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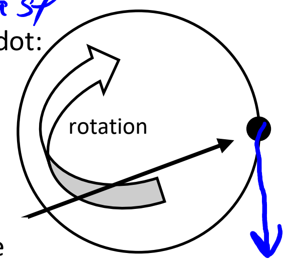
5.1 Circular Motion: Centripetal Acceleration

After watching Merry-Go-Round Fail compilations on YouTube, let's answer a few of these questions:
(By the way, please don't do those stupid things at home. These were exactly the videos used in the TV show: Science of Stupid)

1) When did the people in the merry-go-round flew off the ride? when the merry-go-round was going fast

2) When they left the circle, which direction were they going? Complete the arrow on the black dot:

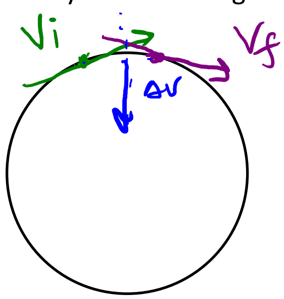


Point when person flew off ride

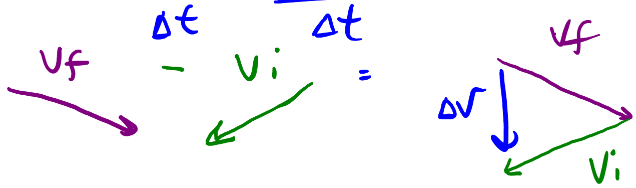
3) Why did these people flew off the ride at this point?
They did not apply enough force on the merry-go-round so the merry-go-round did not apply enough force on them.

Key point: there must be a net force *acting on an object to keep it moving around in a circle. This net* force *must be directed* towards the center *of the circle.*

Doesn't that mean that the object is accelerating towards the center of the circle? Why? Since an object's instantaneous velocity when moving around in a circle is tangent to the circle:



$\vec{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t}$



$v \rightarrow$ speed (m/s)
$r \rightarrow$ radius of circle (m)

We call this acceleration: centripetal acceleration (a_c).

$$a_c = \frac{v^2}{r} \quad (m/s^2)$$

The speed of an object in circular motion is since the circumference of the circle is **2πr**. $v = \frac{d}{t}$

$$v = \frac{2\pi r}{T} \quad (m/s)$$

T = period (s) → time it takes the object to make 1 cycle

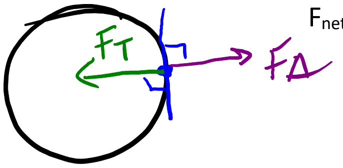
That means a_c can also be expressed as:

$$a_c = \frac{v^2}{r} = \left(\frac{2\pi r}{T}\right)^2 \frac{1}{r} = \frac{4\pi^2 r^{\cancel{2}}}{T^2 \cancel{r}} = \frac{4\pi^2 r}{T^2} \quad (m/s^2)$$

We can use Newton's 2nd Law: $F_{net} = ma$ to show that an object's (m) centripetal acceleration is proportional to the the sum of the forces **towards the center of the circle.**

$$F_{net} = ma = \frac{mv^2}{r} = m\left(\frac{4\pi^2 r}{T^2}\right)$$

When I write F_{net} for circular motion problems (as sum of the forces), I like to think of it as:



F_{net} = Forces towards center of circle (F_T) − Forces away from the center of the circle (F_A)

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Below are some examples:

Ex 1: A plane makes a complete circle with a radius of 3622m in 2.10 min.

a) What is the speed of the plane? (ANS: 181m/s)

b) What is the centripetal acceleration of the plane? (ANS: 9.01m/s^2)

a) $v = \frac{2\pi r}{T} = \frac{2\pi(3622m)}{2.10\times 60} = \boxed{181m/s}$

$T = 2.10 \times 60$

b) $a_c = \frac{v^2}{r} = \frac{(180.\ldots)^2}{(3622)} = \boxed{9.01m/s^2}$

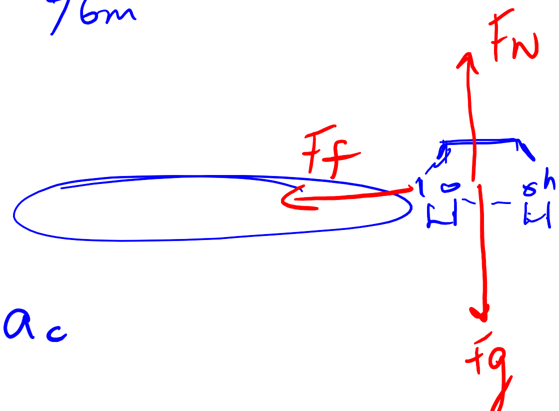
Ex. 2: A car is traveling at 14m/s around an unbanked (flat), curved road that has a radius of 96m.

a) What is the centripetal acceleration? (ANS: 2.0 m/s^2)

b) What is the minimum coefficient of friction between the road and the car's tires? (ANS: 0.21)

a) $a_c = \frac{v^2}{r} = \frac{(14m/s)^2}{96m} = 2.0m/s^2$

b)



$F_N = F_g$

$F_{net} = F_f = ma_c$

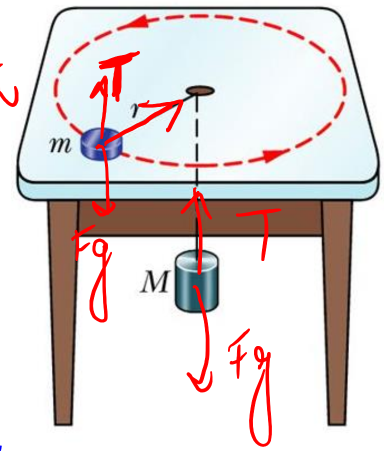
$F_f = \mu F_N = \frac{\mu \cancel{m} g}{\cancel{g}} = \frac{\cancel{m} a_c}{g}$

$\mu = \frac{a_c}{g} = \frac{2.0\ldots}{9.8} = \boxed{0.21}$

Ex. 3: A 0.50 kg mass (m) sits on a frictionless table and is attached via a string to a hanging weight (M) through a hole in the middle of the table. The 0.50 kg mass is whirled in a circle of radius 0.20m at 2.3m/s while the hanging weight is dangling underneath the table without falling onto the floor.

a) Calculate the tension in the string. (ANS: 13N)

b) Calculate the mass of the hanging weight. (ANS: 1.3kg)



a) $F_{net} = T = \frac{mv^2}{r}$

$= \frac{0.5(2.3)^2}{0.2}$

$= \boxed{13N}$

$\cancel{F_c} \rightarrow F_{net}$

b) $F_g = T$

$\frac{T}{g} = \frac{M\cancel{g}}{\cancel{g}}$

$M = \frac{13.\ldots}{9.8}$

$= \boxed{1.3Kg}$

HW: wkst 5.1 $\boxed{ALL}$

$\cancel{F_c} \rightarrow F_{net}$