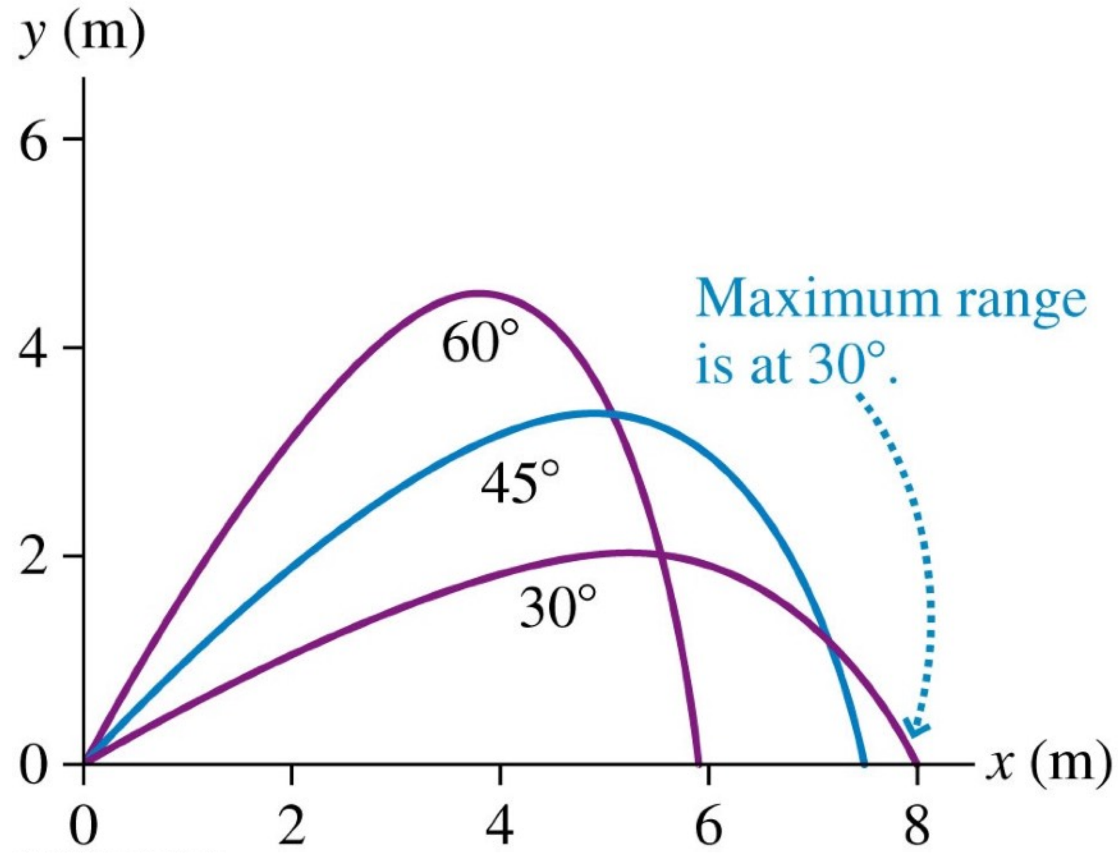
# Projectile Motion with drag

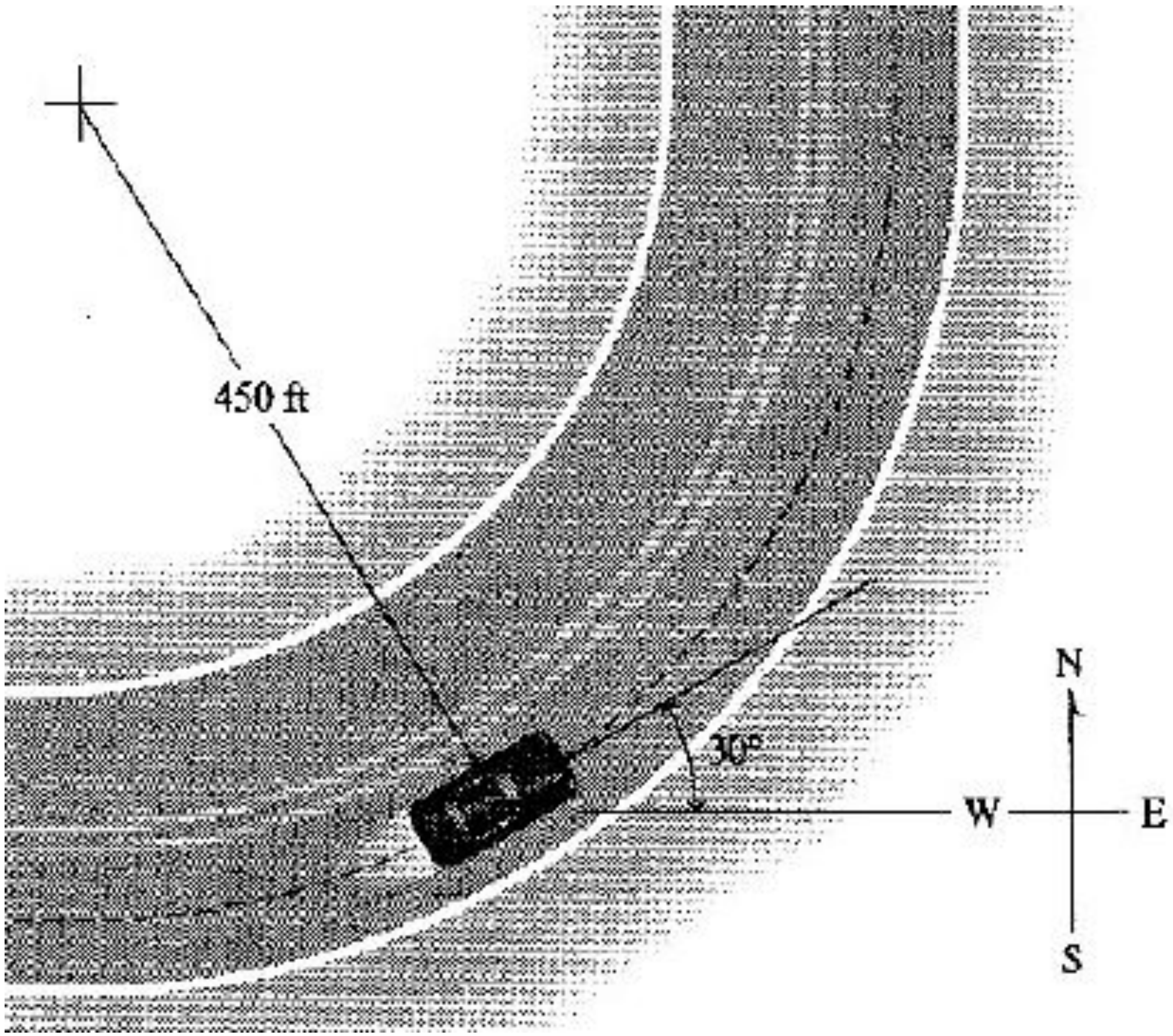



$$a_x = -\frac{\rho C A}{2m} v_x \sqrt{{v_x}^2 + {v_y}^2}$$

$$a_y = -g - \frac{\rho C A}{2m} v_y \sqrt{{v_x}^2 + {v_y}^2}$$

## Question #16

A car travels around a curve at constant speed without sliding. What force is responsible for the acceleration of the car?

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b) Normal Force
c) Static Friction
d) Kinetic Friction
e) Thrust

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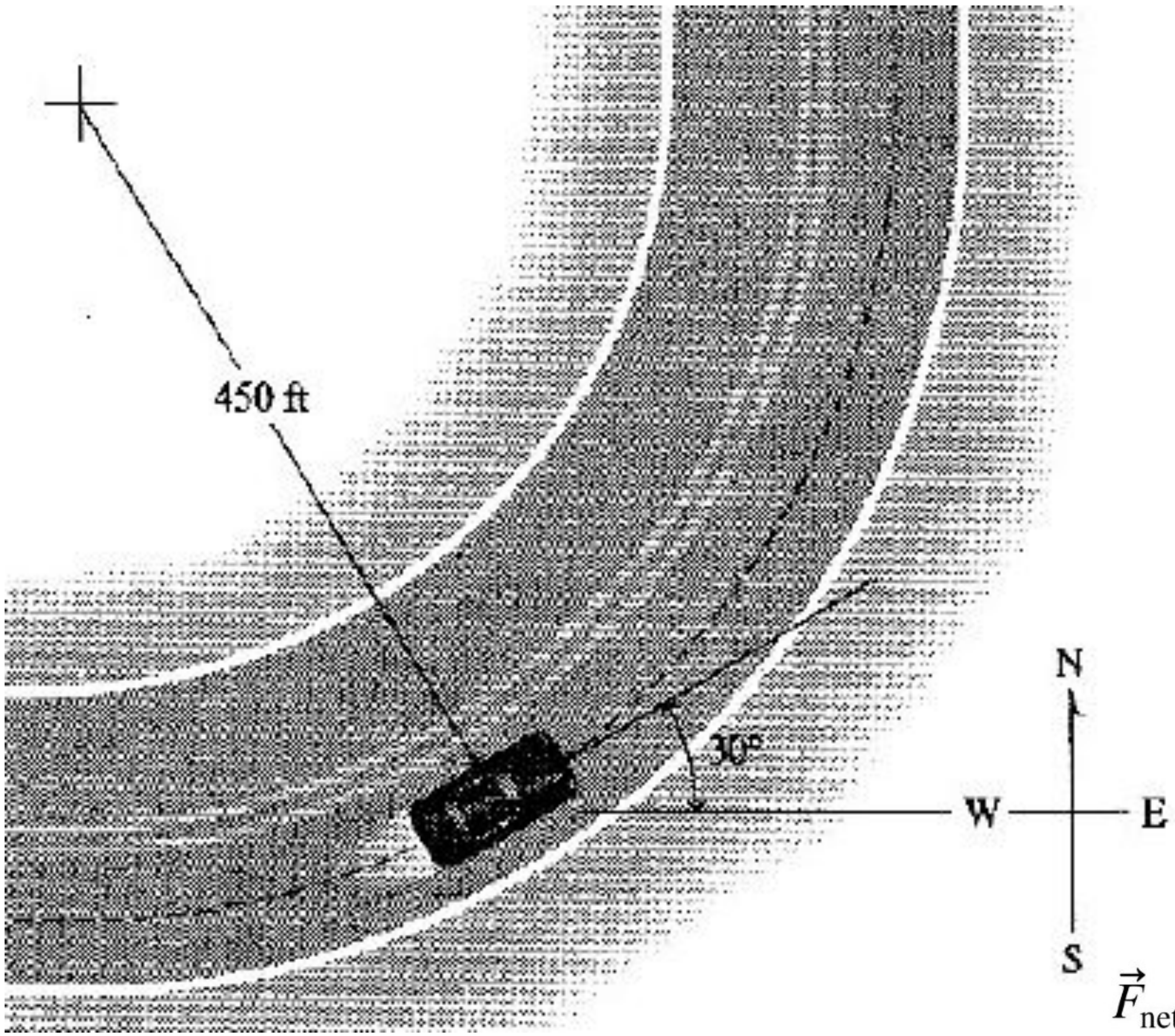


a) Tension
b) Normal Force
c) Static Friction
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e) Thrust

$$\vec{F}_{\text{net}} = m\vec{a} = \left(\frac{mv^2}{r}, \text{toward center of circle}\right)$$

## Question #17

A satellite orbits the earth. What force is responsible for the acceleration of the satellite?

a) Gravity
b) Static Friction
c) Tension
d) Kinetic Friction
e) Thrust

## Question #18

A little girl holds tight to the bars on a merry-go-round as it rotates steadily. What force is responsible for the acceleration of the girl?

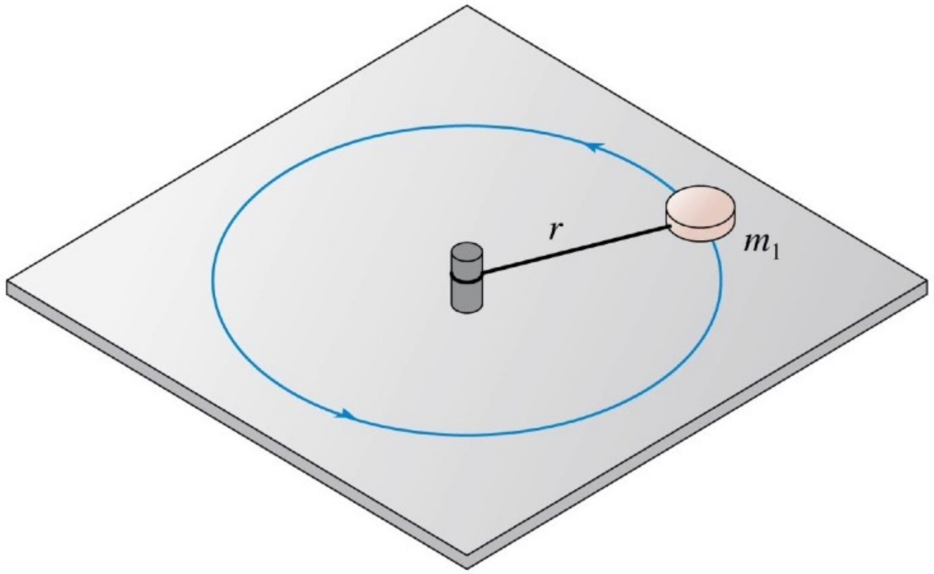
a) Static Friction between shoes and floor
b) Gravity
c) a) and d)
d) Tension in arms
e) Thrust

# Quiz

## Question #19

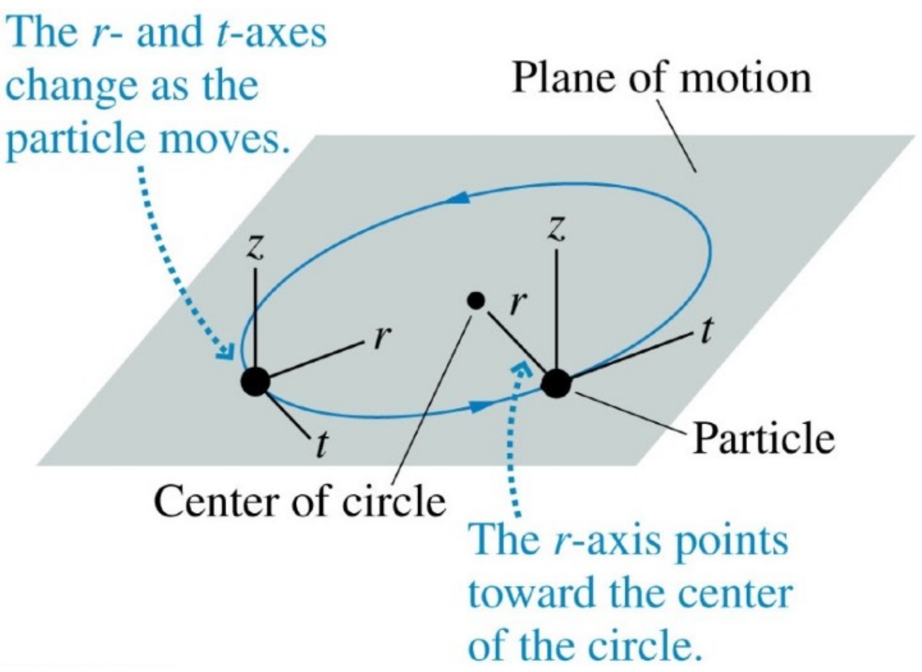
An ice hockey puck is tied by a string to a stake in the ice. The puck is then swung in a circle. What force is producing the centripetal acceleration of the puck?

A. Gravity
B. Tension in the string
C. Friction
D. Normal force
E. Air resistance
F. A new force: the centrifugal force.



# Uniform circular motion

rtz-coordinate system




- The *r*-axis (radial) points *from* the particle *toward* the center of the circle.
- The *t*-axis (tangential) is tangent to the circle, pointing in the ccw direction.
- The *z*-axis is perpendicular to the plane of motion.

# Dynamics of Uniform Circular Motion

An object in uniform circular motion is not traveling at constant velocity.  It is accelerating!

There must be a force that causes this acceleration

$$\vec{F}_{\text{net}} = m\vec{a} = \left(\frac{mv^2}{r}, \text{toward center of circle}\right)$$


Highway and racetrack curves are banked to allow the normal force of the road to provide the centripetal acceleration of the turn.

# Example Problem I

What is the maximum speed with which a 1500 kg car can make a left turn around a curve of radius 50 m on a level (unbanked) road without sliding?

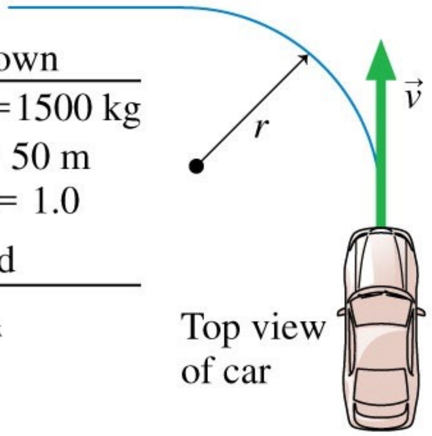
- Draw a free-body diagram for the car (rear view) as it travels around the corner.
- Identify your r-t-z coordinate system.
- Assemble Newton's second law ($F_{net} = ma$) in the "r" and "z" dimensions.

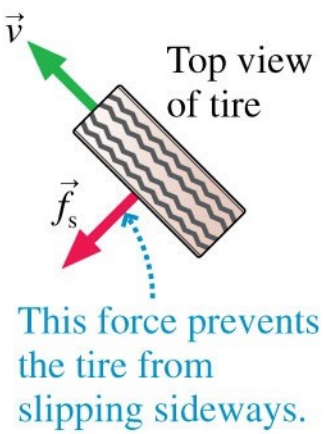
**Known**

$m = 1500$ kg
$r = 50$ m
$\mu_s = 1.0$

**Find**

$v_{max}$



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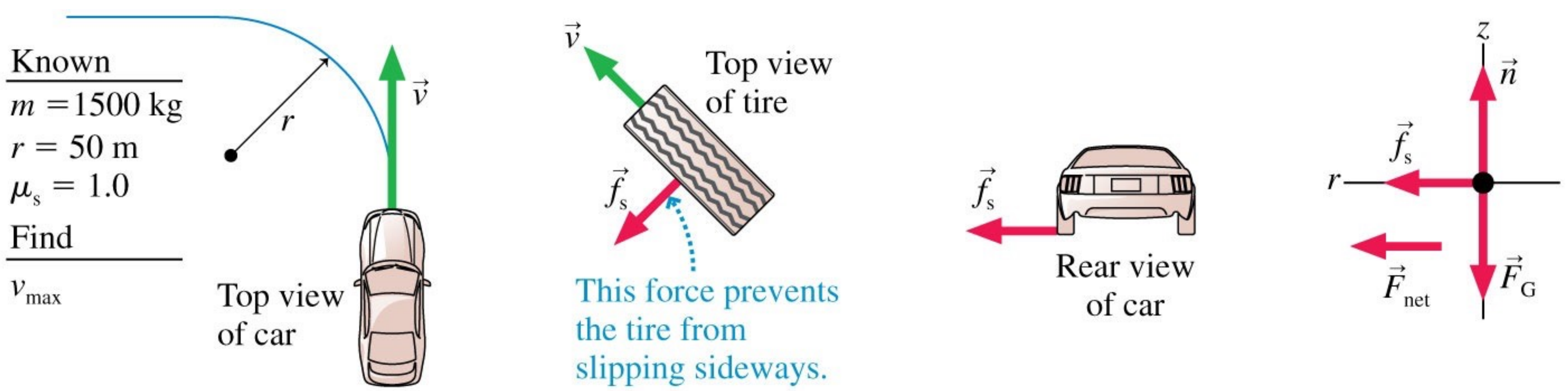
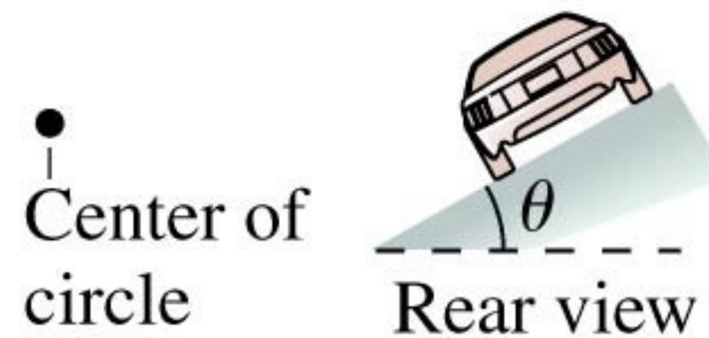
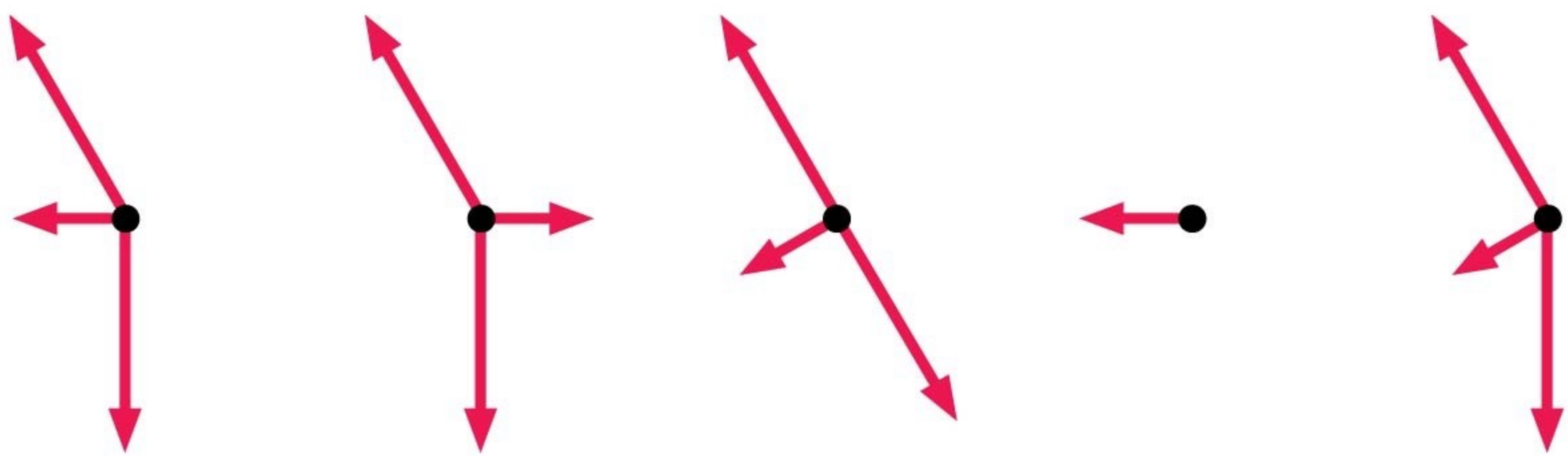


# Quiz

## Question #20

A car turns a corner on a banked road. Which of the other diagrams <u>could</u> be the car's free-body diagram?

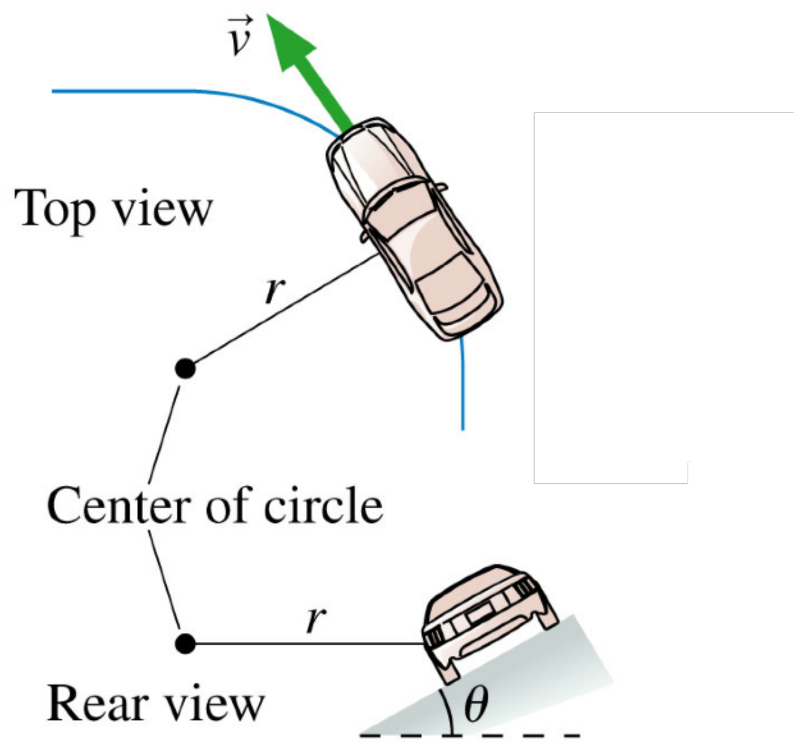


C B D A E

If this were an icy road (no friction), what banking angle must the road have if you are going to be able to make it through the corner?

a) Draw the free-body diagram
b) Identify your coordinate system
c) Put together Newton's second law



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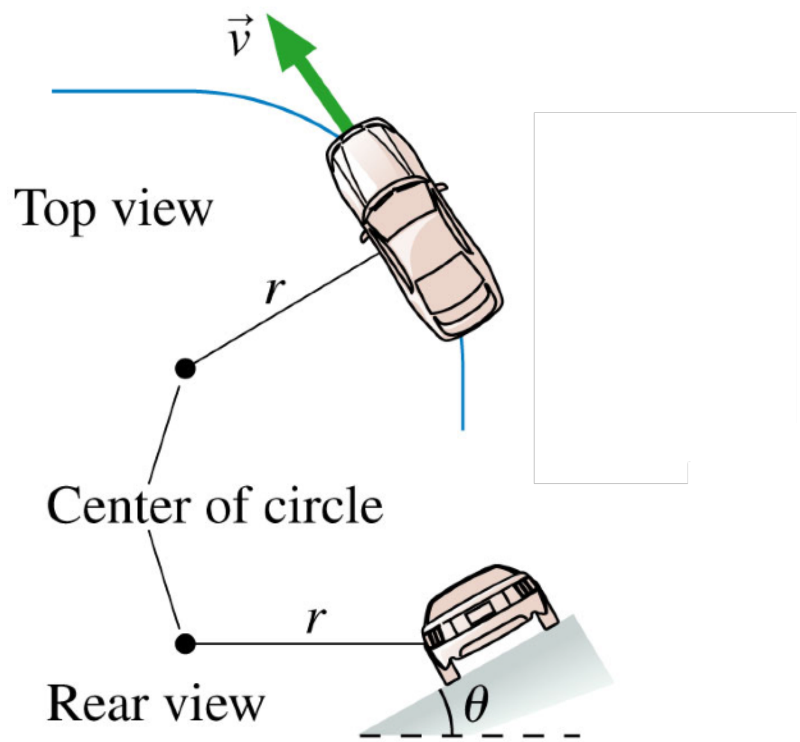


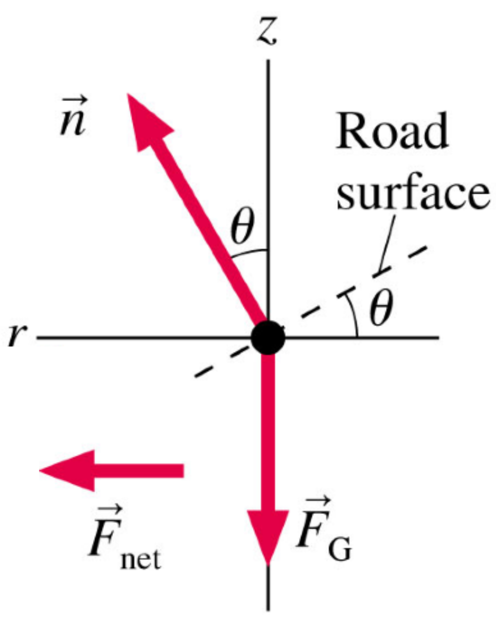

If this were an icy road (no friction), what banking angle must the road have if you are going to be able to make it through the corner?

$$v_0 = \sqrt{rg \tan\theta}$$

a) Draw the free-body diagram
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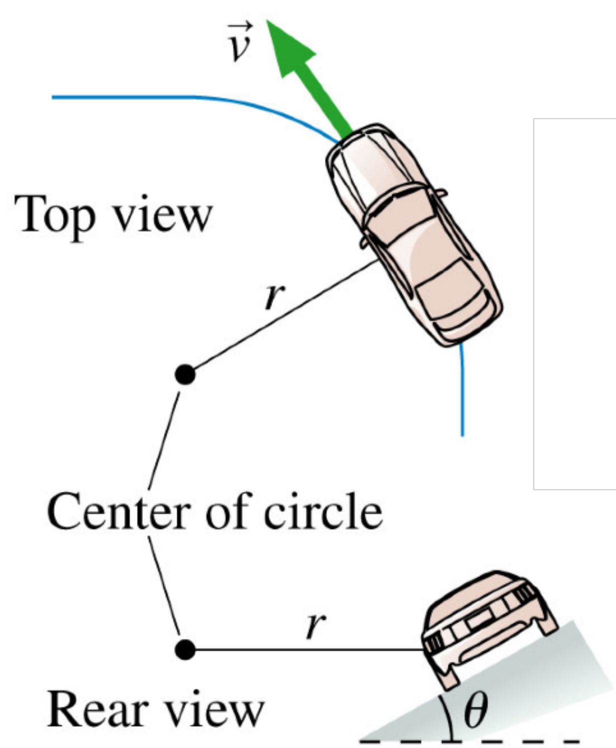
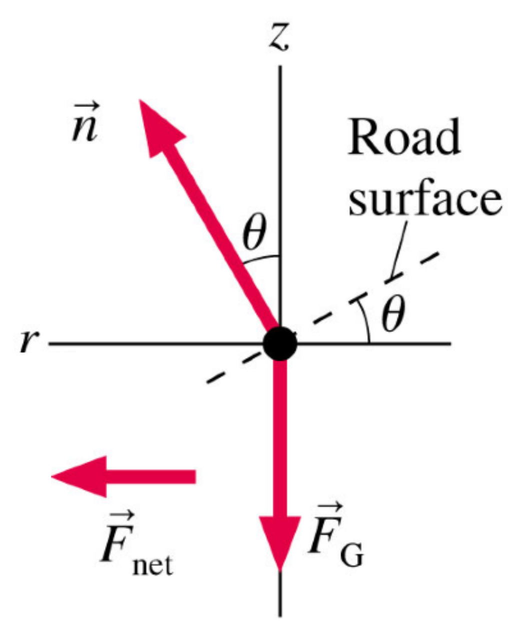
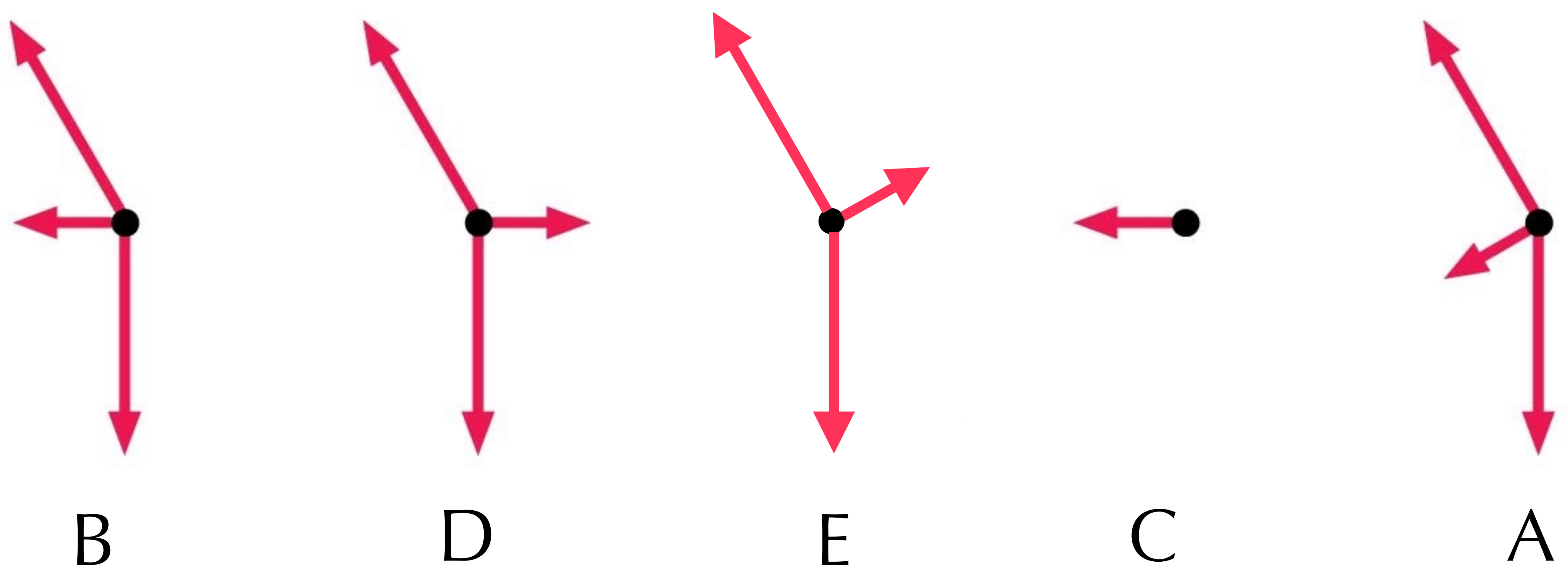


# Banked Curves **Question #21**

If you travel faster than this speed, what must the free-body diagram look like?

$$v_0 = \sqrt{rg\tan\theta}$$

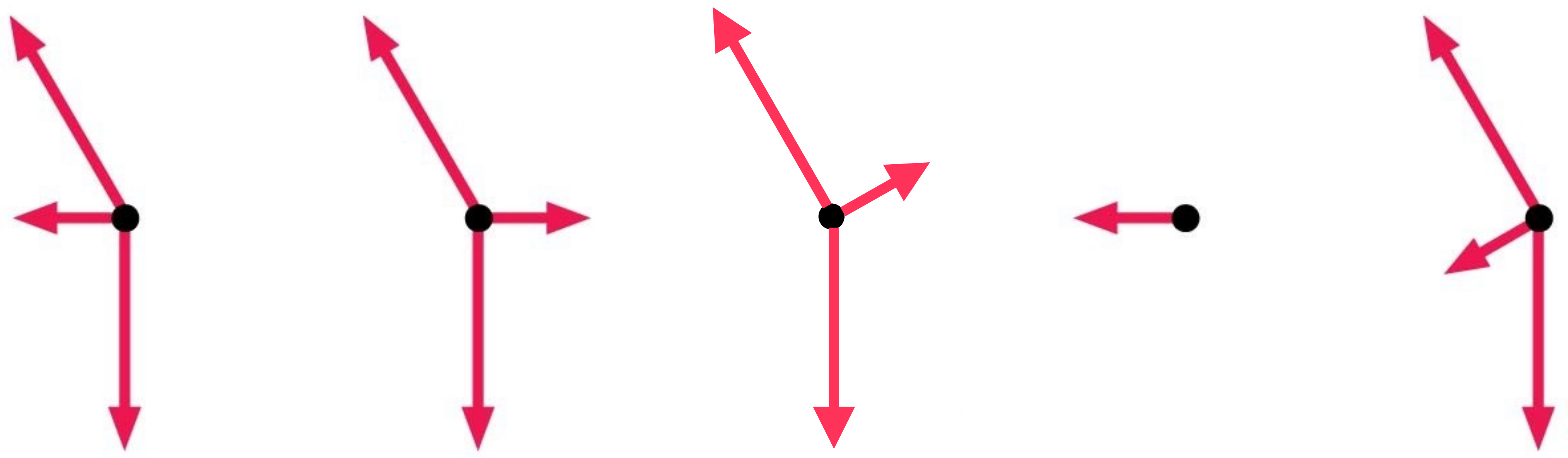


# Banked Curves

**Question #22**

If you travel slower than this speed, what must the free-body diagram look like?

$$v_0 = \sqrt{rg \tan\theta}$$

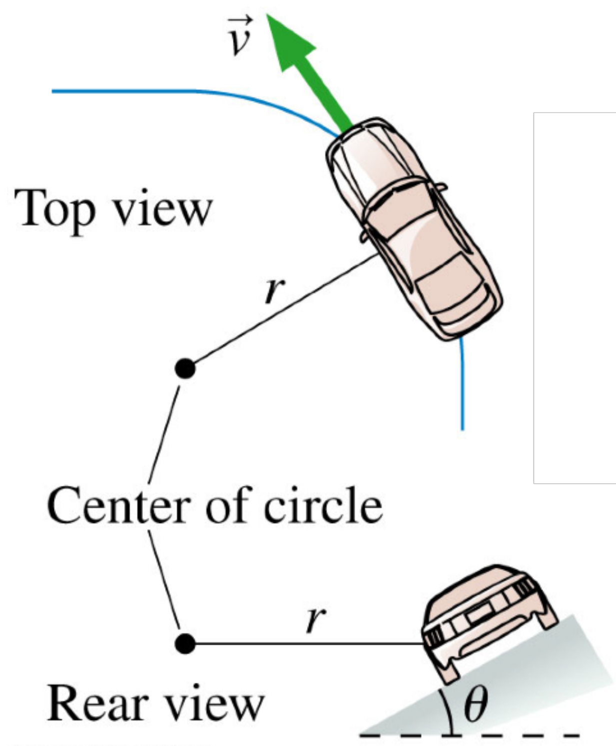


E B C A D

# Banked Curves with friction

What is the maximum speed that this car can travel through the banked curve without slipping off the road. (The road is not frictionless)

a) Draw the free-body diagram
b) Identify your coordinate system
c) Put together Newton's second law



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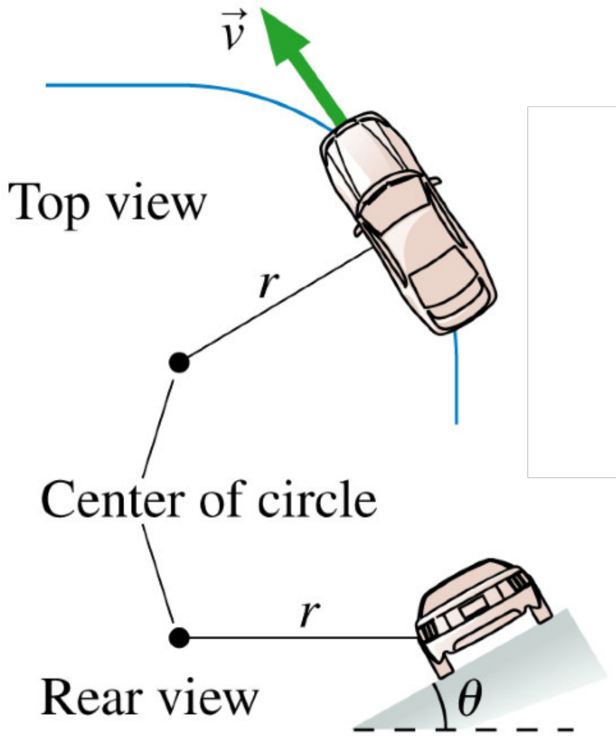
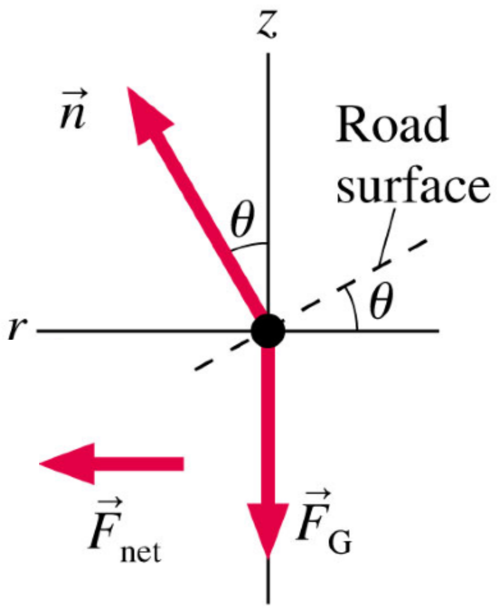
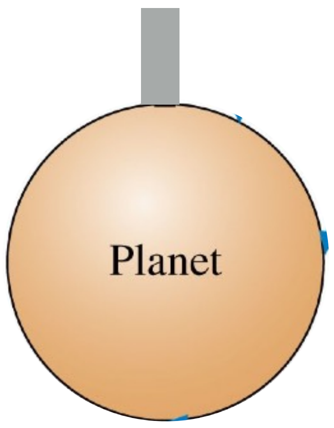


# Circular Orbits

An object is launched from the top of a tall tower.

What will the trajectory look like if you give the object a **small** initial velocity?



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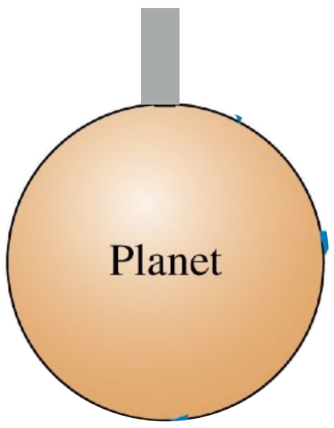

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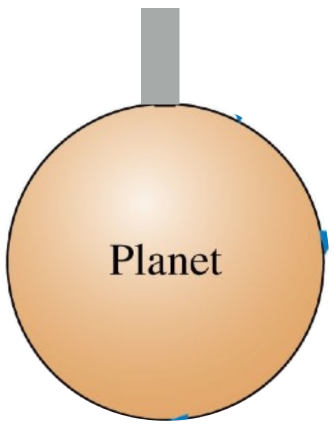

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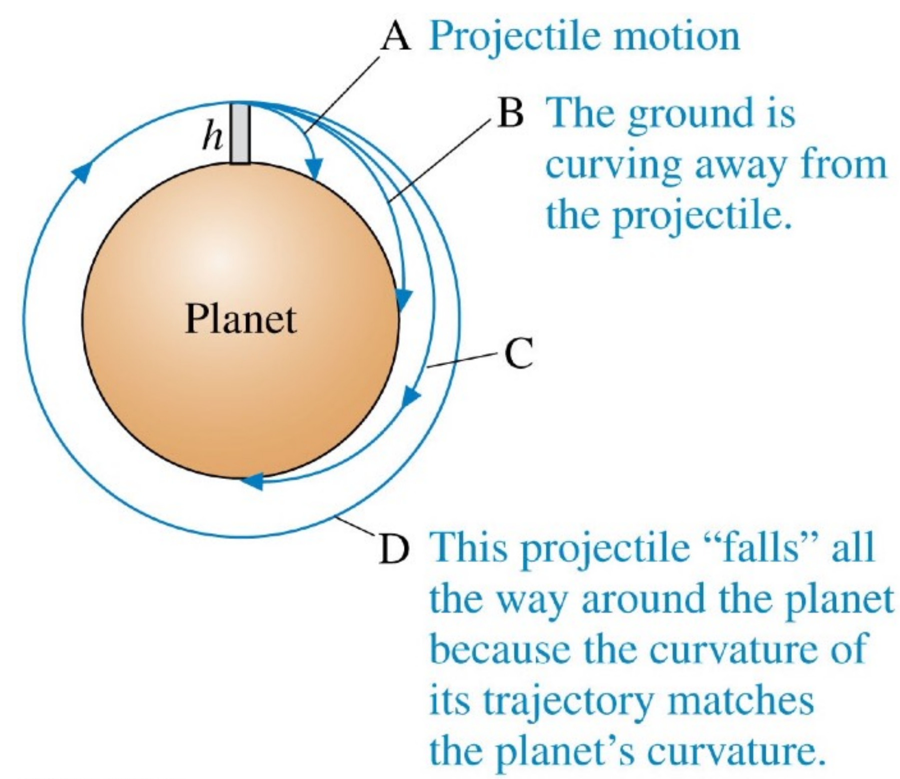


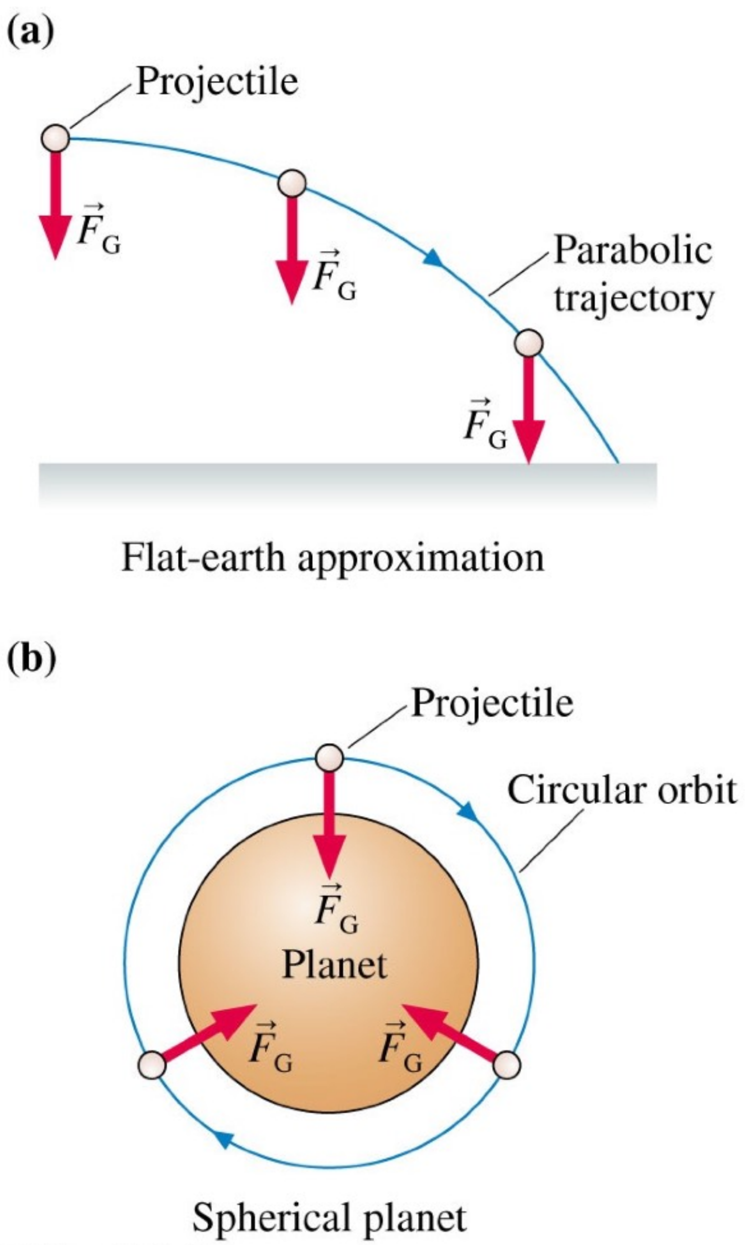
# Circular Orbits

Flat-earth approximation

$$\vec{F}_G = (mg, \text{vertically downward})$$

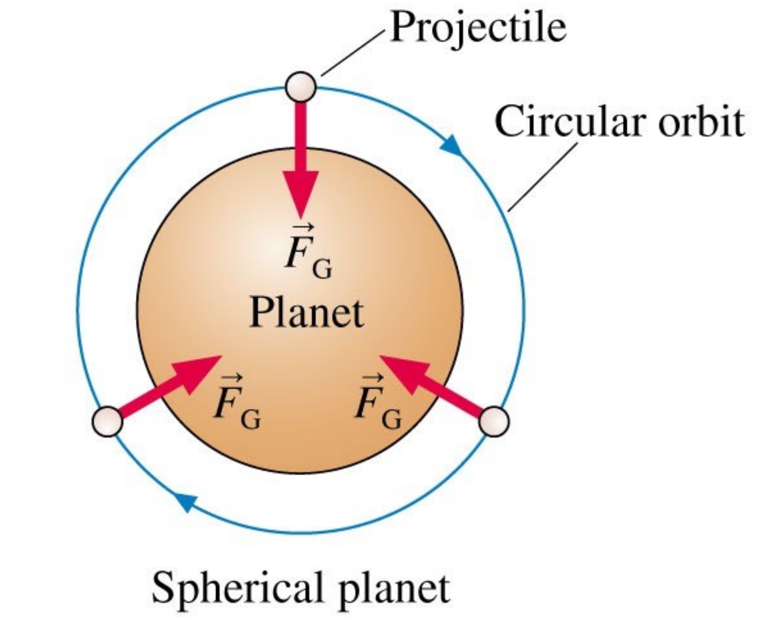
Actual Planet

$$\vec{F}_G = (mg, \text{toward center})$$



# Circular Orbits

Question: An object is orbiting a planet a distance r from the center of the planet.  What speed does the orbiting object have?



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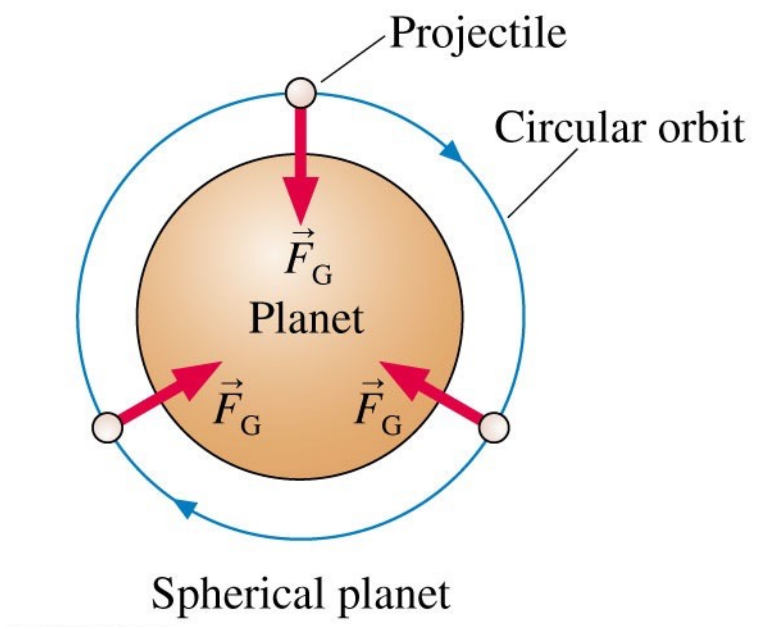
$$\vec{a} = \frac{\vec{F}_{\text{net}}}{m} = (g, \text{toward center})$$



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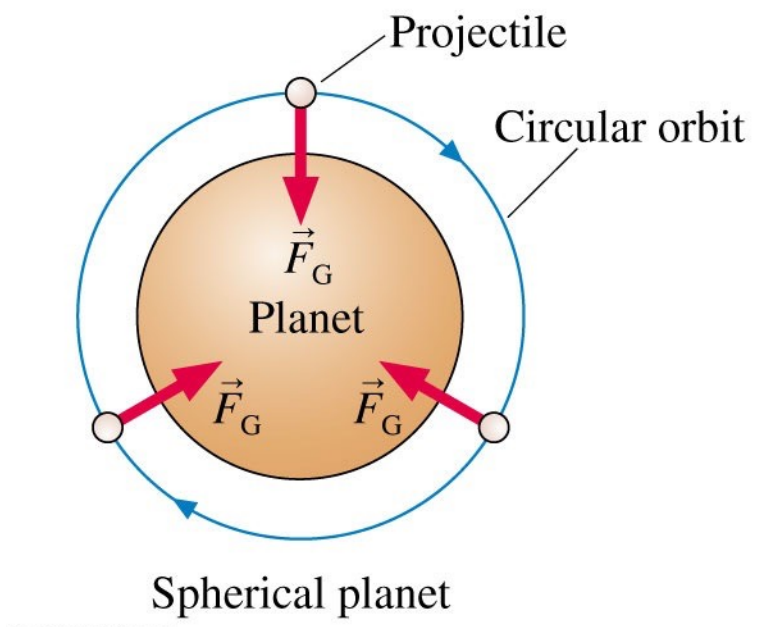


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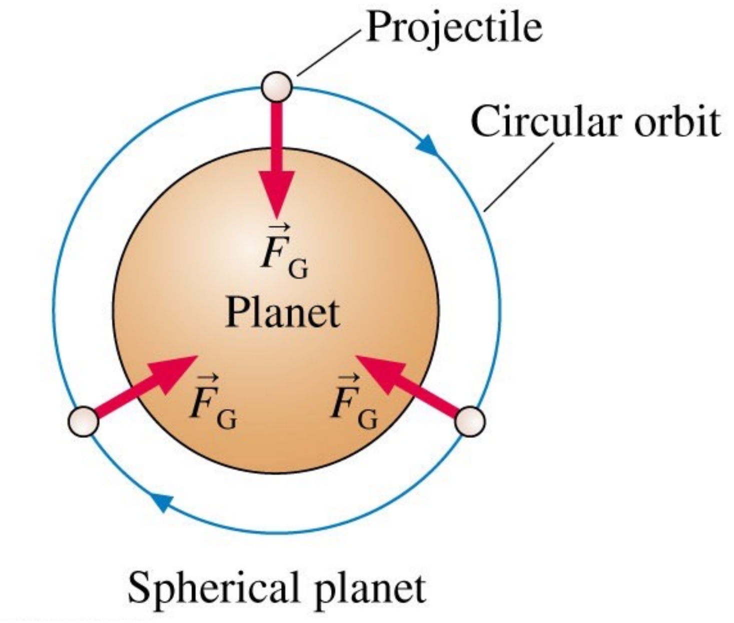


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The required speed for a circular orbit near the planet's surface

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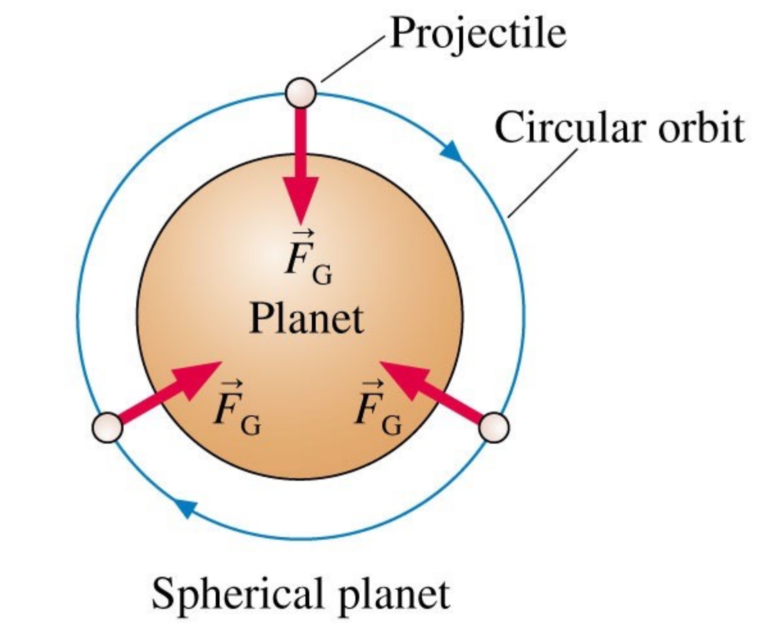


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$$v_{\text{orbit}} = \sqrt{rg}$$

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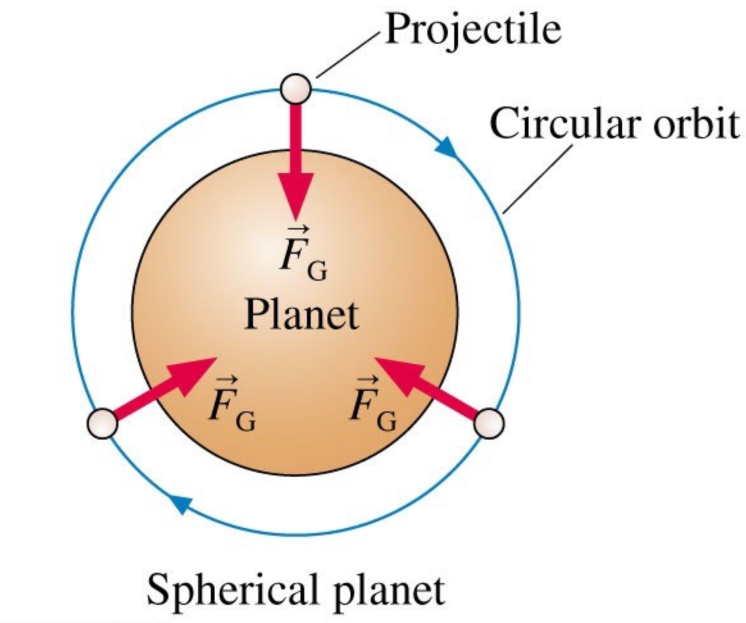


The required speed for a circular orbit near the planet's surface

$$v_{\text{orbit}} = \sqrt{rg}$$

$$v_{\text{orbit}} = \frac{2\pi r}{T}$$