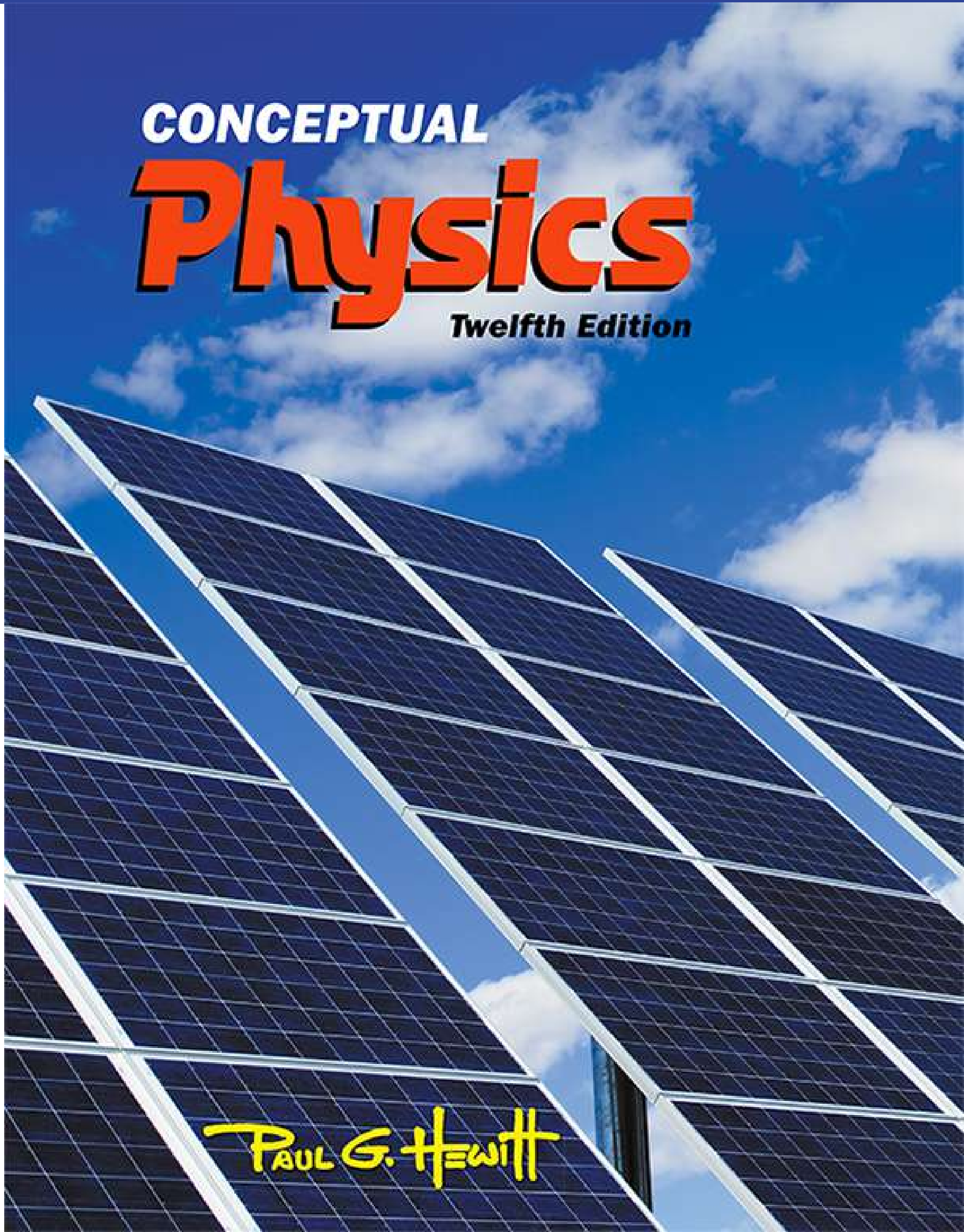
Chapter 8: Rotational Motion

- Centripetal Force
- Centrifugal Force
- Rotating Reference Frames
- Simulated Gravity

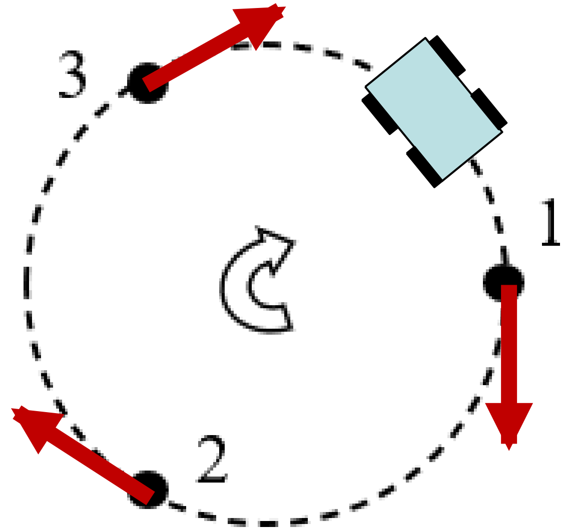


This lecture will help you understand:

- How you can accelerate at constant speed.
- How to safely swing a bucket of water over your head.
- How to safely drive around a curve.
- Why you go off on tangents.
- Why centrifugal forces are not real.
- How artificial gravity works.
- What it would be like on a rotating space station.

A car travels at constant speed in a circle.

Top view:



1) Draw the velocity vectors at points 1, 2 and 3.
2) Is this car accelerating? yes

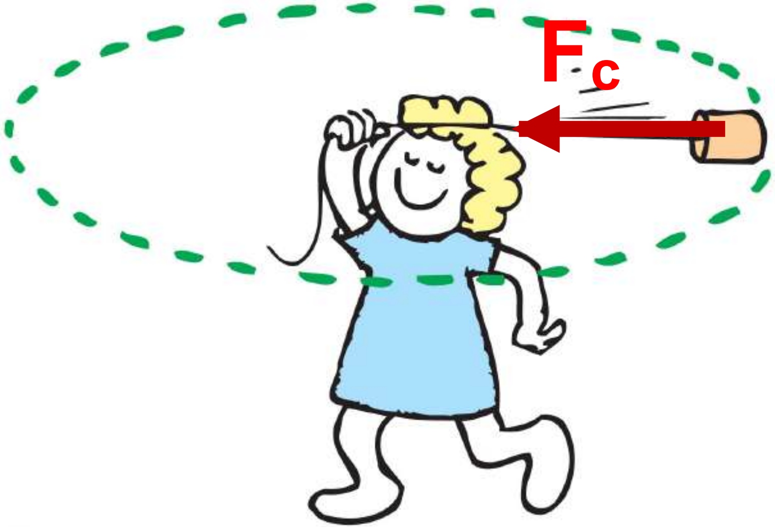
   How can you tell? velocity is changing

3) Is there a net force acting on the car? yes

   How can you tell? because it is accelerating

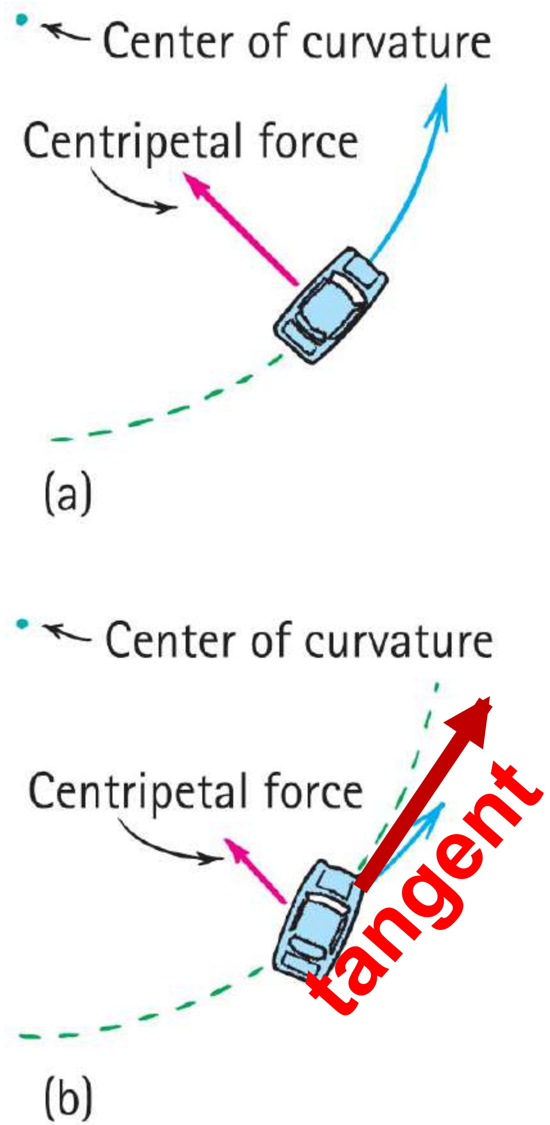
Centripetal Force

- Any force directed toward a fixed center is called a **centripetal force Fc.**
- *Centripetal* means "center-seeking" or "toward the center."
  - Example: To whirl a tin can at the end of a string, you pull the string toward the center and exert a centripetal force to keep the can moving in a circle.



Centripetal Force—Example

- When a car rounds a curve, the centripetal force prevents it from skidding off the road.
- If the road is wet, or if the car is going too fast, the centripetal force is insufficient to prevent skidding off the road.
- The car will go off the road in the direction of its velocity
- This is "off on a **tangent**.



What is the centripetal force.

- The centripetal force F_c is what keeps an object moving in a circle. Below are 5 objects moving in a circle.
- Match the object with the thing that provides the centripetal force.

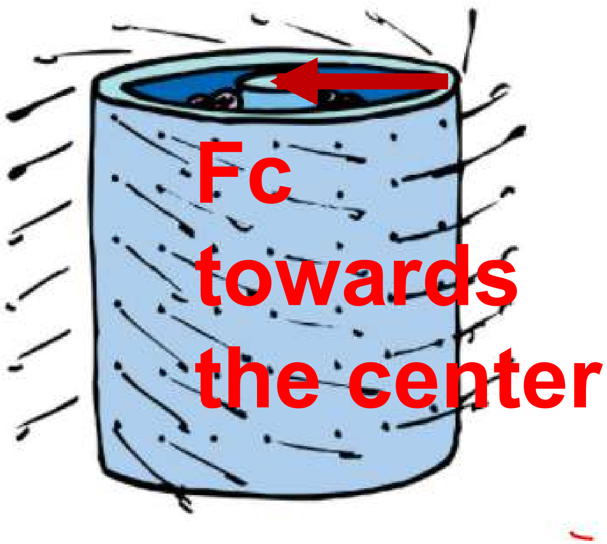
E	bird	A.	friction
A	car on horizontal road	B.	water
D	planet revolving around Sun	C.	string
C	mass on a string twirled in a circle	D.	gravity
B	a sailboat circling a buoy	E.	air

Ex. Spin cycle in a washer

During the spin cycle:

...is water forced away from the clothes?

...or are the clothes forced away from the water?



What is exerting the centripetal force on the clothes to force them into a circular path?

Inside wall of washer

Why isn't the water forced to go in a circle?

it escapes through the holes

Centripetal Force, Continued

- Depends upon
  - mass of object **m**.
  - tangential speed of the object **v**.
  - radius of the circle **r**.
- In equation form:

$$\text{Centripetal force} = \frac{\text{mass x tangential speed}^2}{\text{radius}}$$

$$F_C = \frac{m \cdot v^2}{r}$$

Ex. A 800-kg car moves in a circle with radius 20 m at a tangential speed of 10 m/s. Calculate the centripetal force.

$$F_C = \frac{m \cdot v^2}{r}$$

$$F_C = \frac{(800\,kg) \cdot (10\frac{m}{s})^2}{20\,m}$$

F_C

$$= \frac{(800\,kg) \cdot (100\frac{m^2}{s^2})}{20\,m} = \frac{80{,}000\,kg\frac{m^2}{s^2}}{20\,m}$$

$= 4000\ kg\frac{m}{s^2} = 4000\ N$

Ex. The same 800-kg car moves in the same circle with radius 20 m at twice the speed = 20 m/s. Calculate the centripetal force.

$$F_C = \frac{m \cdot v^2}{r}$$

$$F_C = \frac{(800\,kg)\cdot(20\frac{m}{s})^2}{20\,m}$$

F_C

$$= \frac{(800\,kg)\cdot(400\frac{m^2}{s^2})}{20\,m} = \frac{320,000\,kg\frac{m^2}{s^2}}{20\,m}$$

= 16,000 N

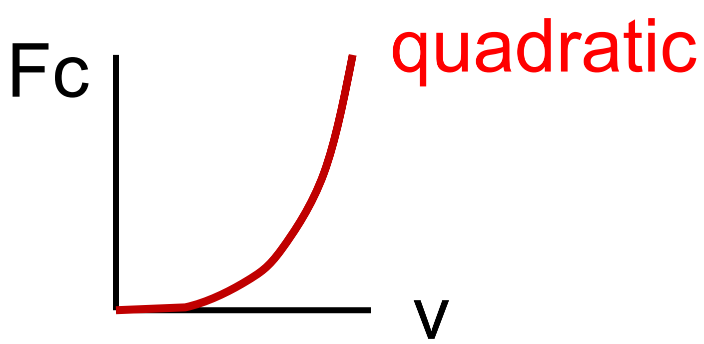
→ If you repeated the calculation for v = 30 m/s you would get an Fc = 36,000 N

→ In summary:

Example	**v**	**F_c**	**increase**
1	10 m/s	4000 N	--
2	20 m/s	16,000 N	4x
3	30 m/s	36,000	9x

This is because F_c is proportional to v^2

$$F_c \propto v^2$$



Ex. Back to the original problem:

A 800-kg car moves in a circle with radius = 20 m at a tangential speed of 10 m/s. We found:

$$F_C = \frac{m \cdot v^2}{r} = 4000 \text{ N}$$

If the radius is 40 m, then $F_c =$ 2000 N

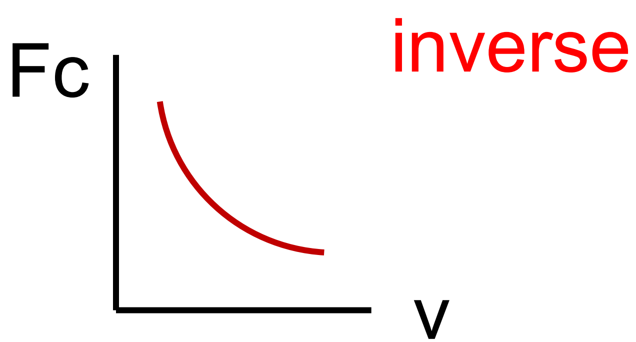
If the radius is 60 m, then $F_c =$ 1333 N

→ In summary:

Example	**r**	**F_c**	**increase**
1	20 m	4000 N	--
2	40 m	2000 N	(1/2)x
3	60 m	1333	(1/3)x

This is because F_c is inversely proportional to r:

$$F_c \ \alpha \frac{1}{r}$$



Centripetal Force
CHECK YOUR NEIGHBOR

Suppose you double the speed at which you round a bend in the curve, by what factor must the centripetal force change to prevent you from skidding?

A. Double
B. Four times
C. Half
D. One-quarter

Centripetal Force
CHECK YOUR ANSWER

Suppose you double the speed at which you round a bend in the curve, by what factor must the centripetal force change to prevent you from skidding?

B. Four times

Explanation:

$$\text{Centripetal force} = \frac{\text{mass x tangential speed}^2}{\text{radius}}$$

Because the term for "tangential speed" is squared, if you *double* the tangential speed, the centripetal force will be *double* squared, which is **four times.**

Centripetal Force
CHECK YOUR NEIGHBOR, Continued

Suppose you take a sharper turn than before and *halve* the radius, by what factor will the centripetal force need to change to prevent skidding?

A. Double
B. Four times
C. Half
D. One-quarter

Centripetal Force
CHECK YOUR ANSWER, Continued

Suppose you take a sharper turn than before and *halve* the radius, by what factor will the centripetal force need to change to prevent skidding?

A. **Double**

Explanation:

$$\text{Centripetal force} = \frac{\text{mass x tangential speed}^2}{\text{radius}}$$

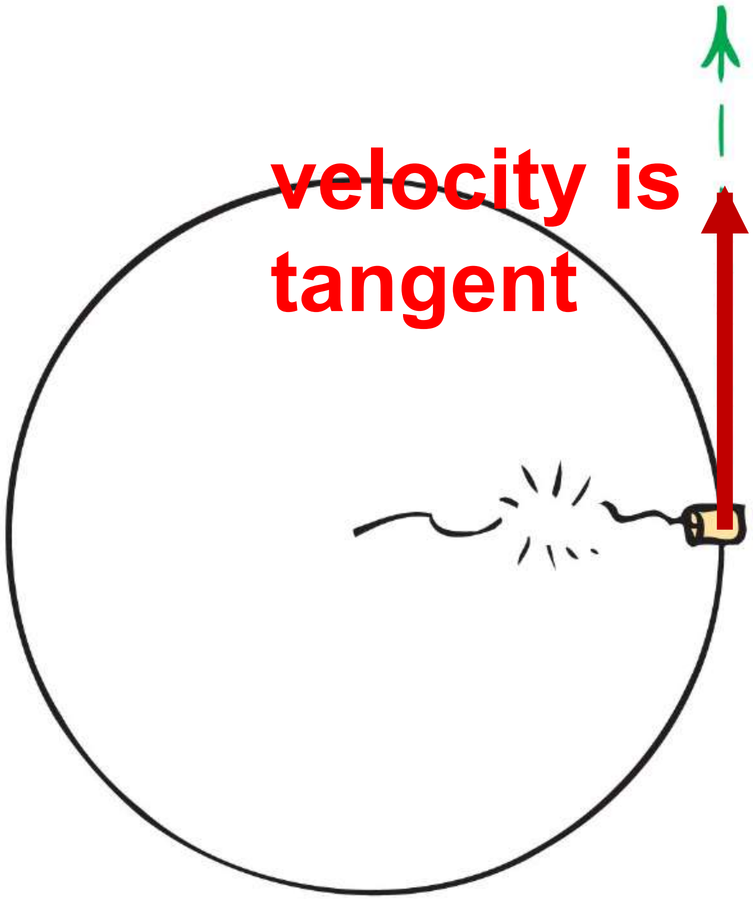
Because the term for "radius" is in the denominator, if you *halve* the radius, the centripetal force will double.

Centrifugal Force

- Although centripetal force is center directed, an occupant inside a rotating system seems to experience an outward force. This apparent outward force is called **centrifugal force.**
- *Centrifugal* means "center-fleeing" or "away from the center."

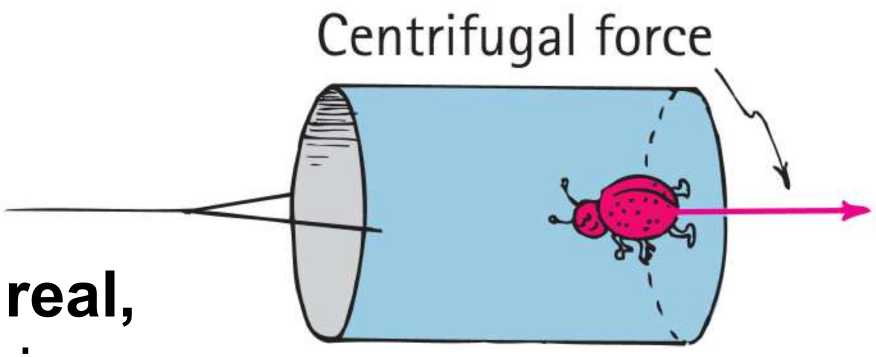
Centrifugal Force
– *A Common Misconception*

- It is a *common misconception* that a *centrifugal force pulls* ***outward*** on an object.
- Example:
  - If the string breaks, the *object doesn't move radially outward*.
  - It continues along its tangent straight-line path—because *no* force acts on it. (Newton's first law)



Rotating Reference Frames

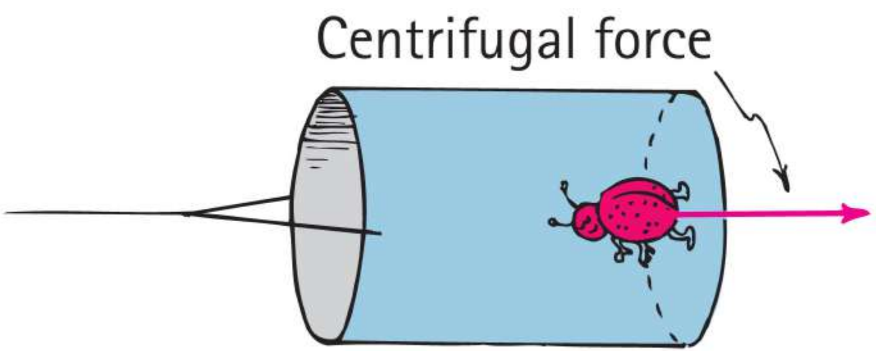
- Centrifugal force *in a rotating reference frame* is a force that is felt because you want to off on a tangent. It is due to your inertia, so it is called an *inertial* force.
- Example:
  - The bug at the bottom of the can experiences a pull toward the bottom of the can.



In the rotating can, it feels real, like gravity, but there is nothing pulling the bug *outwards*.

This "force" is *fictitious* (fake).

Rotating Reference Frames



If the force were real, there would have to be a reaction force of the bug pulling inward on something. There isn't.

The only real force is the centripetal force Fc.

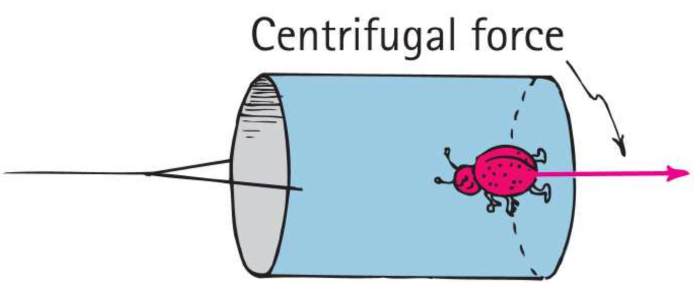
Fc is what pulls the bug *inward towards the circle center.*

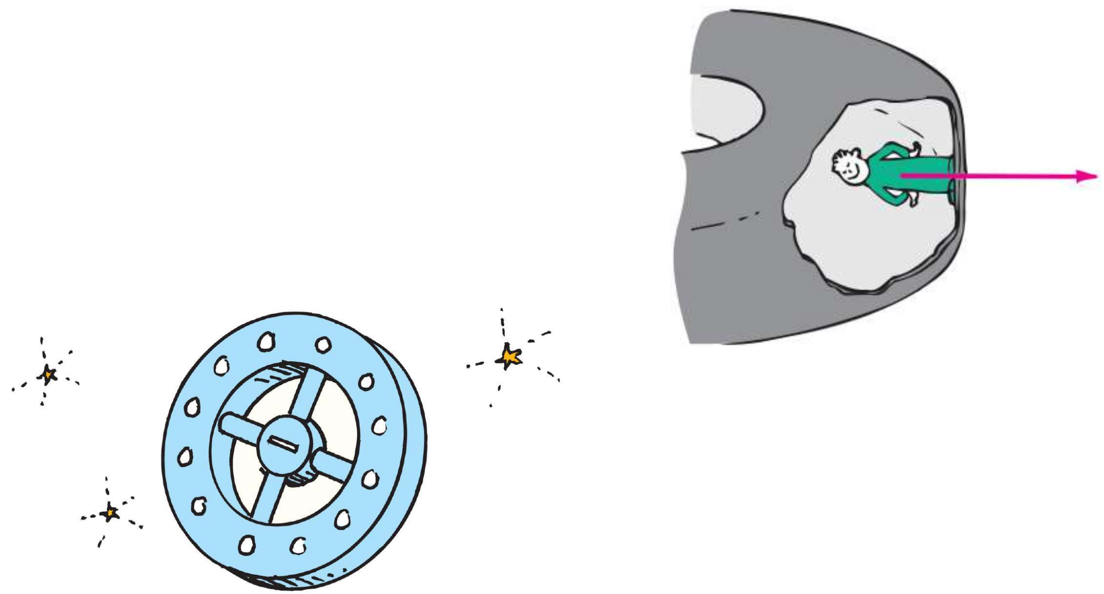
What is exerting the Fc on the *bug*? bottom of can

What is exerting the Fc on the *can*? string

Simulated Gravity

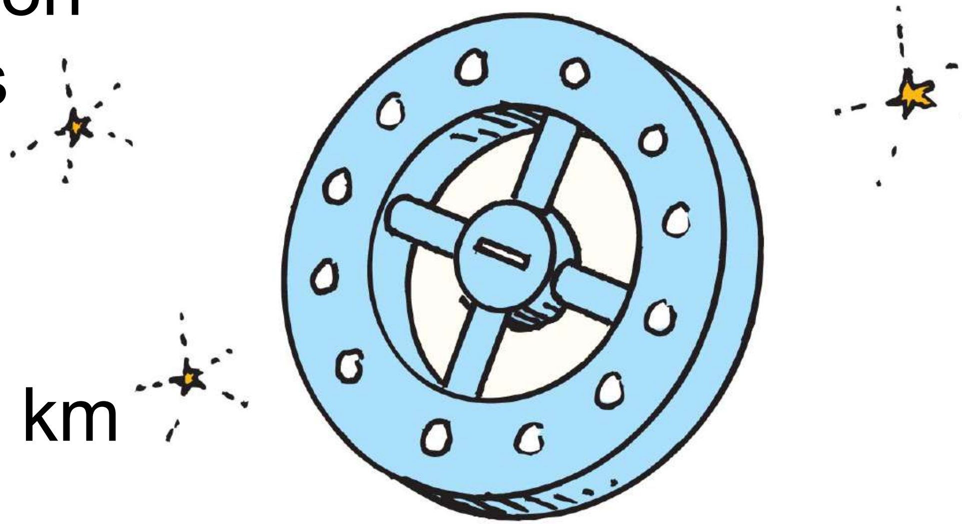
- Centrifugal force can be used to simulate gravity in space stations of the future.
- By spinning the space station, occupants would experience a centrifugal force (simulated gravity) similar to the bug in the can.





Simulated Gravity, Continued

- To simulate an acceleration due to gravity, *g*, which is 10 m/s^2, a space station must:



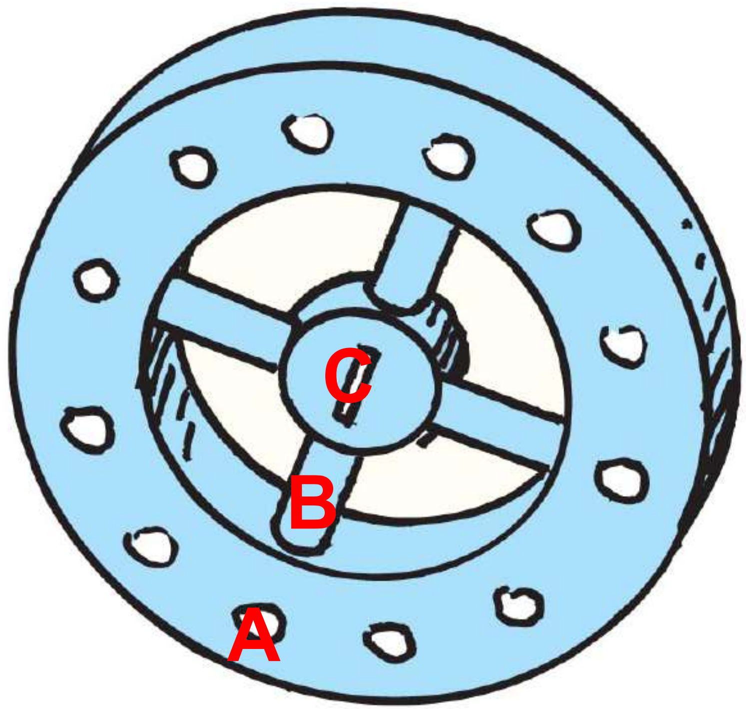
  - have a radius of about 1 km (i.e. diameter of 2 km).
  - rotate at a speed of about 1 revolution per minute.

Simulated Gravity, Continued

- If an astronaut experiences normal gravity $= 10\ m/s^2$ at A on the outside, however….

- At point B (halfway to the center), what gravitational acceleration would they experience?

$5\ m/s^2$



- At the center C, what acceleration would they experience?

$0\ m/s^2$
weightlessnes
s

Homework:

- On page 154; #22-27
- And **show all work** (equation used, substitution with units and answer with units) on:
- On page 155, # 40-41