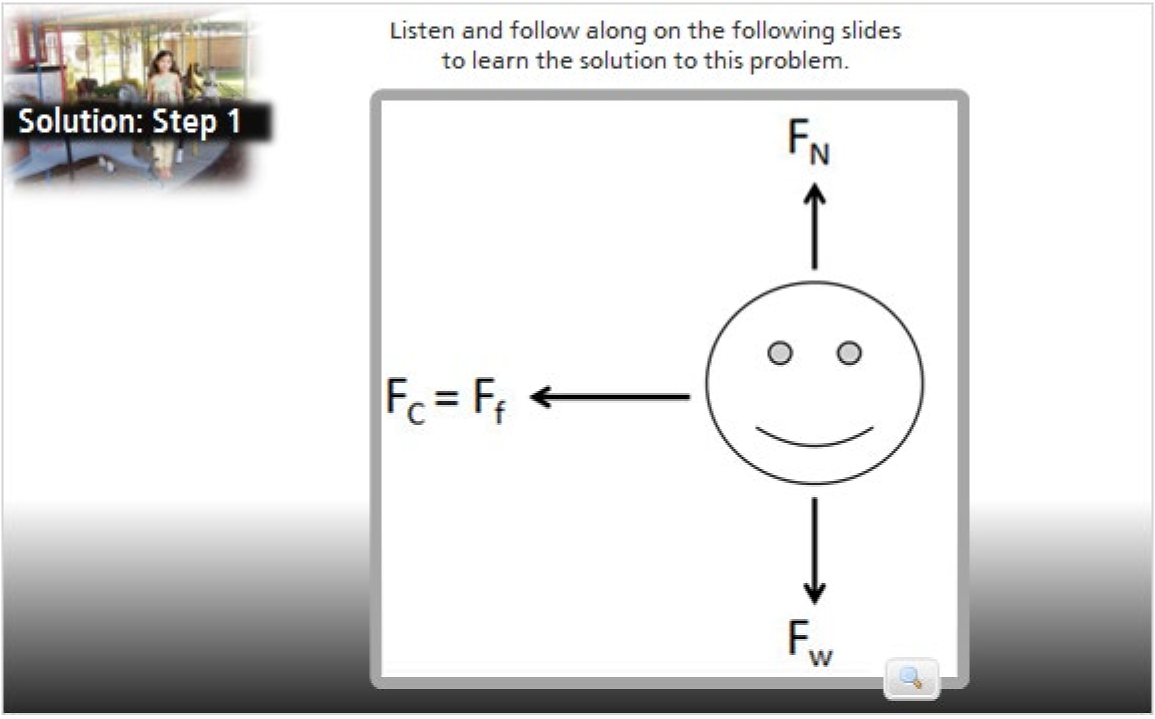
Problem 1



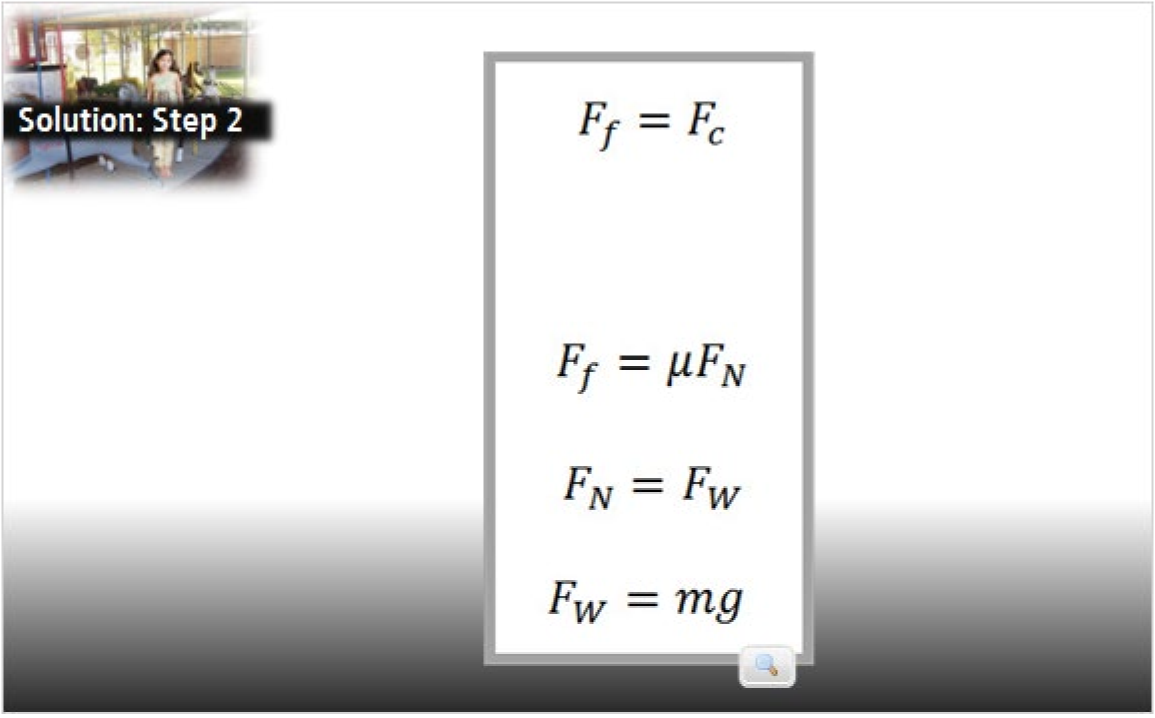
A thirty five kilogram child is standing two point two meters from the center of a merry-go-round and not holding on. If the coefficient of friction between the child's feet and the surface of the merry-go-round is zero point four five, what is the maximum speed that the merry go round could spin before friction could no longer hold the child on the ride?

Problem 1 Solution Step 1



First, you should draw a free body diagram. The gravitational force is straight down. The normal force is straight up, perpendicular to the surface. There must be a force pointed towards the center of the circle that keeps the girl moving in a circle, and this is the friction between the feet and the floor of the ride.

Problem 1 Solution Step 2



To solve this problem, you first have to recognize that that it is the friction between the shoes and the floor of the ride that provides the centripetal force that brings the child around in a circle. So you first must calculate the maximum amount of frictional force, then set this equal to centripetal force to solve for the maximum speed. Recall that the frictional force is equal to the coefficient of friction times the normal force. And the normal force will be equal in magnitude to the gravitational force, which is the mass of the child times the gravitational acceleration.

Problem 1 Solution Step 3

$$F_W = mg = (35)(9.8) = 343N$$

$$F_N = 343\ N$$

$$F_f = \mu F_N = (0.45)(343) = 154.35N$$

$$F_c = F_f$$

$$\frac{mv^2}{r} = 154.35$$

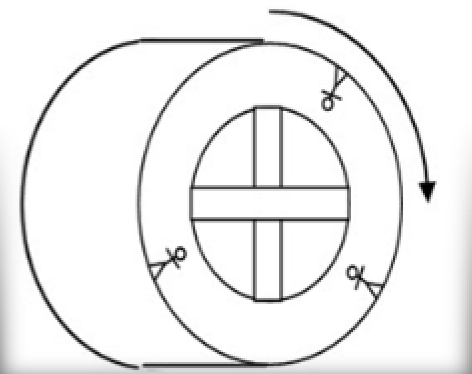
$$\frac{(35)(v^2)}{2.2} = 154.35$$

$$v = 3.11\frac{m}{s}$$

First, you'll solve for the gravitational force, or the weight of the child. You find that the child weighs three hundred forty three Newtons. The normal force opposes this gravitational force, so the normal force is also equal to three hundred forty three Newtons. The force of friction is the coefficient of friction times the normal force, so it is equal to one hundred fifty four point three five Newtons. Finally, you can set this equal to the centripetal force. Substituting and solving for the speed, you find that the maximum speed is three point one one meters per second.

Problem 2

DIRECTIONS: Solve the problem below. Make sure that you work out the problem, then type in your answer in the blank provided. Click submit after entering your answer.



A rotating space station is designed as a large cylinder with radius five point nine meters. It spins around its axis so that the outer surface is moving around at a constant speed of seven point five meters per second. Astronauts standing on the inner surface feel a centripetal acceleration due to the rotation of the cylinder. How does their acceleration compare to the gravitational acceleration near the surface of the earth? **(Write your answer in terms of the percentage of acceleration that they would get from Earth's gravity.)**

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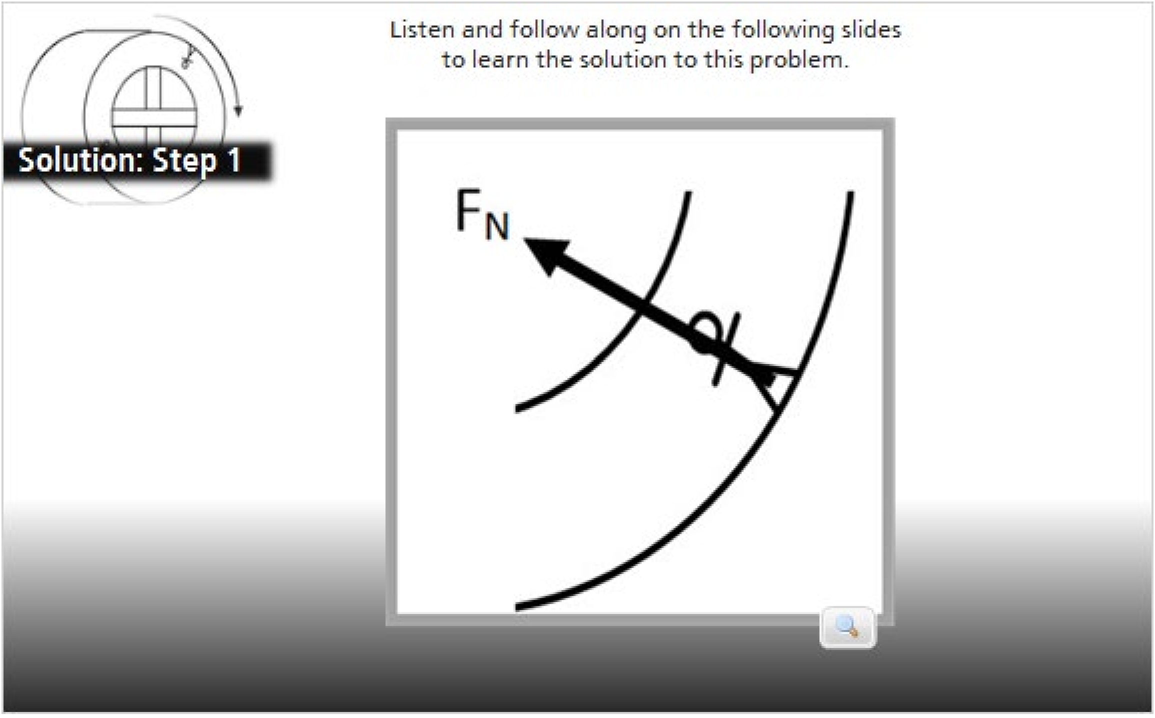
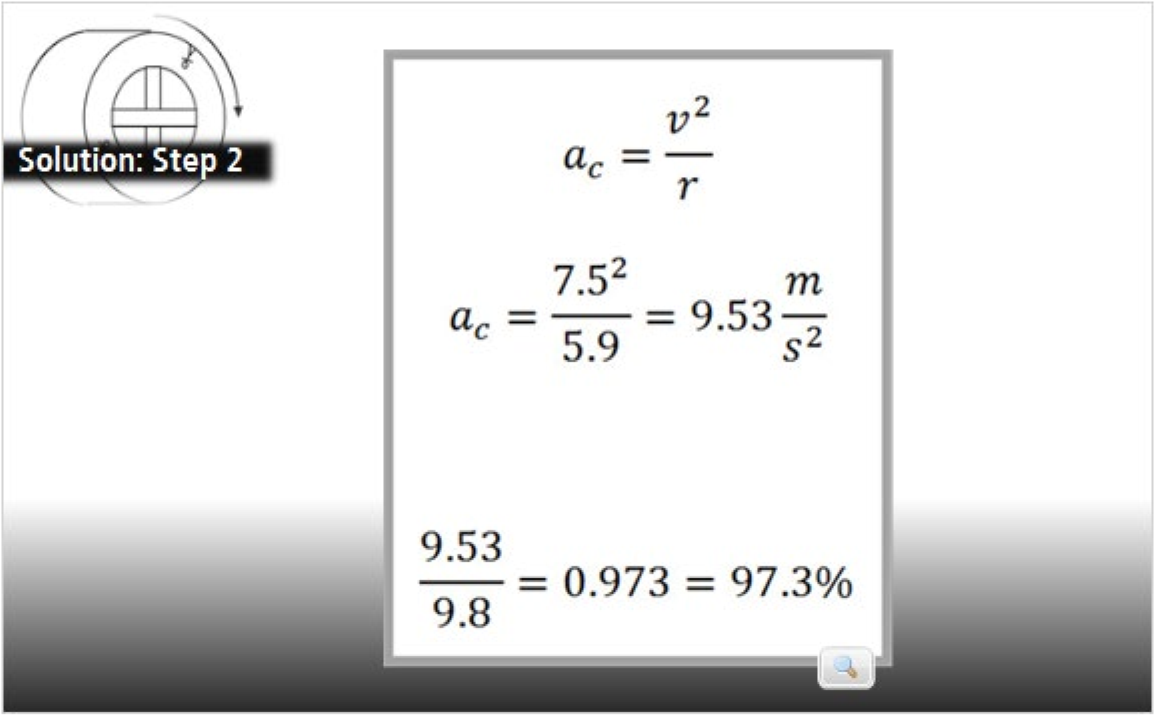
Problem 2 Solution Step 1



It is useful to draw a free body diagram of the astronaut. In this case, there is no gravitational force, only a normal force perpendicular to the floor, pointing towards the center of the circle. This is the centripetal force.

Problem 2 Solution Step 2

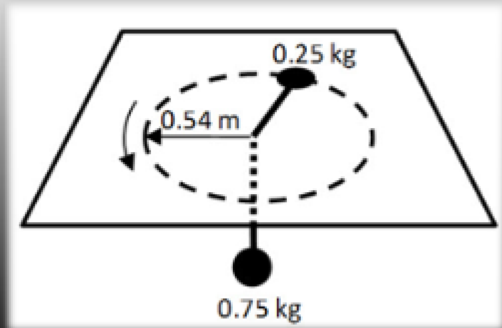


The astronauts will be moving in a circle, so you can calculate their centripetal acceleration. Centripetal acceleration equals v squared over r. Substituting and solving, you see that the astronauts will feel an acceleration of nine point five three meters per second squared. The acceleration of gravity near the surface of Earth is nine point eight meters per second squared. It appears that the space station has been designed well, so that the astronauts will feel about ninety seven percent of the acceleration they would get from Earth's gravity.

Problem 3

DIRECTIONS: Solve the problem below. Make sure that you work out the problem, then type in your answer in the blank provided. Click submit after entering your answer.

A hole is drilled in an air hockey table. The 0.25 kilogram puck is attached to a string and the string is threaded through the hole in the table. To the bottom of the string is attached a 0.75 kilogram mass. The air hockey puck is set in motion so that it spins at constant speed in a circle of radius 0.54 meters. What is the tension in the string?



A hole is drilled in an air hockey table. The zero point two five kilogram puck is attached to a string and the string is threaded through the hole in the table. To the bottom of the string is attached a zero point seven five kilogram mass. The air hockey puck is set in motion so that it spins at constant speed in a circle of radius zero point five four meters. What is the tension in the string?

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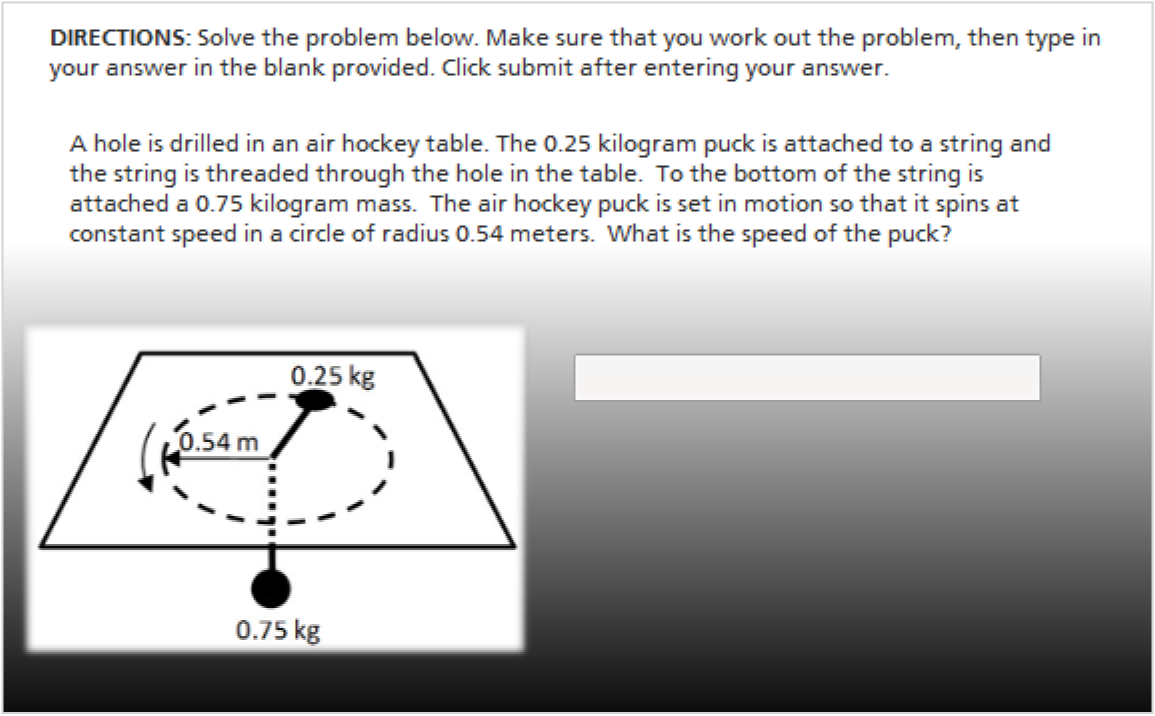
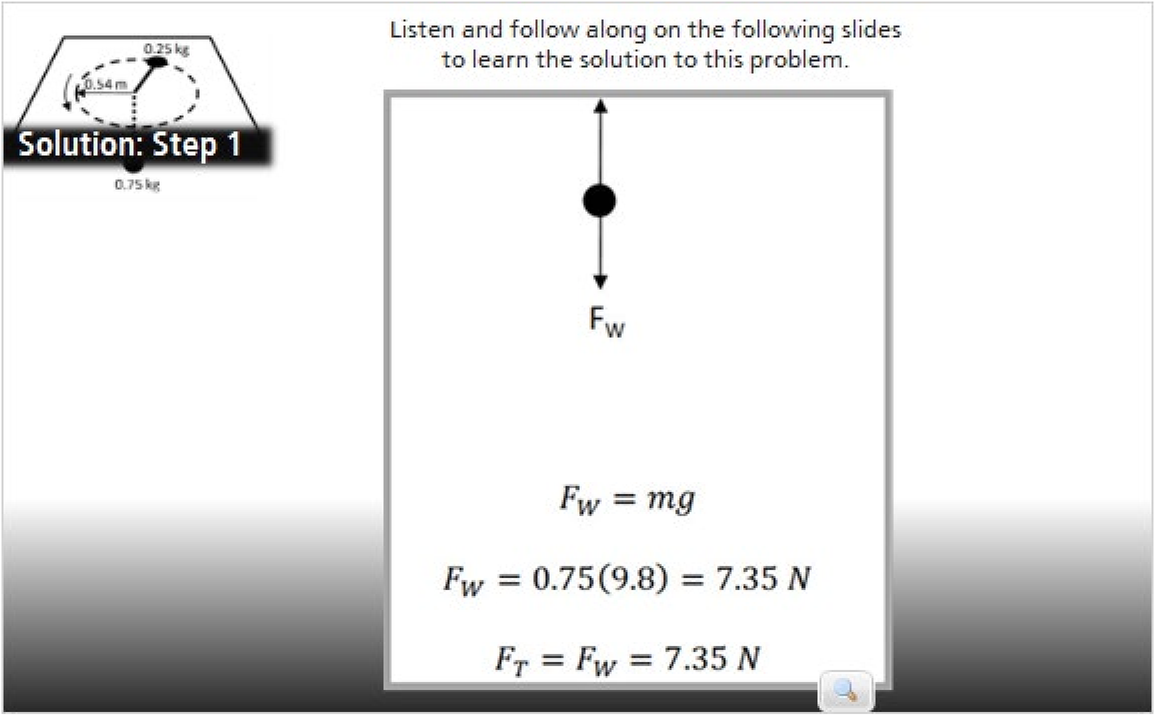
Problem 4



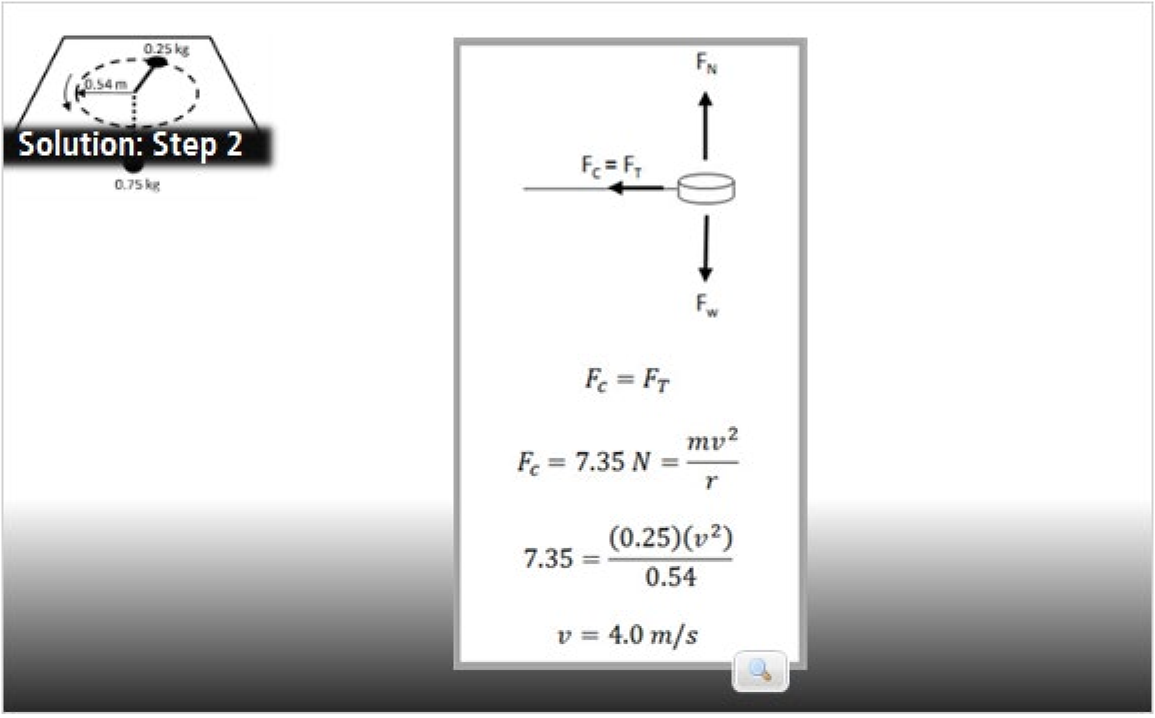
A hole is drilled in an air hockey table. The zero point two five kilogram puck is attached to a string and the string is threaded through the hole in the table. To the bottom of the string is attached a zero point seven five kilogram mass. The air hockey puck is set in motion so that it spins at constant speed in a circle of radius zero point five four meters. What is the speed of the puck?

Problem 3 & 4 Solution Step 1



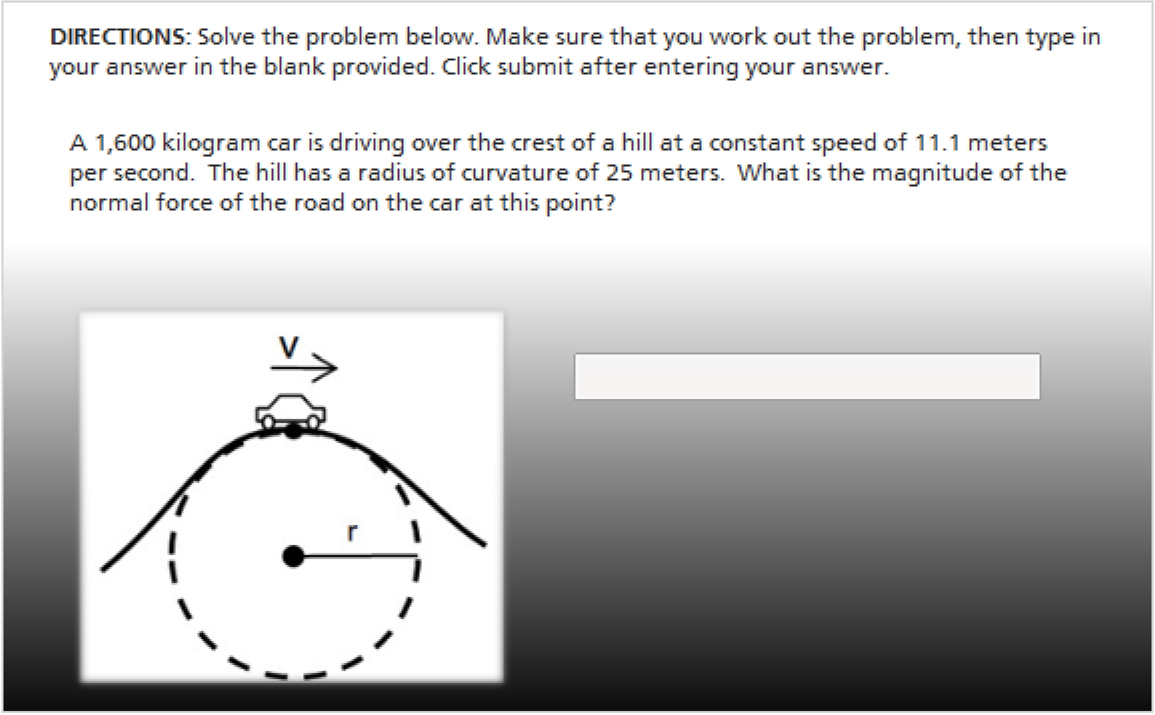
The hanging mass is in equilibrium. To determine the tension in the string, you need to look at a free body diagram of the hanging mass. The only two forces on this mass are the gravitational force and a force of tension from the string. The gravitational force on the hanging mass is its mass times the acceleration of gravity. Substituting, you see that the weight of the mass is seven point three five Newtons. Since the system is at equilibrium, then tension in the string must be equal in magnitude to the weight of the hanging mass, also seven point three five Newtons.

Problem 3 & 4 Solution Step 2



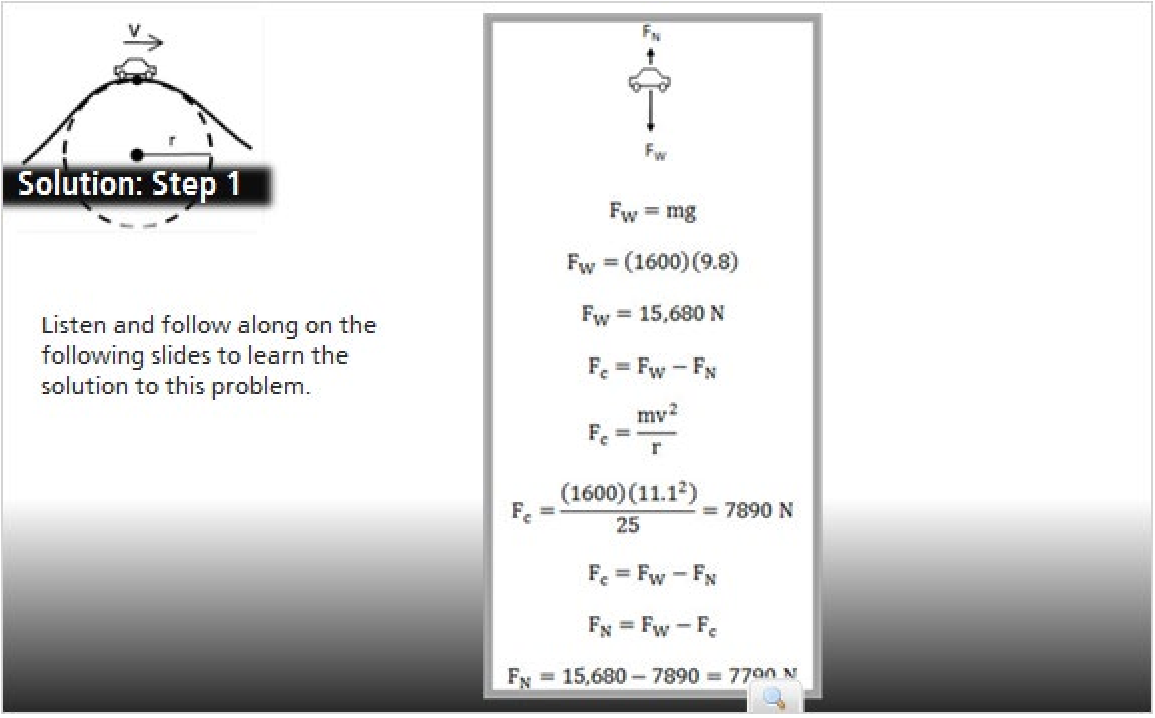
To determine the speed of the puck, you must recognize that it is going around in a circle at a constant speed. The force moving the puck in a circle is provided by the tension in the string. The only other forces acting on the puck are the normal force and the gravitational force, but these are equal and opposite. So you can write that the centripetal force equals the tension force. Substituting and solving, you see that the puck is moving at a speed of four point zero meters per second.

Problem 5



A sixteen hundred kilogram car is driving over the crest of a hill at a constant speed of eleven point one meters per second. The hill has a radius of curvature of twenty five meters. What is the magnitude of the normal force of the road on the car at this point?

Problem 5 Solution Step 1



It helps to first draw a free body diagram of the car. There are two forces acting on the car; the gravitational force and the normal force. you also know that the car is moving in a circular path, so the net force on the car at this point must be the centripetal force and must point towards the center of the circle. The gravitational force is simply the mass of the car times the acceleration of gravity. In this case, you see that the weight of the car is fifteen thousand six hundred eighty Newtons. It would be tempting to say that the normal force equals the gravitational force, since you've done so quite often in the past, but in this case, the car is moving on a downward curve, so the downward force must be greater than the upward force, and the net force must point down. You can say that the centripetal force is equal to the gravitational force minus the normal force. You can calculate the centripetal force using our centripetal force equation. Substituting and solving yields a centripetal force of seven thousand eight hundred eighty five Newtons. Now you can calculate the normal force by subtracting the centripetal force from the gravitational force. You see that the normal force equals seven thousand seven hundred ninety Newtons.

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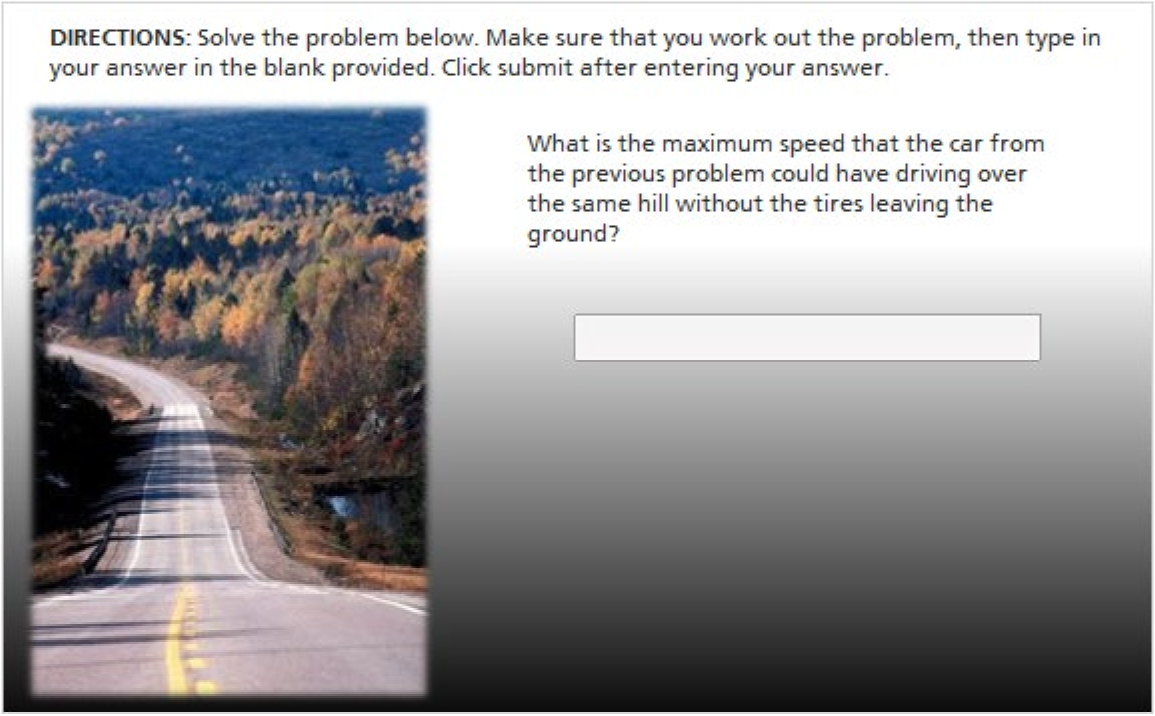
Centripetal Force

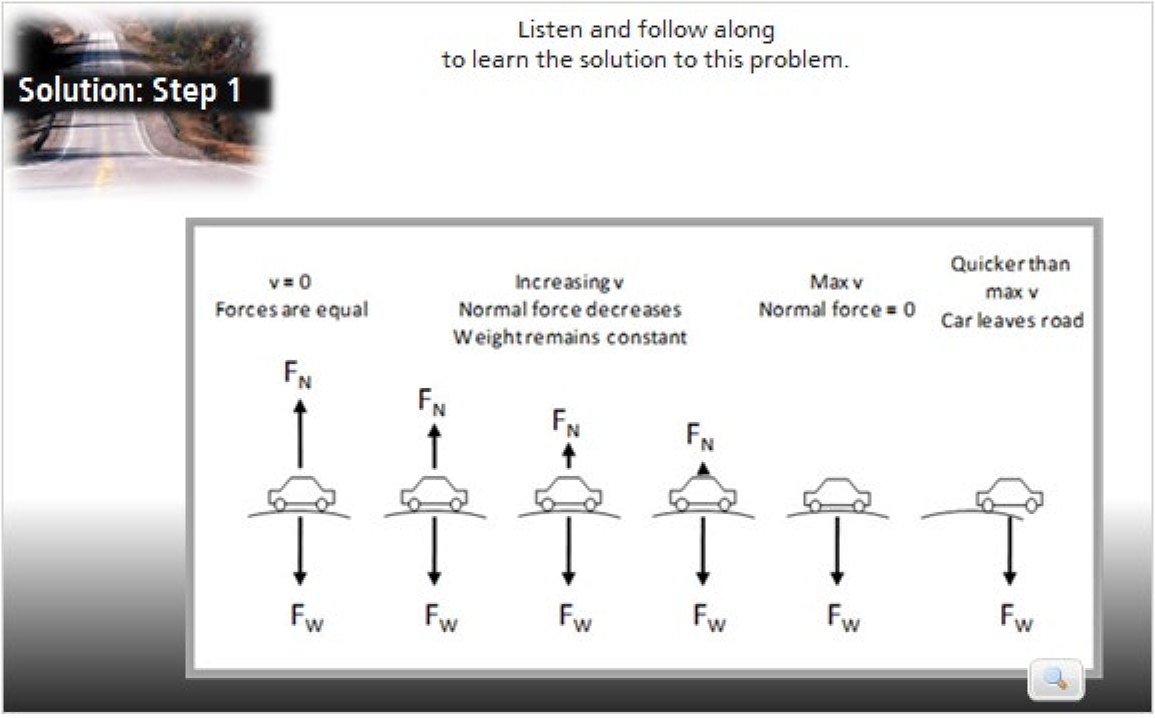
If you think about what it would feel like to drive quicker and quicker over the crest of a hill, you can see that the quicker you go, the lighter you feel in your seat. If you imagine sitting on a bathroom scale, the reading of the scale would be less and less as you moved quicker and quicker over the top of the hill. The bathroom scale is a good way to think about the normal force. As you move faster over the crest of the hill, the normal force decreases. There is a point where the reading of the scale would go to zero. This is the point where the normal force would go to zero, and you would feel momentarily weightless. Since the centripetal force is the difference between the constant gravitational force and the normal force, you can see that as the normal force decreases, the centripetal force increases, which makes sense, since you need more centripetal force to pull the car around at a higher velocity.

Problem 6



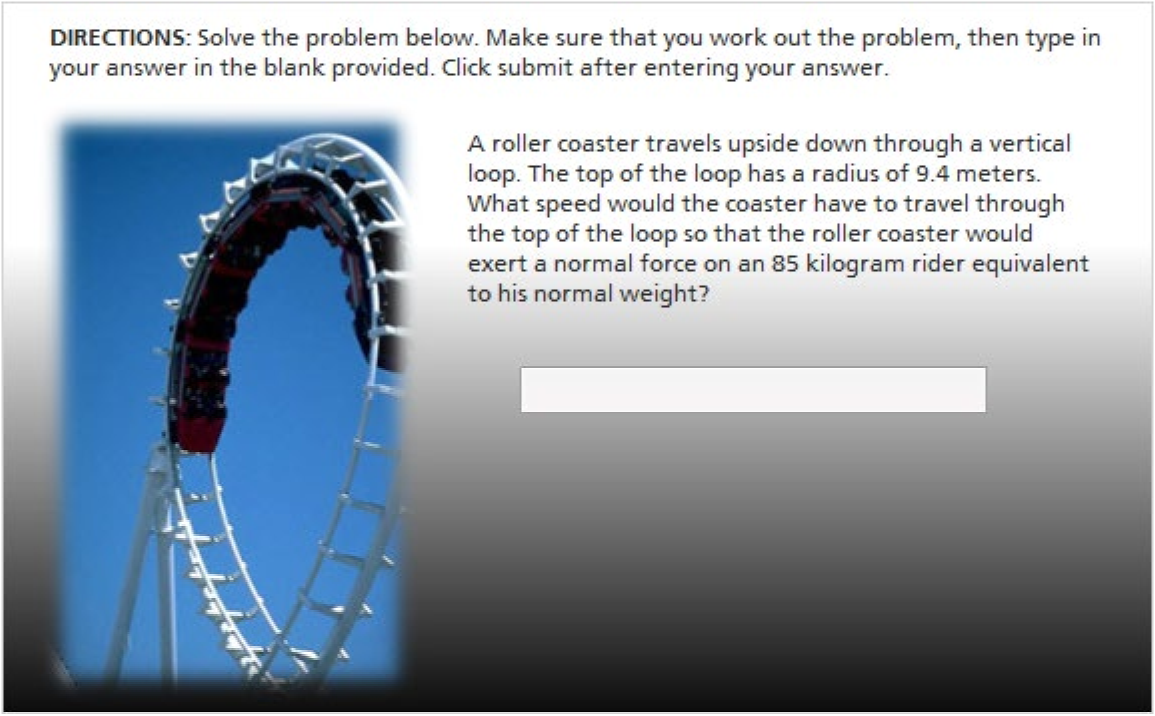
What is the maximum speed that the car from the previous problem could have driving over the same hill without the tires leaving the ground?

Problem 6 Solution Step 1



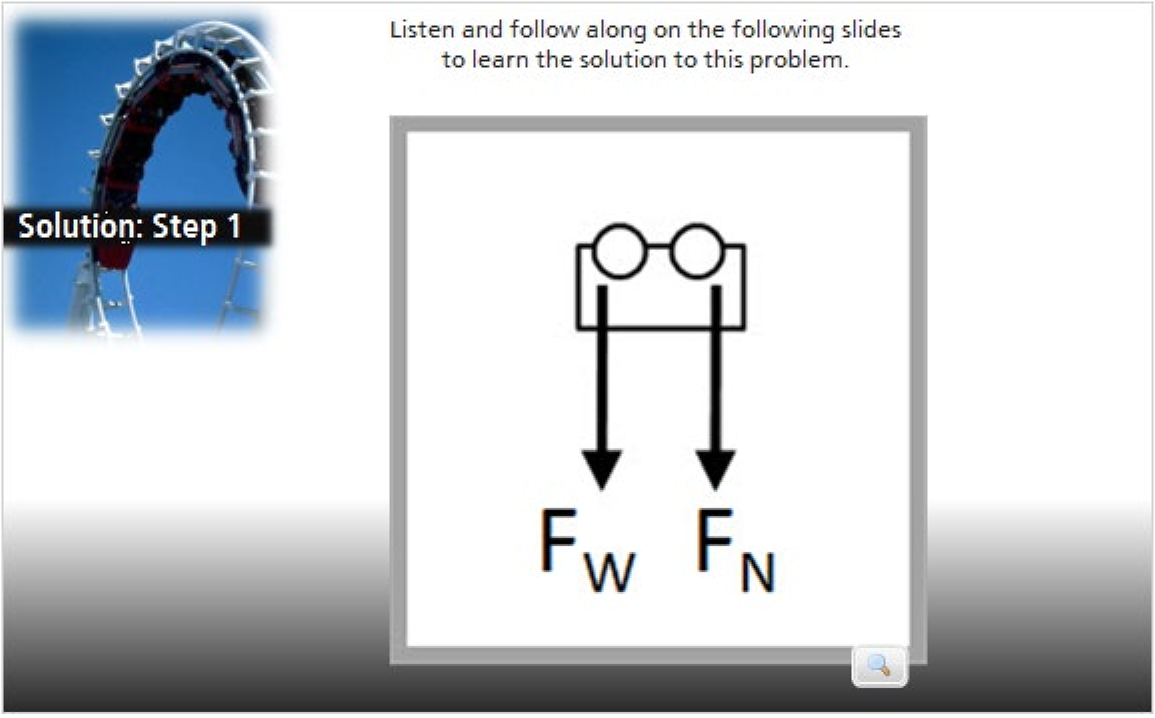
If you set the normal force to zero, we see that the centripetal force equals the gravitational force. If the car moves any quicker, the gravitational force will not be sufficient to provide enough centripetal force to keep the tires on the road. If you set centripetal force equal to gravitational force, you see that the mass cancels out, leaving the centripetal acceleration on the left and the gravitational acceleration on the right. You can now substitute the radius of the hill and solve for the speed. You find that the maximum speed is fifteen point seven meters per second. Since the mass cancels out, this is the maximum speed for any vehicle, regardless of size.

Problem 7



A roller coaster travels upside down through a vertical loop. The top of the loop has a radius of nine point four meters. What speed would the coaster have to travel through the top of the loop so that the roller coaster would exert a normal force on an 85 kilogram rider equivalent to his normal weight?

Problem 7 Solution Step 1



Again, a free body diagram would be useful. At the top of the loop, the track is exerting a downwards directed normal force. The gravitational force is also directed downwards. The centripetal force will be the net force, and since both forces are pointed in the same direction, the centripetal force is equal to the sum of the gravitational force and the normal force. Since the problem asked for a situation where the normal force is equal to the weight, you can say that the centripetal force is equal to twice the gravitational force.

Problem 7 Solution Step 2

$$F_c = F_W + F_N$$

$$F_C = 2(F_W)$$

$$F_c = 2(mg)$$

$$F_c = 2(85)(9.8) = 1{,}666\ \text{N}$$

$$F_c = \frac{mv^2}{r}$$

$$1{,}666 = \frac{(85)(v^2)}{9.4}$$

$$v = 13.6\frac{\text{m}}{\text{s}}$$

Substituting and solving, you see that the centripetal force must equal one thousand six hundred sixty six Newtons. Now you can use our centripetal force equation to solve for the required velocity. Substituting and solving you see that the velocity equals thirteen point six meters per second.