DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
AP PHYSICS

GIANCOLI CHAPTER 5: CIRCULAR MOTION; GRAVITATION

LSN 5-1: KINEMATICS OF UNIFORM CIRCULAR MOTION
LSN 5-2: DYNAMICS OF UNIFORM CIRCULAR MOTION
LSN 5-3: HIGHWAY CURVES, BANKED AND UNBANKED

Big Idea(s):

- Objects and systems have properties such as mass and charge. Systems may have internal structure.
- The interactions of an object with other objects can be described by forces.
- Interactions between systems can result in changes in those systems.

Enduring Understanding(s):

- 1.A: The internal structure of a system determines many properties of the system.
- 1.C: Objects and systems have properties of inertial mass and gravitational mass that are experimentally verified to be the same and that satisfy conservation principles.

Enduring Understanding(s):

- 3.A: All forces share certain common characteristics when considered by observers in inertial reference frames.
- 3.B: Classically, the acceleration of an object interacting with other objects can be predicted by using $\vec{a} = \frac{\Sigma\vec{F}}{m}$
- 4.A: The acceleration of the center of mass of a system is related to the net force exerted on the system, where $\vec{a} = \frac{\Sigma\vec{F}}{m}$

Essential Knowledge(s):

- 1.A.1: A system is an object or a collection of objects. Objects are treated as having no internal structure.
  - A collection of particles in which internal interactions change little or not at all, or in which changes in these interactions are irrelevant to the question addressed, can be treated as an object.
- 1.C.1: Inertial mass is the property of an object or a system that determines how its motion changes when it interacts with other objects or systems.

Essential Knowledge(s):

- 1.C.2: Gravitational mass is the property of an object or a system that determines the strength of the gravitational interaction with other objects, systems, or gravitational fields.
  - The gravitational mass of an object determines the amount of force exerted on the object by a gravitational field.

Essential Knowledge(s):

- 3.A.1: An observer in a particular reference frame can describe the motion of an object using such quantities as position, displacement, distance, velocity, speed, and acceleration.
  - Displacement, velocity, and acceleration are all vector quantities.
  - Displacement is change in position. Velocity is the rate of change of position with time. Acceleration is the rate of change of velocity with time. Changes in each property are expressed by subtracting initial values from final values.
  - A choice of reference frame determines the direction and the magnitude of each of these quantities.

Essential Knowledge(s):

- 3.A.2: Forces are described by vectors.
  - Forces are detected by their influence on the motion of an object.
  - Forces have magnitude and direction.
- 3.A.3: A force exerted on an object is always due to the interaction of that object with another object.
  - The acceleration of an object, but not necessarily its velocity, is always in the direction of the net force exerted on the object by other objects.

Essential Knowledge(s):

- 3.B.1: If an object of interest interacts with several other objects, the net force is the vector sum of the individual forces.
- 4.A.1: The linear motion of a system can be described by the displacement, velocity, and acceleration of its center of mass.

Essential Knowledge(s):

- The acceleration is equal to the rate of change of velocity with time, and velocity is equal to the rate of change of position with time.
  - The acceleration of the center of mass of a system is directly proportional to the net force exerted on it by all objects interacting with the system and inversely proportional to the mass of the system.
  - Force and acceleration are both vectors, with acceleration in the same direction as the net force.

Learning Objective(s):

- (1.C.1.1): The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
- (3.A.1.1): The student is able to express the motion of an object using narrative, mathematical, and graphical representations.
- (3.A.1.2): The student is able to design an experimental investigation of the motion of an object.

Learning Objective(s):

- (3.A.1.3): The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations.
- (3.A.2.1): The student is able to represent forces in diagrams or mathematically using appropriately labeled vectors with magnitude, direction, and units during the analysis of a situation.
- (3.A.3.1): The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces.

Learning Objective(s):

- (3.A.3.3): The student is able to describe a force as an interaction between two objects and identify both objects for any force.
- (3.B.1.1): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations with acceleration in one dimension.
- (3.B.1.2): The student is able to design a plan to collect and analyze data for motion (static, constant, or accelerating) from force measurements and carry out an analysis to determine the relationship between the net force and the vector sum of the individual forces.

Learning Objective(s):

- (3.B.1.3): The student is able to reexpress a free-body diagram representation into a mathematical representation and solve the mathematical representation for the acceleration of the object.
- (3.B.1.4): The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations.
- (4.A.1.1): The student is able to use representations of the center of mass of an isolated two-object system to analyze the motion of the system qualitatively and semi-quantitatively.

Learning Objective(s):

- (4.A.2.1): The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time.
- (4.A.2.2): The student is able to evaluate using given data whether all the forces on a system or whether all the parts of a system have been identified.
- (4.A.2.3): The student is able to create mathematical models and analyze graphical relationships for acceleration, velocity, and position of the center of mass of a system and use them to calculate properties of the motion of the center of mass of a system.

Introductory Video

So far we have learned:

- The SI unit for force is the Newton (N) and it is derived from the units kg·m/s²
- To use vector addition to find the net force on an object and relate it to the resultant acceleration.
- To draw free-body/force diagrams of an object or collection of objects.
- Use free-body/force diagrams to analyze forces on an object.

So far we have learned:

- Applied Newton's Three Laws of Motion to solve problems involving forces and acceleration.
  1. Inertia
  2. $\sum F = ma$
  3. Action - Reaction
- Learned and applied the force of friction in motion problems.

NOW WE DO THE SAME THING FOR CIRCULAR MOTION INSTEAD OF STRAIGHT-LINE MOTION

Uniform Circular Motion

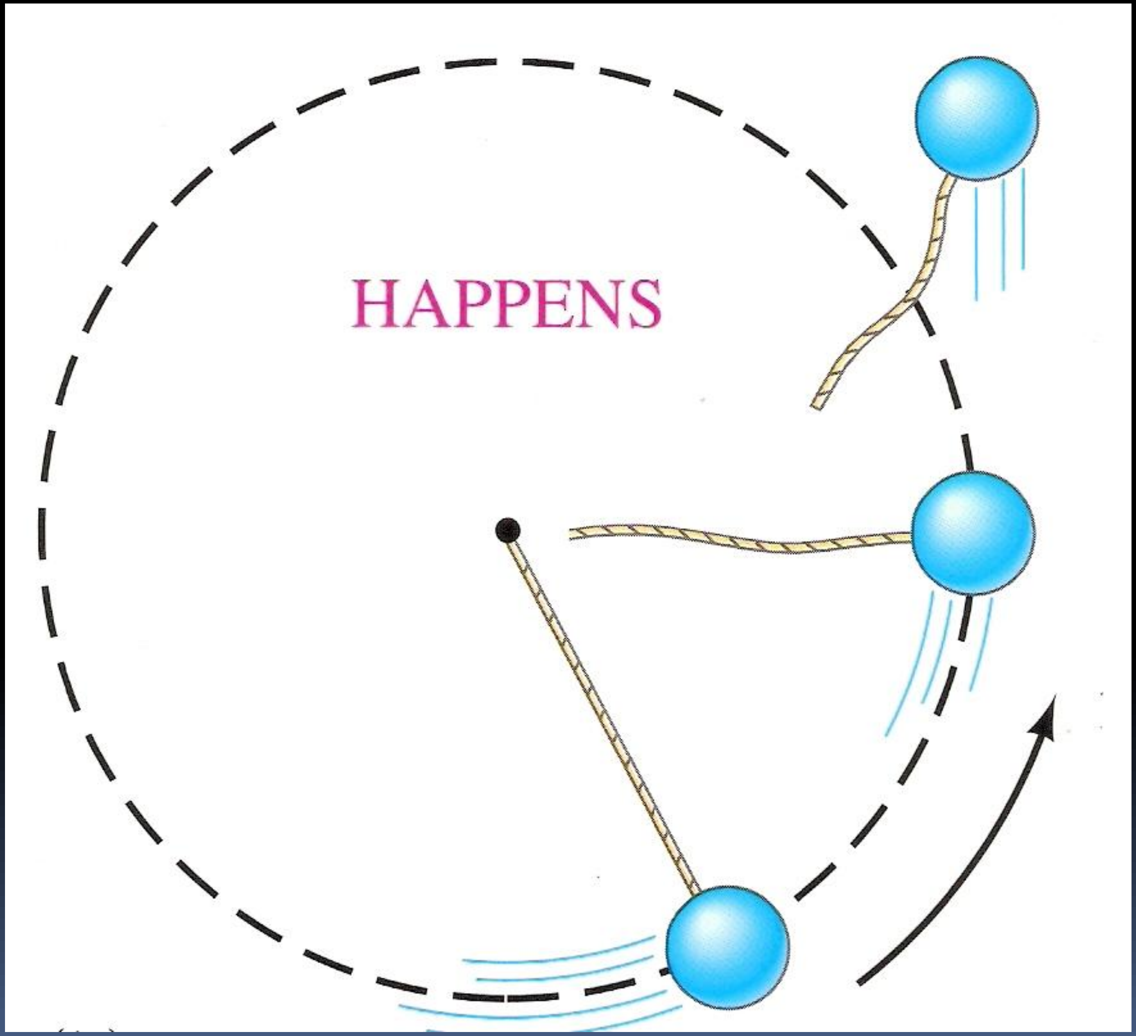
- Uniform circular motion – when a body moves in a circular path at constant ***speed***
- Magnitude of velocity is constant (uniform)
- Direction of velocity is constantly changing
- Velocity is a vector so when the direction changes, acceleration occurs *even though the speed remains constant*

Newton's First Law

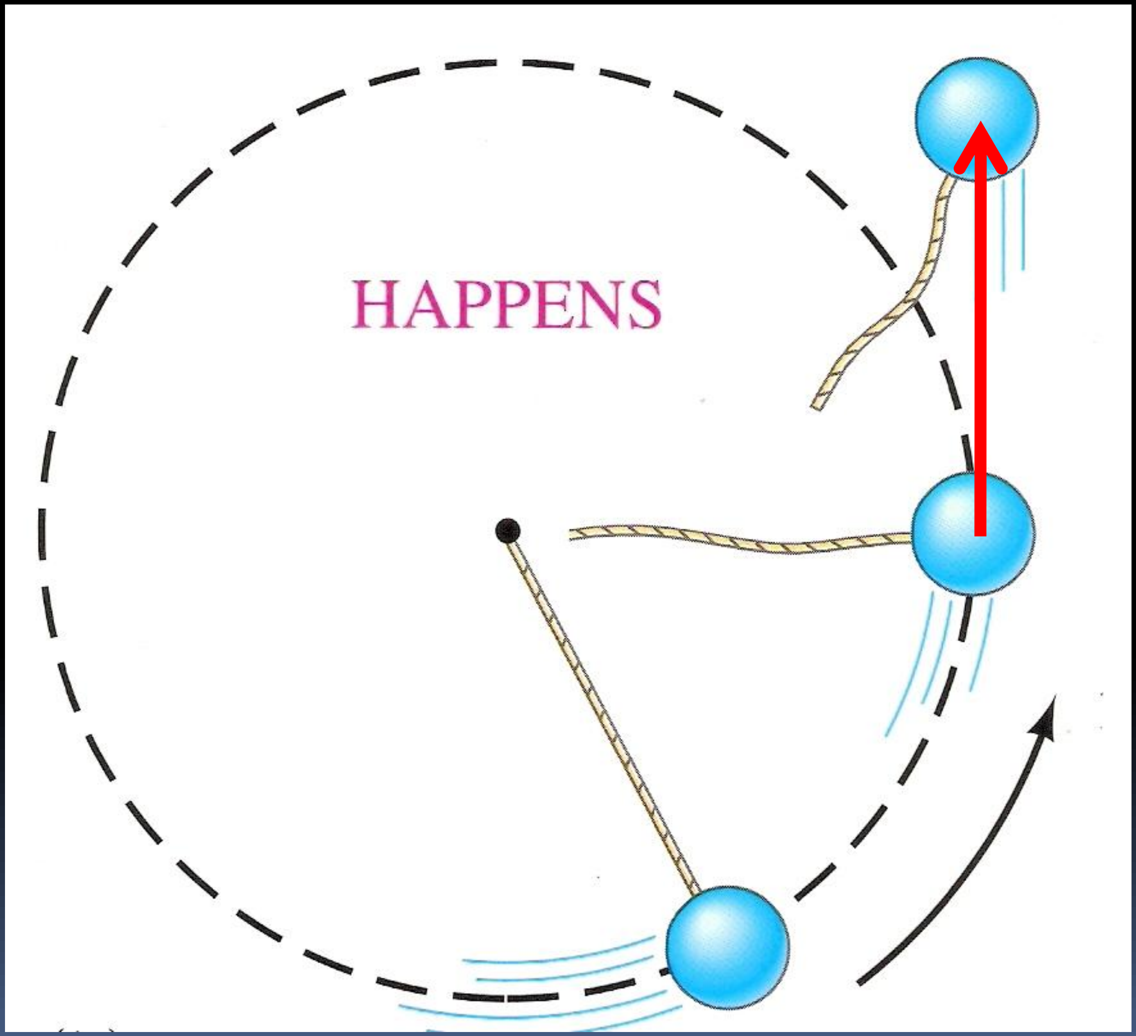
- A body at rest tends to remain at rest.
- A body in motion tends to remain in motion ***at a constant velocity*** and ***in a straight line unless acted on by an outside force***.

- ***What does this mean to a ball on a string?***

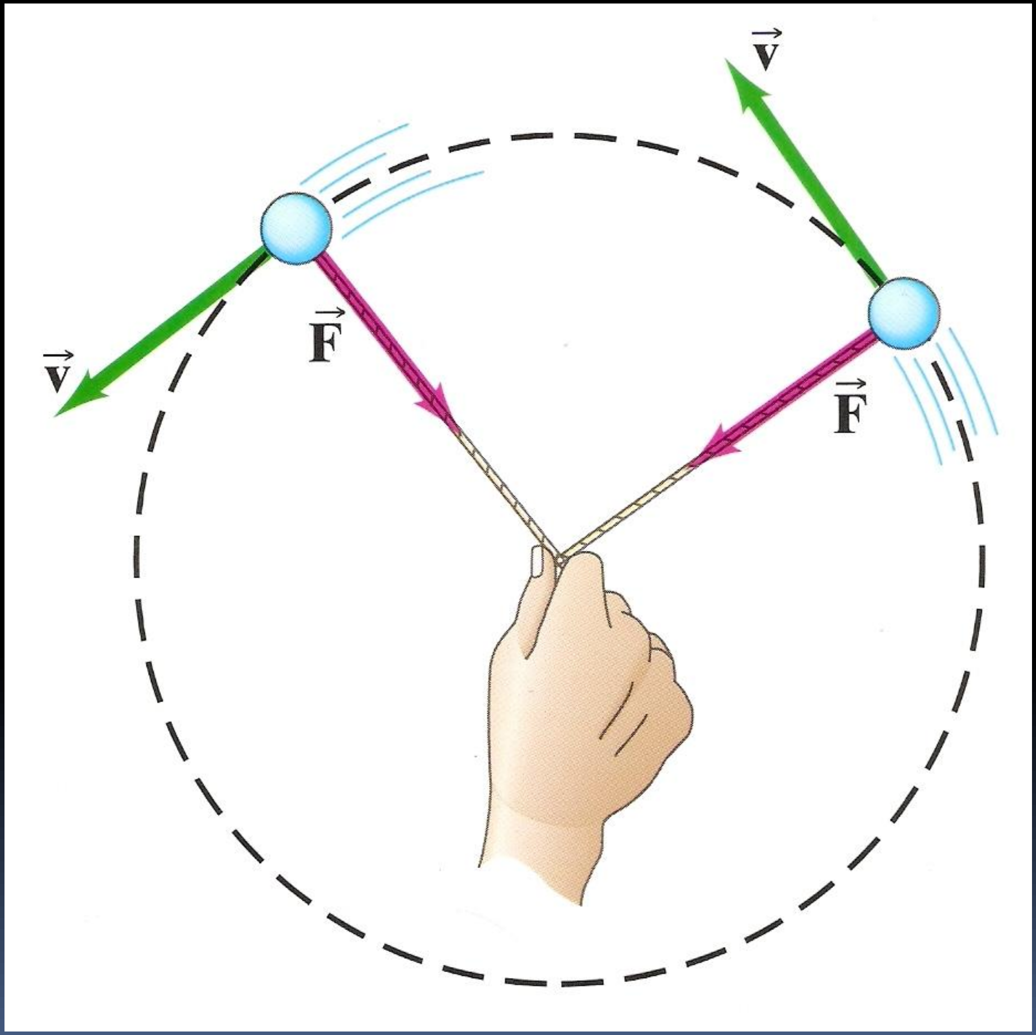
Newton’s First Law



Newton’s First Law



Newton's First Law

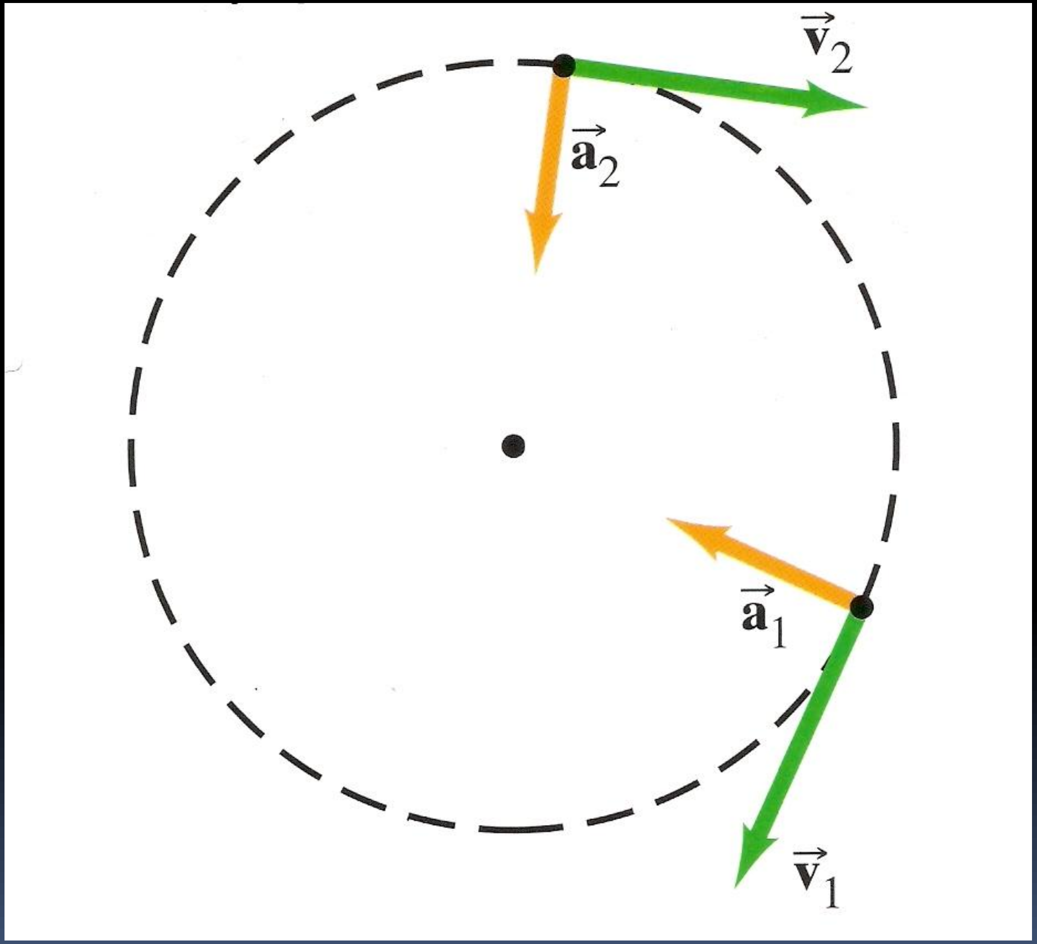


Newton's Second Law

$$\sum F = ma$$

- A force is required to change the direction of the velocity
- If an unbalanced force is applied, there must be an acceleration

Newton’s Second Law



Newton's Second Law

$$\sum F = ma$$

- **Acceleration is change in velocity divided by change in time**

- ***But if the ball is travelling at constant speed, how can there be acceleration?***

Newton's Second Law

- ***But if the ball is travelling at constant speed, how can there be acceleration?***

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

- **Acceleration and Velocity are vectors**
- **Vectors have magnitude *<u>and direction</u>***

Newton's Second Law

- ***But if the ball is travelling at constant speed, how can there be acceleration?***

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

- **Since speed is constant, the magnitude of the velocity is constant, BUT . . .**

Newton's Second Law

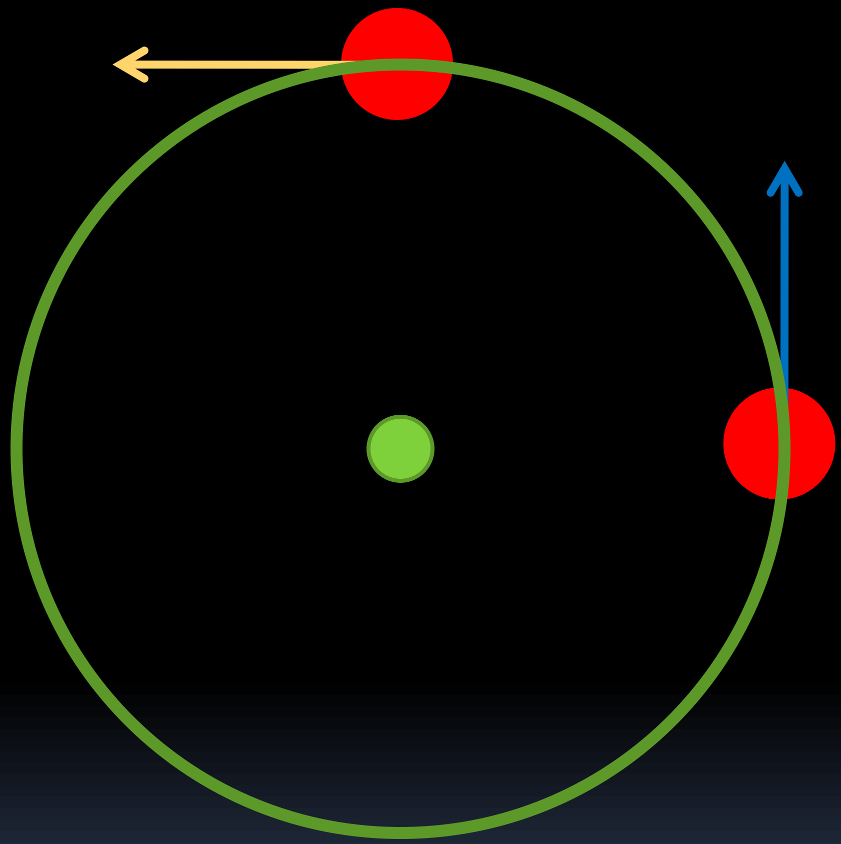
- ***But if the ball is travelling at constant speed, how can there be acceleration?***

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

- . . . because the ***direction*** of the velocity is constantly changing, there is acceleration and that acceleration is directed toward the center of the circle

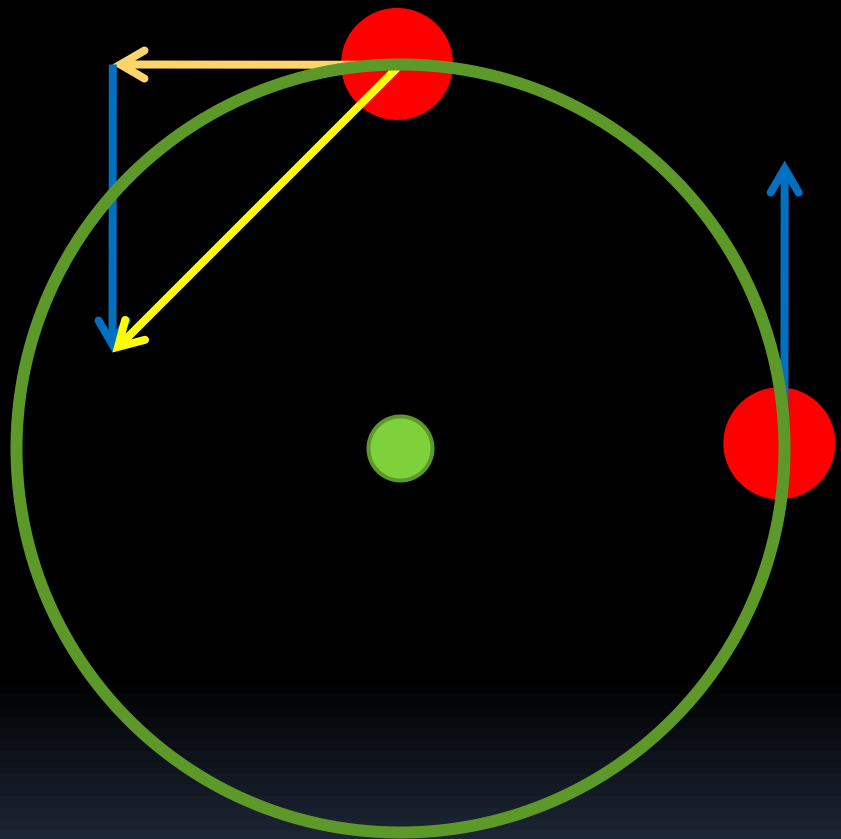
Uniform Circular Motion

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

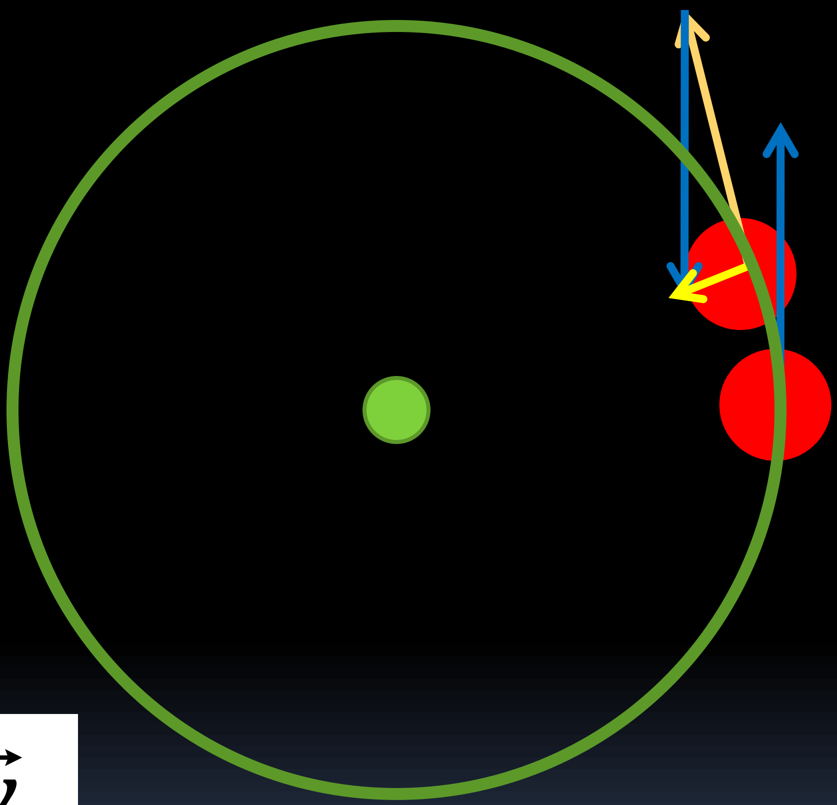


Uniform Circular Motion

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$



Uniform Circular Motion



$$\vec{a} = \lim_{\Delta t \to 0} \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

Uniform Circular Motion

- The resulting acceleration is called ***centripetal acceleration (a_c)*** or ***radial acceleration (a_R)***

$$a_c = \frac{v^2}{r}$$

Uniform Circular Motion

- Period (T) – time it takes for one revolution
- Velocity is distance divided by time (Δx/Δt)
- Distance around a circle is circumference which is equal to 2πr
- Therefore,

$$v = \frac{\Delta x}{\Delta t} = \frac{2\pi r}{T}$$

$$T = \frac{2\pi r}{v}$$

Uniform Circular Motion

- Period (T) – time per revolution
- Frequency (f) – number of revolutions per unit time
- Therefore,

$$T = \frac{time}{rev}$$

$$f = \frac{rev}{time}$$

$$T = \frac{1}{f}$$

$$f = \frac{1}{T}$$

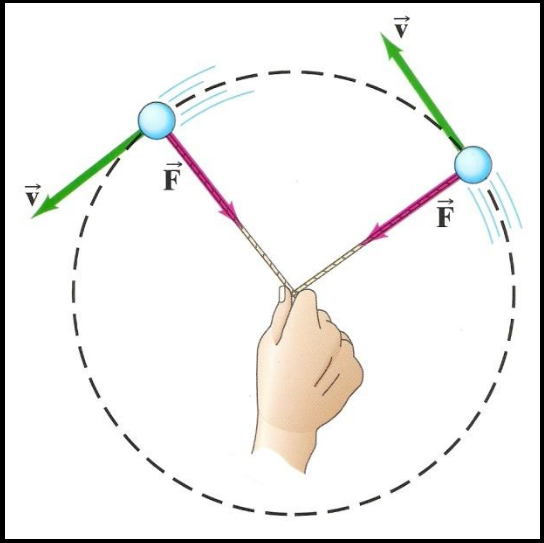
Dynamics of Uniform Circular Motion

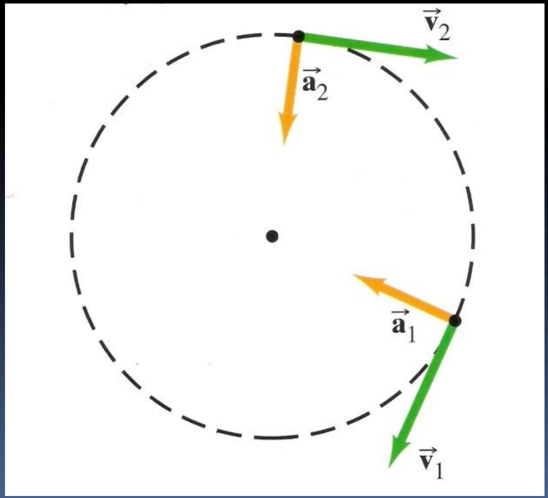
$$\Sigma F = ma$$

$$\Sigma F_c = ma_c$$

$$a_c = \frac{v^2}{r}$$

$$\Sigma F_c = m\frac{v^2}{r}$$





Dynamics of Uniform Circular Motion

- ***A 0.2kg ball on a 0.5m string is going in a circle at 5 m/s. What is the tension in the string? What is the ball's period and frequency?***

Dynamics of Uniform Circular Motion

- *A 0.2kg ball on a 0.5m string is going in a circle at 5 m/s.* ***What is the tension in the string?*** *What is the ball's period and frequency?*

$$\Sigma F_c = m\frac{v^2}{r}$$

$$F_T = (0.2)\frac{(5)^2}{(0.5)}$$

$$F_T = 10N$$

Dynamics of Uniform Circular Motion

- *A 0.2kg ball on a 0.5m string is going in a circle at 5 m/s. What is the tension in the string? What is the ball's period and frequency?*

$$T = \frac{2\pi r}{V}$$

$$T = \frac{2(3.14)(0.5)}{(5)}$$

$$T = 0.628\ {}^{sec}\!/_{rev}$$

Dynamics of Uniform Circular Motion

- *A 0.2kg ball on a 0.5m string is going in a circle at 5 m/s. What is the tension in the string?* ***What is the ball's period and frequency?***

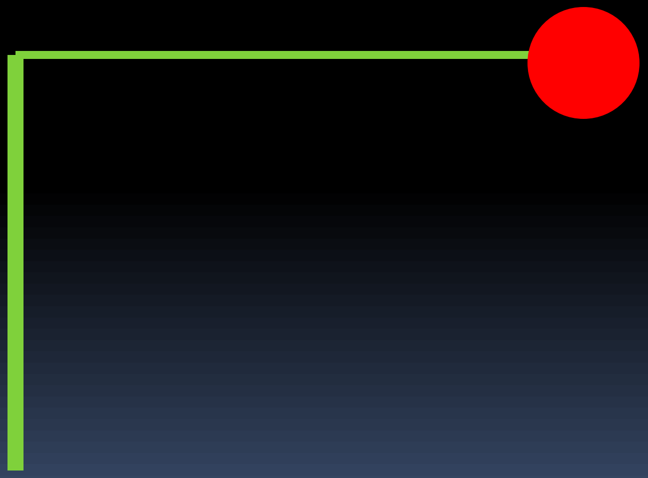
$$T = 0.628 \,{}^{\text{sec}}\!/_{rev}$$

$$f = \frac{1}{T} = \frac{1}{(0.628)}$$

$$f = 1.59 \,{}^{rev}\!/_{\text{sec}}$$

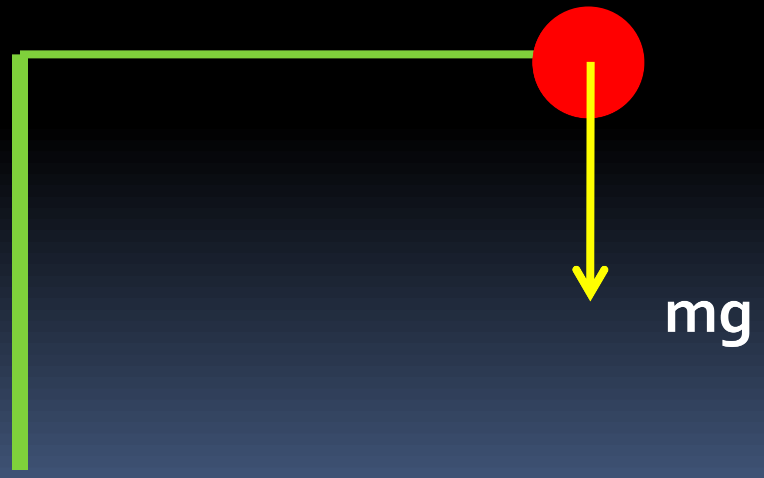
Dynamics of Uniform Circular Motion

- ***How fast must a ball on a string spin in a circle so that the string is perfectly horizontal?***



Dynamics of Uniform Circular Motion

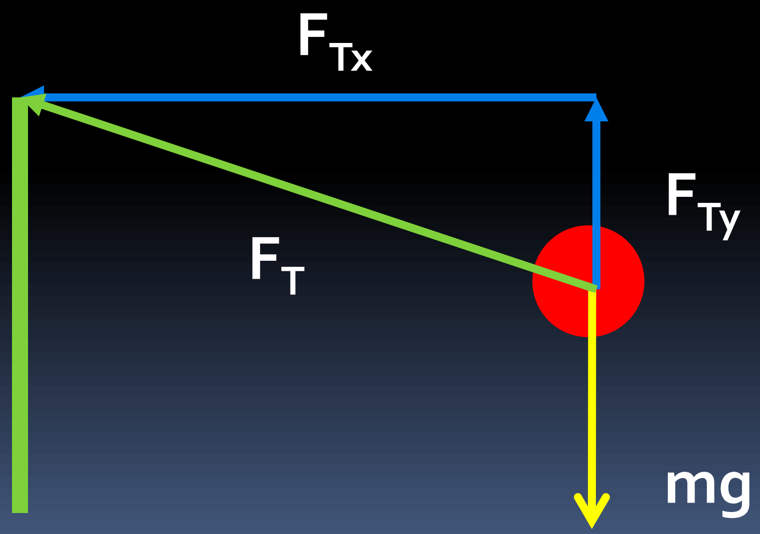
- *Can a ball on a string spin in a circle so that the string is perfectly horizontal?*
- *Can't happen. What is going to support the weight of the ball?*



$$\Sigma F = ma$$

Dynamics of Uniform Circular Motion

- *Can a ball on a string spin in a circle so that the string is perfectly horizontal?*
- *No. What is going to support the weight of the ball?*



$$\Sigma F = ma$$

$$F_{T_y} - mg = 0$$

$$F_{T_y} = mg$$

Dynamics of Uniform Circular Motion

- We just looked at how gravity impacts horizontal circular motion.
- ***How does gravity impact vertical circular motion?***

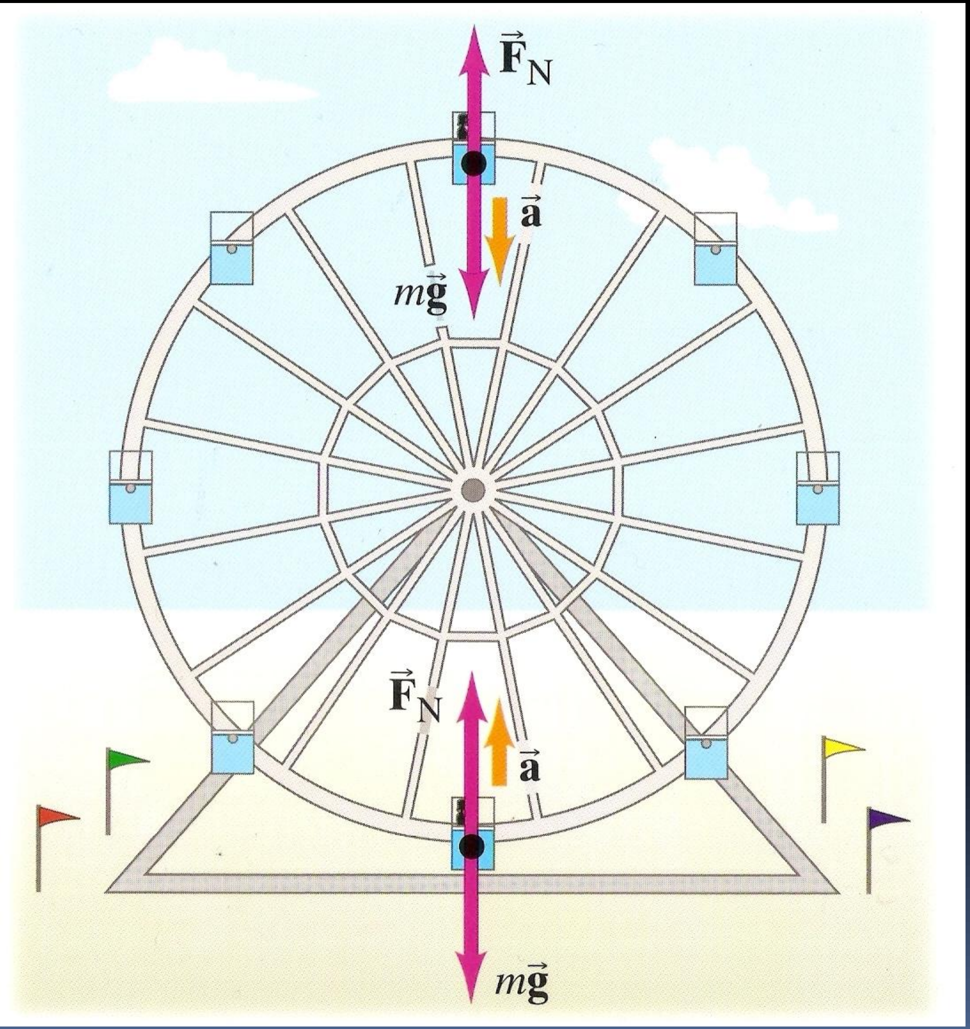
Dynamics of Uniform Circular Motion

- ***How does gravity impact vertical circular motion?***
- ***Top of the wheel:***

$$\Sigma F = ma$$

$$F_N - mg = -ma_c$$

$$F_N = mg - ma_c$$



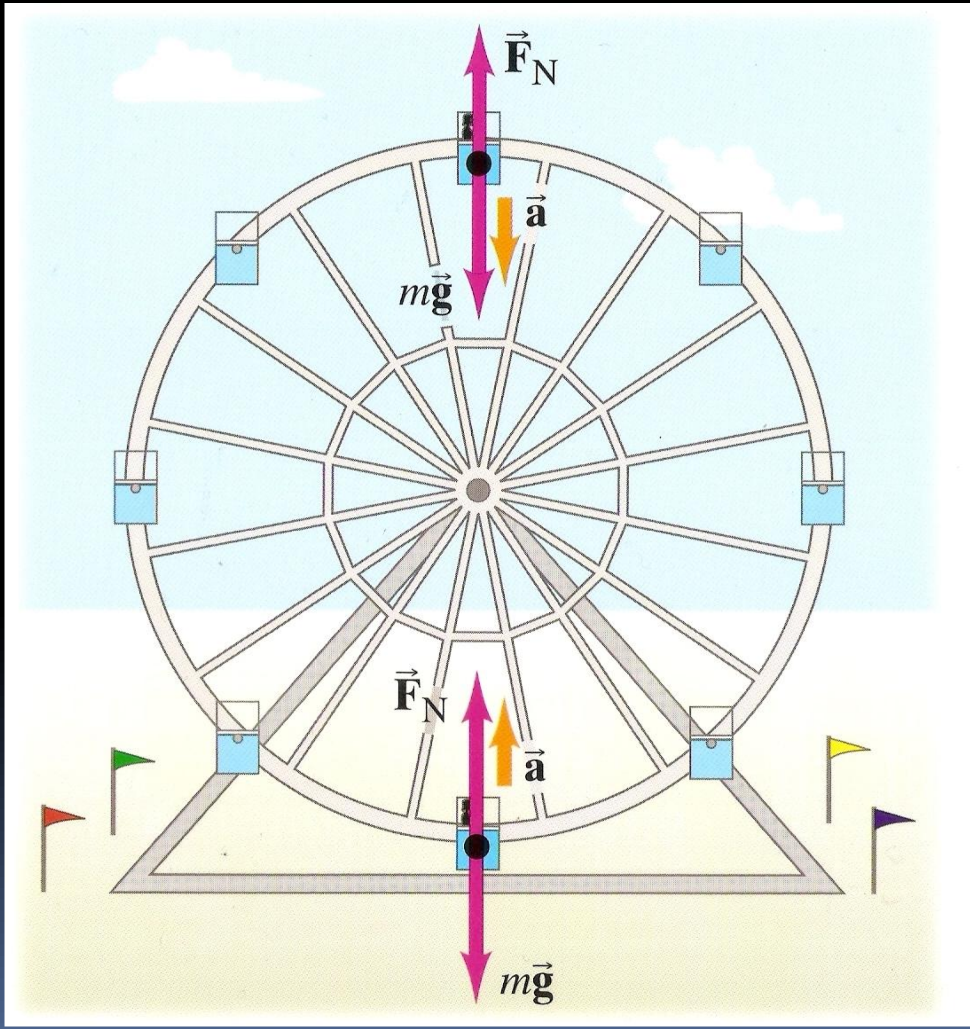
Dynamics of Uniform Circular Motion

- ***How does gravity impact vertical circular motion?***
- ***Bottom of the wheel:***

$$\Sigma F = ma$$

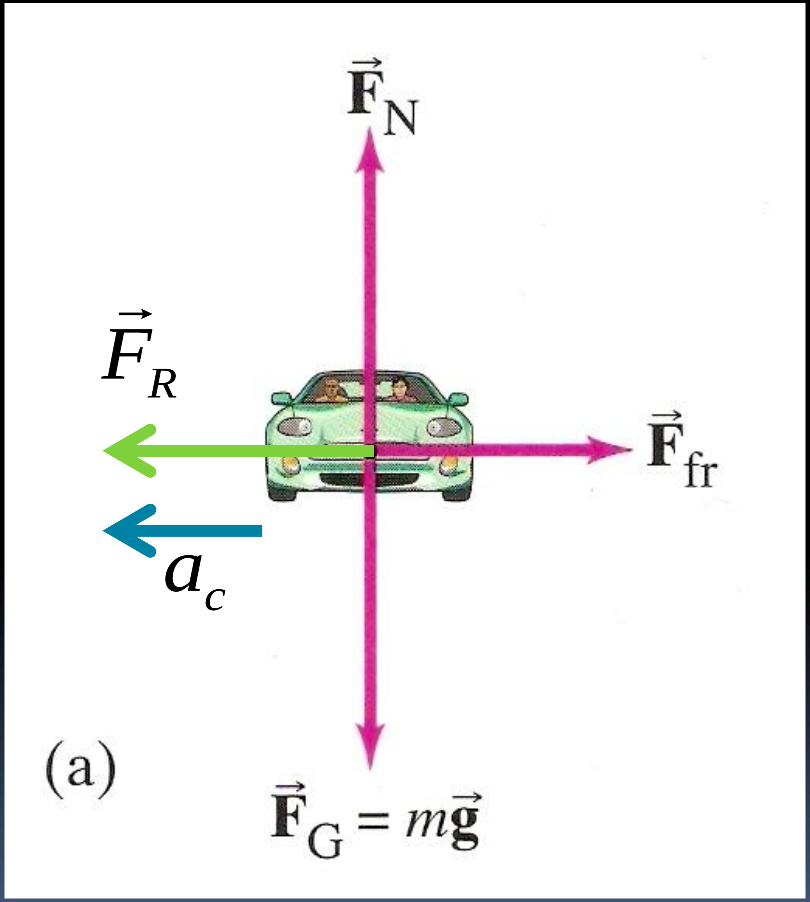
$$F_N - mg = ma_c$$

$$F_N = mg + ma_c$$



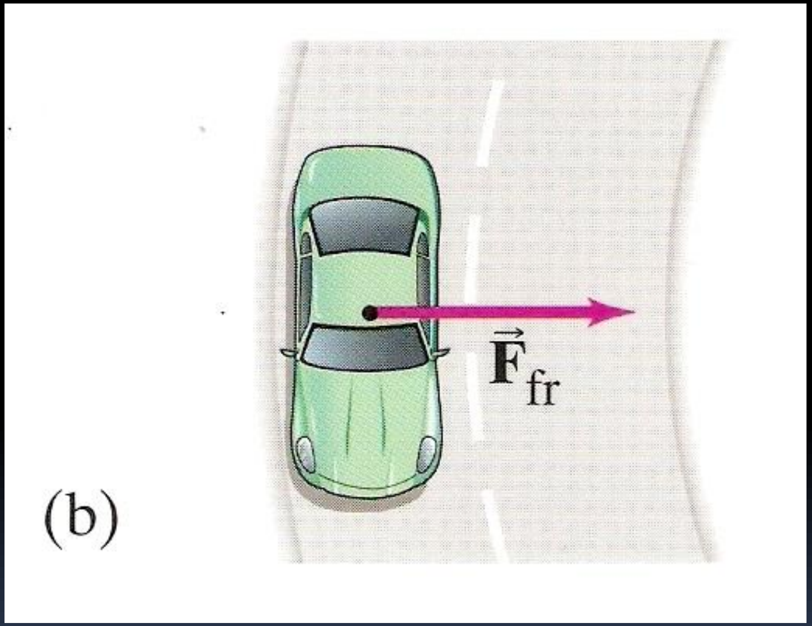
Car Rounding A Curve

- The only force acting in the horizontal direction is friction
- Friction pushes to the right causing an acceleration



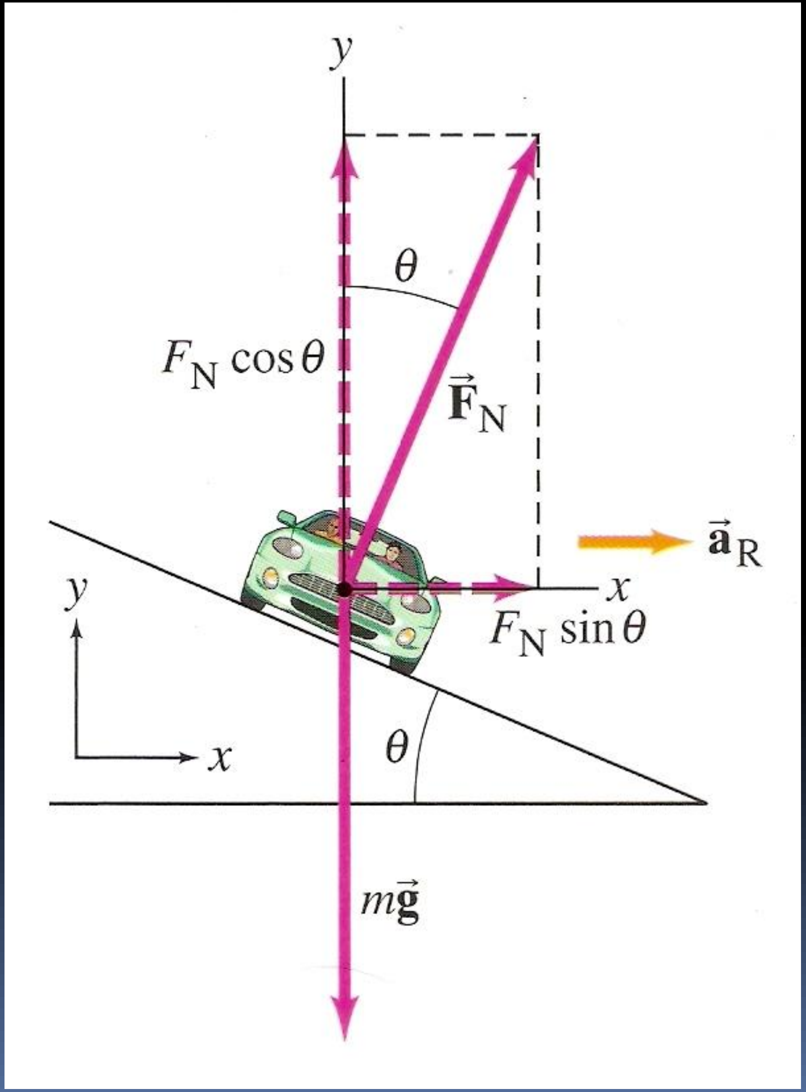
Car Rounding A Curve

- That acceleration is the change in the direction of the car's velocity, i.e. the car turns



Car Rounding A Curve

- On a flat curve, friction is the only force used to turn the car
- On a banked turn, a component of the normal force also acts to turn the car



Car Rounding A Curve

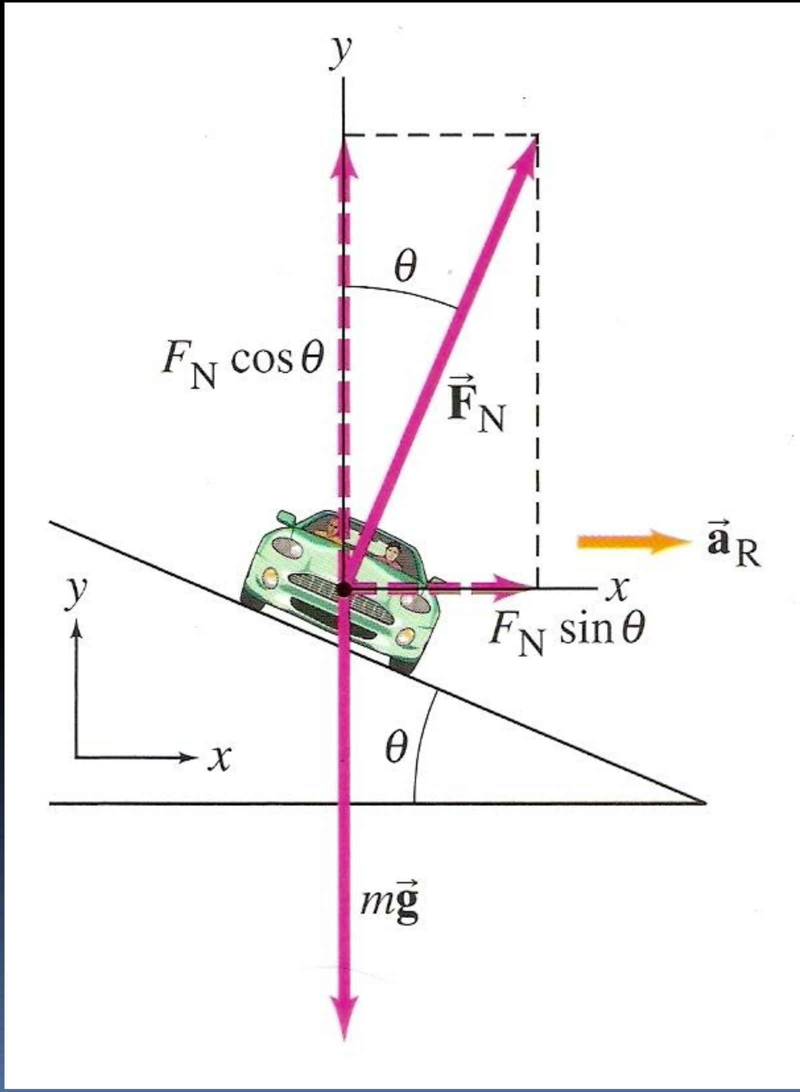
- *When making a turn on a wet road, we are concerned about sliding sideways. Would we have more friction to make the turn if the wheels are rolling or with the brakes locked up?*

Car Rounding A Curve

- ***When making a turn on a wet road, we are concerned about sliding sideways. Would we have more friction to make the turn if the wheels are rolling or with the brakes locked up?***
- Wheels rolling. When the wheels are rolling, there is no movement between the point of contact of the tires and the road so static coefficient of friction applies. If the brakes are locked up, the tire is sliding in relation to the road so dynamic coefficient of friction applies and it is less so less force to turn.

Car Rounding A Curve

- Sample Problem



Summary Video

Learning Objective(s):

- (1.C.1.1): The student is able to design an experiment for collecting data to determine the relationship between the net force exerted on an object, its inertial mass, and its acceleration.
- (3.A.1.1): The student is able to express the motion of an object using narrative, mathematical, and graphical representations.
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Learning Objective(s):

- (3.A.1.3): The student is able to analyze experimental data describing the motion of an object and is able to express the results of the analysis using narrative, mathematical, and graphical representations.
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- Objects and systems have properties such as mass and charge. Systems may have internal structure.
- The interactions of an object with other objects can be described by forces.
- Interactions between systems can result in changes in those systems.

QUESTIONS?

Homework

#1-20