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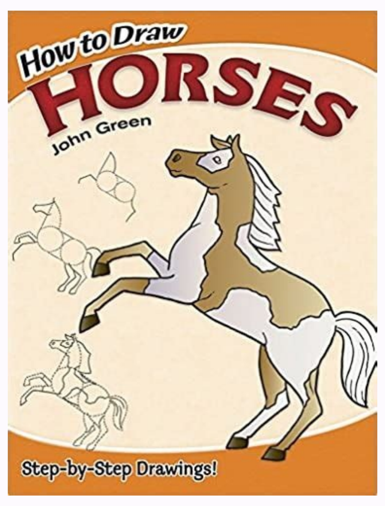
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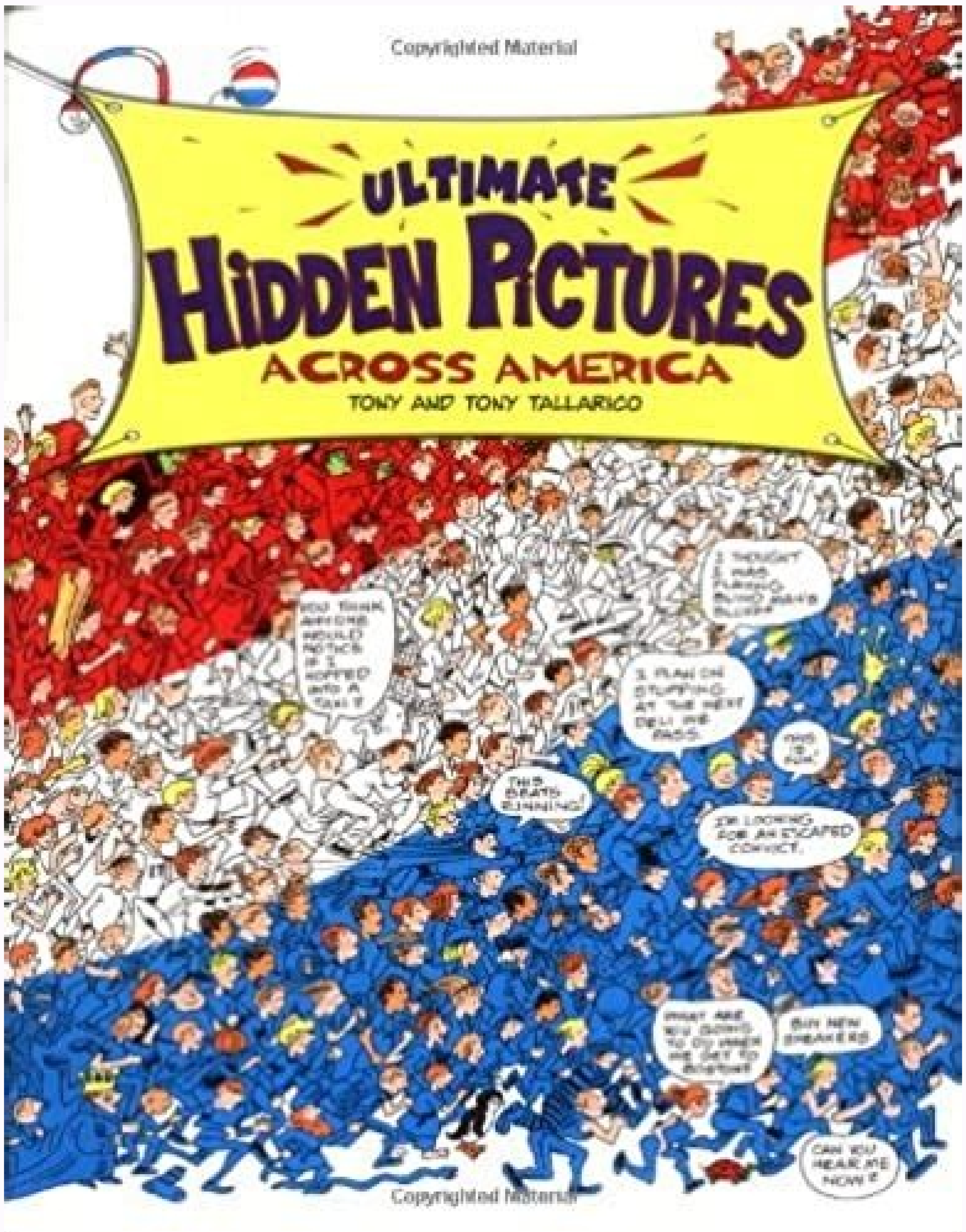
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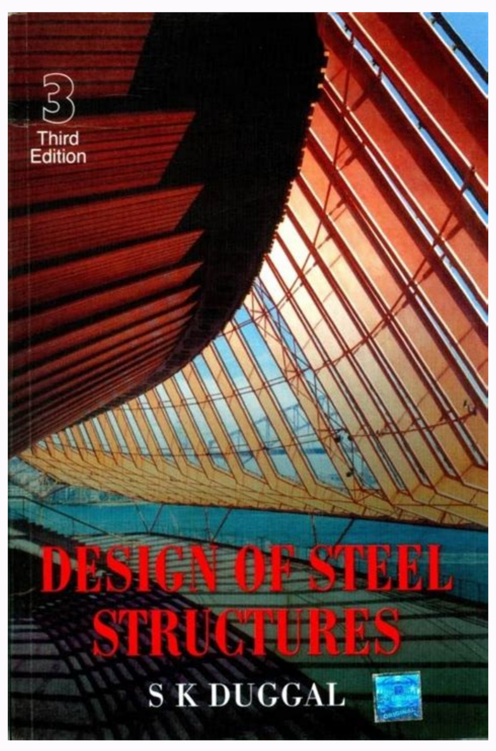
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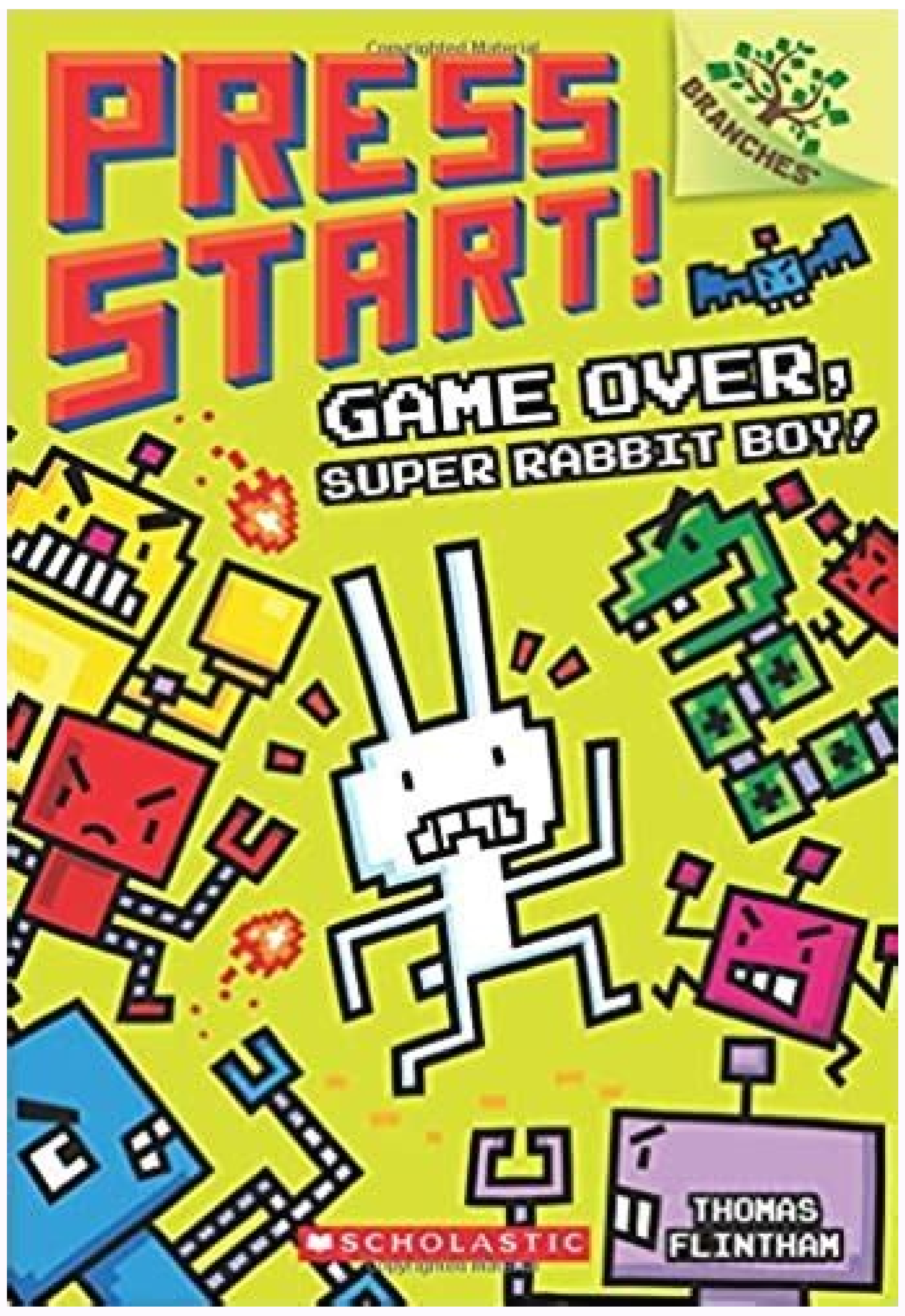

Learning Objectives Explain the equation for centripetal acceleration Apply Newton¢ÃÂÂs second law to develop the equation for centripetal force Use circular motion concepts in solving problems involving Newton¢ÃÂÂs laws of motion In Motion in Two and Three Dimensions, we examined the basic concepts of circular motion. An object undergoing circular motion, like one of the race cars shown at the beginning of this chapter, must be accelerating because it is changing the direction of its velocity. We proved that this centrally directed acceleration, called centripetal acceleration, is given by the formula \[a_{c} = \frac{v^{2}}{r}\] where v is the velocity of the object, directed along a tangent line to the curve at any instant. If we know the angular velocity \(\omega\), then we can use \[a_{c} = r \omega^{2} \ldotp\] Angular velocity gives the rate at which the object is turning through the curve, in units of rad/s. This acceleration acts along the radius of the curved path and is thus also referred to as a radial acceleration. An acceleration must be produced by a force. Any force or combination of forces can cause a centripetal or radial acceleration. Just a few examples are the tension in the rope on a tether ball, the force of Earth¢ÃÂÂs gravity on the Moon, friction between roller skates and a rink floor, a banked roadway¢ÃÂÂs force on a car, and forces on the tube of a spinning centrifuge. Any net force causing uniform circular motion is called a centripetal force. The direction of a centripetal force is toward the center of curvature, the same as the direction of centripetal acceleration. According to Newton¢ÃÂÂs second law of motion, net force is mass times acceleration: Fnet = ma. For uniform circular motion, the acceleration is the centripetal acceleration: a = ac. Thus, the magnitude of centripetal force Fc is \[F_{c} = ma_{c} \ldotp\] By substituting the expressions for centripetal acceleration ac (\(a_{c} = A_ {C} = R \ Omega^{2} \)), we obtain two expressions for the centripetal force fc in terms of mass, speed, angular speed and curvature radius: \ [f_ {c} = m \ franc {v ^{2}} {r}; \ quad f_ {C} = mr \ omega^{2} \ ldotp \ label {6.3} \] It is possible to use any expression for the centripetal force is more convenient. The centripetal force \ (\ vec {f} _ {c} \) is always perpendicular to the path and aims at the center of the curvature, because © \ (\ vec {a} _ {c} \) is perpendicular to the speed e to the points at the center of the curvature. Note that if the first expression is resolved for r, you get \ [r = \ franc {mv^{2}} {c}} \ ldotp \] This implies that for a certain mass and speed, a great centripetal force It causes a small radius of curvature - that is a narrow curve, as in the figure \ (\ pageindex {1} \). Figure \ (\ pageindex {1} \): the friction force provides the centripetal force and is numerically equal to it. The centripetal force is perpendicular to speed and causes uniform circular movement. The greater the FC, more small is the radius of the curvature r and more clearly the curve. The second curve has the same V, but a larger FC produces an most small r ã ¢ Example \ (\ pageindex {1} \): which coefficient of friction do cars need a flat curve? Calculate the centripetal force exerted on a 900.0 kg car that negotiates a radius curve of 500.0 m at 25.00 m/s. Assuming an non -banking curve, it finds the minimum static coefficient of friction between the tires and the road, the static friction is the reason that prevents the car from sliding (Figure \ (\ pageindex {2} \)). Figure \ (\ pageindex {2} \): this level car is moving away and turns left. The centripetal force that causes the car in a circular route is due to friction between the tires and the road. A minimum friction coefficient is needed or the car moves in a curve a ;\ ;\ 0.009({ carf \ = }r{ }}2{^v{ carf \ m = }c{ _f $$ idniuQ .)\ }r{ }}2{^v{ carf \ m = }c{ _f(\ ehc omaippas ol aigetartS .ataiggerrac al Ârecsal e eroiggam m/s)^{2}}{(500.0\; m)} = 1125\; N \ldotp$$ Figure \(\PageIndex{2}\) shows the forces acting on the car on an unbanked (level ground) curve. Friction is to the left, keeping the car from slipping, and because it is the only horizontal force acting on the car, the friction is the centripetal force in this case. We know that the maximum static friction (at which the tires roll but do not slip) is \(\mu_{s}\) N, where \(\mu_{s}\) is the static coefficient of friction and N is the normal force. The normal force equals the car¢ÃÂÂs weight on level ground, so N = mg. Thus the centripetal force in this situation is $$F_{c} = f = \mu_{s} N = \mu_{s} mg \ldotp$$Now we have a relationship between centripetal force and the coefficient of friction. Using the equation $$F_{c} = m \frac{v^{2}}{r} \ldotp$$we obtain $$m \frac{v^{2}}{r} = \mu_{s} mg \ldotp$$We solve this for \(\mu_{s}\), noting that mass cancels, and obtain $$\mu_{s} = \frac{v^{2}}{rg} \ldotp$$Substituting the knowns, $$\mu_{s} = \frac{(25.00\; m/s)^{2}}{(500.0\; m)(9.80\; m/s^{2})} = 0.13 \ldotp$$(Because coefficients of friction are approximate, the answer is given to only two digits.) Significance The coefficient of friction found in Figure \(\PageIndex{2b}\) is much smaller than is typically found between tires and roads. The car still negotiates the curve if the coefficient is greater than 0.13, because static friction is a responsive force, able to assume a value less than but no more than \(\mu_{s}\)N. A higher coefficient would also allow the car to negotiate the curve at a higher speed, but if the coefficient of friction is less, the safe speed would be less than 25 m/s. Note that mass cancels, implying that, in this example, it does not matter how heavily loaded the car is to negotiate the turn. Mass cancels because friction is assumed proportional to the normal force, which in turn is proportional to mass. If the surface of the road were banked, the normal would be less, as discussed next. Exercise \(\PageIndex{1}\) A car moving at 96.8 km/h travels around a circular curve of radius 182.9 m on a flat country road. What must be the minimum coefficient of static friction to keep the car from slipping? Let us now consider banked curves, where the slope of the road helps you negotiate the curve (Figure \(\PageIndex{3}\)). The greater the angle Â¸Â , the faster you can take the curve. Race tracks for bikes as well as cars, for example, often have steeply banked curves. In an ¢ÃÂÂideally banked curve,¢ÃÂÂ the angle \(\theta\) is such that you can negotiate the curve at a certain speed without the aid of friction between the tires and the road. We will derive an expression for \(\theta\) for an ideally banked curve and consider an example related to it. Figure \(\PageIndex{3}\): The car on this banked curve is moving away and turning to the left. For ideal banking, the net external force equals the horizontal centripetal force in the absence of friction. The components of the normal force N in the horizontal and vertical directions must equal the centripetal force and the weight of the car, respectively. In cases in which forces are not parallel, it is most convenient to consider components along perpendicular axes¢ÃÂÂin this case, the vertical and horizontal directions. Figure \(\PageIndex{3}\) shows a free-body diagram for a car on a frictionless banked curve. If the angle \(\theta\) is ideal for the speed and radius, then the net external force equals the necessary centripetal force. The only two external forces acting on the car are its weight \(\vec{w}\) and the normal force of the road \(\vec{N}\). (A frictionless surface can only exert a force perpendicular to the surface¢ÃÂÂthat is, a normal force.) These two forces must add to give a net external force that is horizontal toward the center of curvature and has magnitude \(\frac{mv^{2}}{r}\). Because this is the crucial And it is horizontal, we use a coordinate system with vertical and horizontal axes. Only the normal force has a horizontal component, therefore this must be the same as the centripetal force, that is, \ [n \ sin \ theta = \ franc {mv^{2}} {r} \ ldotp \] in the car It does not leave the surface of the road, the net vertical force must be zero, which means that the vertical components of the two external forces must be equal in magnitude and opposed towards the direction. From the figure \ (\ pageindex {3} \), we see that the vertical component of the normal force is n so \ (\ theta \), and the only other vertical force is the weight of the car. These must be the same in size; So, \ [n \ cos \ theta = mg \ ldotp \] Now we can combine these two equations to eliminate n and obtain an expression for \ (\ theta \), as desired. Solve the second equation for n = \ (\ FRACC {mg} {(\ Cos \ theta)} \) and replace it in the first returns \ [\ begin {split} mg \ franc {\ sin \ theta} {\ cos \ theta } & = \ FRACC {mv^{2}} {r} \\ mg \ tan \ theta & = \ franc {mv^{2}} {r} \\\\ tan \ theta & = \ franc {v ^{2}} {rg} \ ldotp \ end {Split} \\ take the inverse tangent of the [\ theta = \ tan^{-1} \ left (\ Dfrac {v^{2} {rg} \ right) \ ldotp \ label {6.4} \] This expression can be understood considering how \ (\ theta \) depends on v and r. A large \ (\ theta \) is obtained for a large V and a small r. That is, the roads must be restlessly covered for high speed and sharp curves. The clutch helps, because it allows you to take the greater or lower velocity curve than the curve was without friction. Note that \ (\ theta \) does not depend on the mass of the vehicle. Example \ (\ pageindex {2} \): what is the ideal speed for taking a steeply banking curve? The curves on some trial tracks and the race courses, such as Daytona International Speedway in Florida, are very steeply banking. This bank, with the help of the friction of tires and configurations Very stable, it allows you to take curves with very high speed. To illustrate, calculate the speed to which a one radius curve banked at 31.0Â°Â should be driven if the road were frictionless. Strategy We first note that all terms in the expression for the ideal angle of a banked curve except for speed are known; thus, we need only rearrange it so that speed appears on the left-hand side and then substitute known quantities. Solution Starting with \[\tan \theta = \frac{v^{2}}{rg},\] we get \[v = \sqrt{rg \tan \theta} \ldotp\] Noting that tan 31.0Â°Â = 0.609, we obtain \[v = \sqrt{(100.0\; m)(9.80\; m/s^{2})(0.609)} = 24.4\; m/s \ldotp\] Significance This is just about 165 km/h, consistent with a very steeply banked and rather sharp curve. Tire friction enables a vehicle to take the curve at significantly higher speeds. Airplanes also make turns by banking. The lift force, due to the force of the air on the wing, acts at right angles to the wing. When the airplane banks, the pilot is obtaining greater lift than necessary for level flight. The vertical component of lift balances the airplane¢ÃÂÂs weight, and the horizontal component accelerates the plane. The banking angle shown in Figure \(\PageIndex{4}\) is given by \(\theta\). We analyze the forces in the same way we treat the case of the car rounding a banked curve. Figure \(\PageIndex{4}\): In a banked turn, the horizontal component of lift is unbalanced and accelerates the plane. The normal component of lift balances the plane¢ÃÂÂs weight. The banking angle is given by \(\theta\). Compare the vector diagram with that shown in Figure 6.22. Simulation Join the ladybug in an exploration of rotational motion. Rotate the merry-go-round to change its angle or choose a constant angular velocity or angular acceleration. Explore how circular motion relates to the bug¢ÃÂÂs xy-position, velocity, and acceleration using vectors or graphs. Note A circular motion requires a force, the so-called centripetal force, which is directed to the axis of rotation. This simplified model of a carousel This force. What to take off in a jet plane, turning a corner in a car, riding a ride-round, and the circular movement of a tropical cyclone have in common? Each has inertial forces, forces that simply seem to be born of the movement, because the frame of reference of the observer is accelerating or rotating. When you take off in a jet, most people would agree that you feel as if you are pushing back into the seat as the plane speeds down the track. Yet a physicist would say that he tends to remain stationary while the seat pushes forward on you. An even more common experience occurs when you make a narrow curve in your car—yes, right (Figure \(\PageIndex{5}\)). You feel as if you throw (i.e. forced) towards the left relative to the machine. Once again, a physicist would say that you are going in a straight line (rename the first Newton law) but the machine moves right, not that you are experiencing a force from the left. Figure \(\PageIndex{5}\): (a) The driver feels forced to the left when he turns right. It is an inertial force resulting from the use of the car as a reference frame. (b) In the framework of Earth's reference, the driver moves in a straight line, obeying Newton's first law, and the car moves right. There's no force left on the Earth-related driver. Instead, there is a force on the right on the machine to turn it. We can reconcile these views by examining the frames used. Let's focus on people in the car. Passengers instinctively use the car as a reference frame, while a physicist could use the Earth. The physicist could make this choice because Earth is almost an inertial frame of reference, in which all forces have an identifiable physical origin. InThis framework of reference, Newton's laws of movement take the form given in Newton's Laws of Movement. The car is a non-inertial frameBecause it is accelerated on the side. The force on the left detected by the passengers of the car is an inertial force that has no physical origin (it is due purely to the passenger's inertia, not to some physical causes such as tension, friction or gravitation). The car, as well as the driver, is actually accelerating to the right. This inertial force is said to be an inertial force because it does not have a physical origin, such as gravit. A physique choose any reference frame is more convenient for the situation analyzed. There is no problem for a physique including inertial forces and the second law of Newton, as usual, if it is more convenient, for example, on a carousel or on a rotating planet. Noninertial (accelerated) reference frames are used when it is useful to do it. Several reference frames must be considered in discussing the movement of an astronaut in a space vehicle that travels to speed near the speed of light, as you will appreciate in the study of the special theory of the relativity. Let's now take a mental ride on a particular carousel-in ", a rapid rotation carousel of the playground (Figure \ (\ pageindex {6} \)). Take the carousel to be your reference framework because it rotates together. When It rotates in that noninertial reference framework, feel an inertial force that tends to throw you away; this is often defined as a centrifugal force (not to be confused with the centripetal force). The centrifugal force is a commonly used term, but in reality not It exists. It is necessary to resist strictly to contrast inertia (that people often refer as a centrifugal force). In the reference framework of the earth, there is no strength that tries to throw you away; we underline that the centrifugal force is a fiction. You must cling to get you in a circle because otherwise you would go to a straight line, right outside the carousel, in line with the Newton's law. 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A person standing next to the carousel sees the ball that moves straight and the carousel that revolves under it. In the reference framework of Marry-Go-Round, we explain the apparent curve on the right using an inertial force, called the Coriolis force, which makes the ball curved on the right. The strength of Coriolis can be used by anyone in that framework of reference to explain why the objects follow the curved paths and allows us to apply Newton's laws in noninertial reference frames. Figure \ (\ pageindex {8} \): looking down on the anti -eral direction of a carousel, we see that a ball slipped straight towards the edge follows a curved path to the right. The person slides the ball towards point B, starting from point A. both points revolve in shaded positions (A over the "â â ¢ and bâ ¢ âvelop" ¢) shown over time that the ball follows The curved route in the rotating frame and a straight route of the earth. Until now, we have considered the earth as an inertial reference framework with little or no concern for the effects due to its rotation. Yet these effects exist - for example in the rotation of weather systems. Most of the consequences of the rotation of the earth can be qualitatively understood by the analogy with the carousel. Seen from above the north pole, the earth revolves counterclockwise, as well as the carousel in the figure \ (\ pageindex {8} \). As on the carousel, any movement in the northern hemisphere of the Earth experiences a Coriolis force on the right. The opposite occurs in the southern hemisphere; There, the force is on the left. Since the corner speed of the earth is small, the power of Coriolis is generally negligible, but for large -scale movements, such as wind models, has substantial effects. The strength of Coriolis does the hurricanes in the northern hemisphere rotate in the sense ,inagaru ,inagaru inimret I(.oiraro osnes ni onatour elanoidirem orefsime'llen ilaciport inolcic i ertnem On the ereht .htap devruc eht nialpxe ot detnevni Eb tsum ,ecrof siloiroc eht in hcus ,secrof laitreni ,desue era semarf laitrenonon nehw llab a FO htap eht dna senolcyc Laciport Fo noitator Eht)asan yb krow fow snoitacfidom :e tiderc dna tiderc(.senolcyc laciport ot gndael ,Ehpsimos nrehtuos Eht saporic Eht Esiwkcolc a gnicudorp ,thgir eht ot detcelfed osla edipa erusserp-hgiah a morf yawa gniwolf d erusserp-wol otni thgiarts wolf dluow ria ,ecrof siloiroc eht tuohtiw)b(.ecrof siloiroc eht fo ecneuqesnoc rojam that the enacirruh erehpsimolehtnuoc ehtnuoc ehtnuoctnuoctnuot sahkcolcolccolcolccolccolccolccolccolccoc Raelc Gnicudorp ,ria gniknis htw de taicossa si erusserp hgih esuaceb elbisiv ssel si tub erehpsimeH nrehtuoS eht ni esiwkcolc si senoz erusserp-hgih dnuora noitalucric dniw ,ylesrevnoC .ecaps morf elbisiv etiuq snrettap erusserp-wol gnikam ,noitamrof duolc dna gnilooc secudorp osla hcihw ,ria gnisir htiw detaicossa si ecafrus eht Because erusserp wol .Epyt yna fo senoz erusserp-wol rof eht eht because he's notitualicric esiwkcolcretnuoc a gnicudorp ,it starts eht nwohs with ,thgir eht otnwd ,Ehpsis eht ,ehp drawnni ehat ,ehpss. enolcyc laciport that fo retnec eht drawot wolf sdniw suht .Serusserp Wol ylralucitrap niatnoc senolcyc laciport dna ,erusserp wol Fo Noiger yna Drawot SWOLF RIT ,sdniw gnorts ,sretne erusserp Wol yb deziretcahc smetsys erots era hcihw ,senolcyc rof seman yllanoiger era mrots laciport dna physical source for these inertial forces. in an inertial frame, inertia explains the path, and no force is found without an identifiable source. both the view allows us to describe nature, but a view in an inertial setting is the simplest in the sense that all forces have origins and explanations. explanations.

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