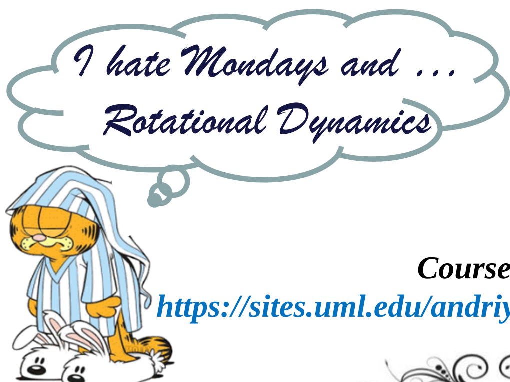
Lecture 10

Physics I

Chapter 8

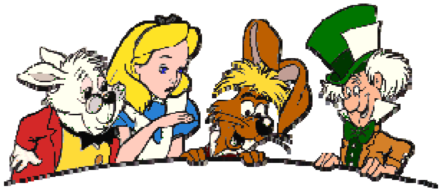
Rotational Dynamics



Course website:
https://sites.uml.edu/andriy-danylov/teaching/physics-i/

Today we are going to discuss:

Chapter 8:



- ***Uniform Circular Motion:*** *Section 8.2*
- ***Circular Orbits:*** *Section 8.3*
- ***Reasoning about Circular Motion:*** *Section 8.4*

ConcepTest *Heartbroken Mosquito*

A mosquito runs head-on into a truck. Which is true <u>during</u> the collision?

A) The magnitude of the mosquito's acceleration is larger than that of the truck.

B) The magnitude of the truck's acceleration is larger than that of the mosquito.

C) The magnitude of the mosquito's acceleration is the same as that of the truck.

D) The truck accelerates but the mosquito does not.

E) The mosquito accelerates but the truck does not.

Newton's 3rd law:

$$F_{MT} = F_{TM} = F$$

Newton's 2nd law:

$$a = \frac{F}{m}$$

F: Same for both

m: Huge difference

$$\Rightarrow a_M >> a_T$$

Don't confuse cause and effect! The same force can have very different effects.

The same idea can be applied to an interaction of an apple and the Earth in the slide at the end of the presentation. But you don't have to read it. Only if you want.

Tension in a rope

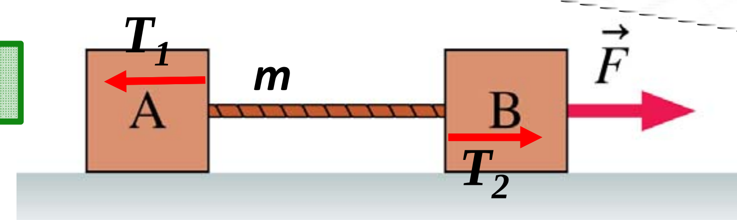
Tension is the same at any point of the rope if the rope is massless

(Read this proof if you want)

If a flexible cord pulls an object, the cord is said to be under ***TENSION***

Let's assume that the cord is a described object and apply N 2nd law

$$\sum \vec{F} = m\vec{a} \Longrightarrow T_2 - T_1 = \cancel{m}a = 0 \Longrightarrow \boldsymbol{T_2 = T_1 = T}$$



Often in problems the mass of the string or rope is much less than the masses of the objects that it connects. $m=0$

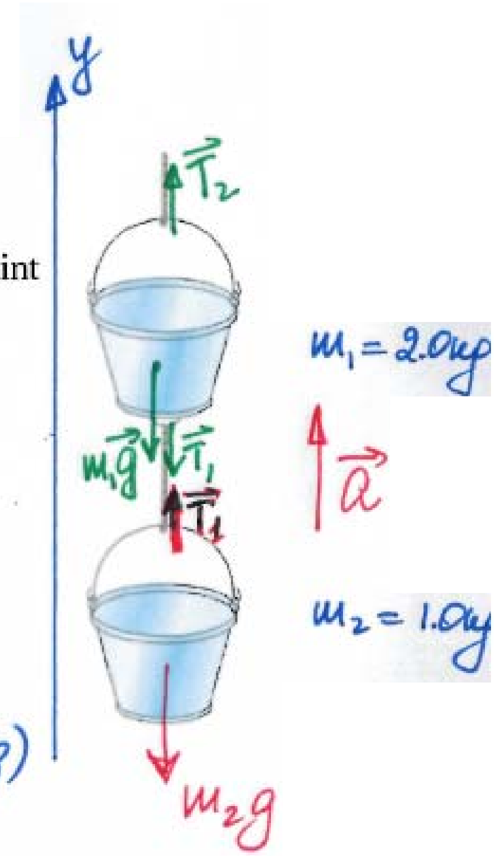
massless string approximation: Tension is the same at any point of the rope

If we apply a force to one end of the cord, the same force will be on the other end

For problems in this book, you can assume that any strings or ropes are massless unless it explicitly states otherwise.

Example. Two Buckets

One 1.0-kg paint bucket is hanging by a massless cord from another 2.0-kg paint bucket, also hanging by a massless cord, as shown in the figure.
If the two buckets are pulled upward with an acceleration of 2.0 m/s² by the upper cord, calculate the tension in each cord.



Given: $m_1 = 2.0\,kg$; $m_2 = 1.0\,kg$; $a = 2.0\,m/s^2$

Let's apply N. 2nd law for each bucket:

$$m_2 \Rightarrow \sum F_2 = m_2 a \Rightarrow T_1 - m_2 g = m_2 a \Rightarrow T_1 = m_2(a+g)$$

$$m_1 \Rightarrow \sum F_1 = m_1 a \Rightarrow T_2 - T_1 - m_1 g = m_1 a$$

$$T_2 = m_1 a + m_1 g + T_1 = m_1(a+g) + m_2(a+g)$$

$$T_2 = (m_1 + m_2)(a+g) = (2.0\,kg + 1.0\,kg)\cdot(2.0\,m/s^2 + 9.8\,m/s^2) = 35.4\,N$$

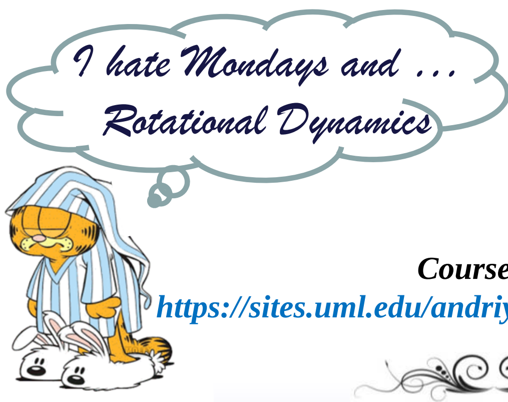
$$T_1 = m_2(a+g) = 1.0\,kg\,(2.0\,m/s^2 + 9.8\,m/s^2) = 11.8\,N$$

Lecture 11

Physics I

Chapter 8

Rotational Dynamics



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The best coordinate system

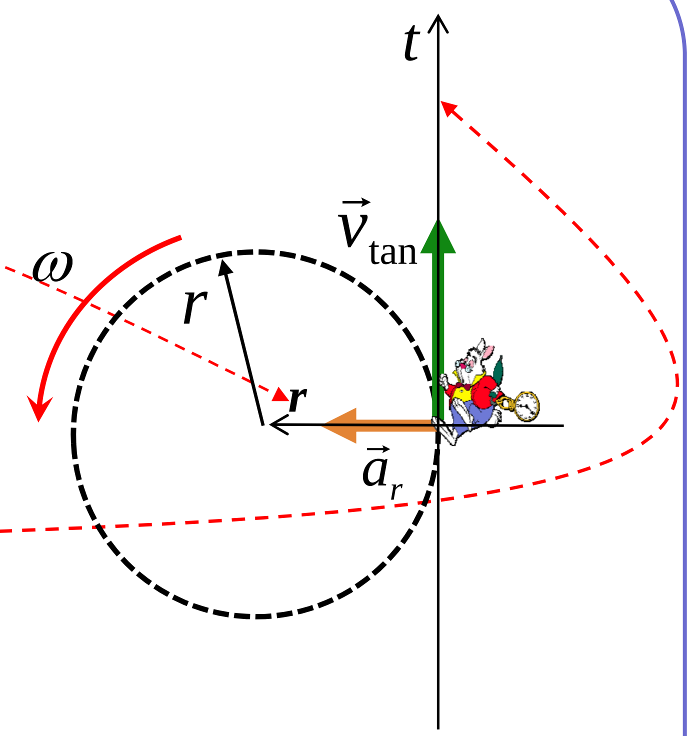
for a Uniform Circular Motion

When describing circular motion, it is convenient to define a moving *rt*-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 origin "moves" along with a certain particle moving in a circular path.



If there is an acceleration, there must be a force

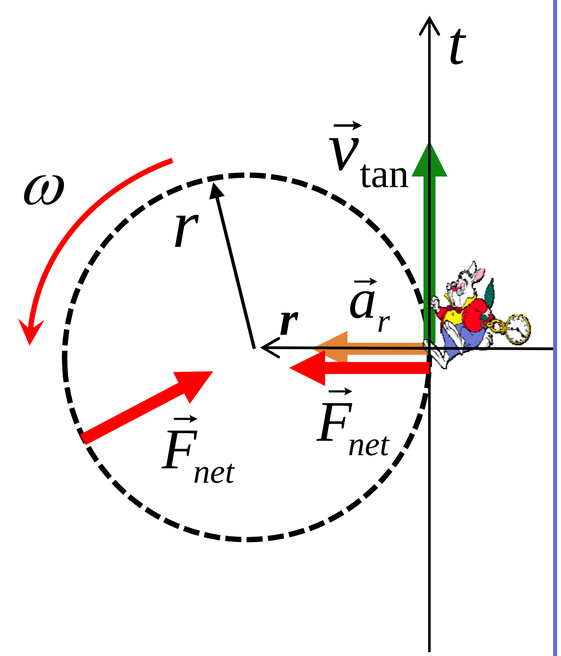
The figure shows a particle in uniform circular motion.

If there is an centripetal (radial) acceleration, there must be a radial force (called *centripetal*) according to N. 2nd law.

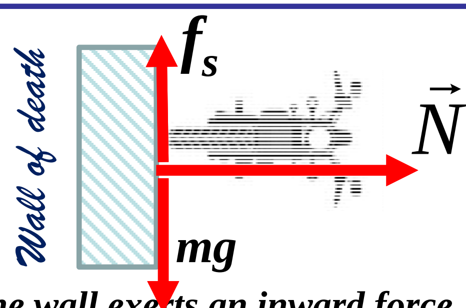
$$\sum F_r = ma_r \quad \Rightarrow \quad \sum F_r = \frac{mv^2}{r}$$

The net force points in the radial direction, toward the center of the circle.

This centripetal force is not a new force. This can be any one of the forces we have already encountered: tension, gravity, normal force, friction, …



Examples



Bike going in a circle: the wall exerts an inward force (normal force) on a bike to make it move in a circle.

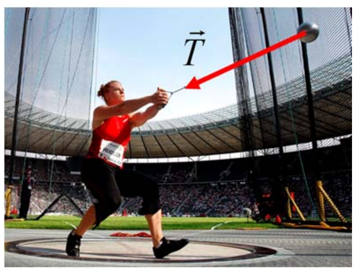
$$\sum F = ma_r \Rightarrow \quad a_r = \frac{v^2}{R} \qquad N = \frac{mv^2}{R}$$

v –velocity of the motorbike

R- radius of the circle

Normal force provides the centripetal acceleration

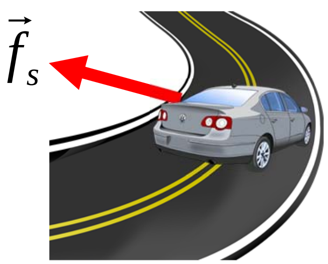
https://www.youtube.com/watch?v=9H4jUptw4Vk



A hammer going in a circle: the cord exerts an inward force (tension) on a hammer to make it move in a circle.

$$\sum F = ma_r \Rightarrow \quad T = \frac{mv^2}{R}$$

Tension provides the centripetal acceleration



Car going in a circle:
the road exerts an inward force (friction) on a car to make it move in a circle.

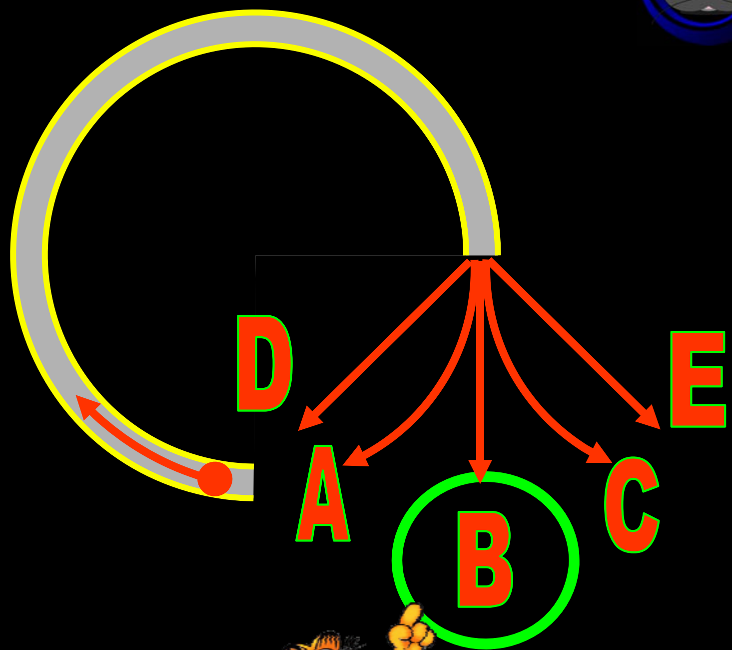
$$\sum F = ma_r \Rightarrow \quad f_s = \frac{mv^2}{R}$$

Friction provides the centripetal acceleration

ConcepTest

Missing Link

A Ping-Pong ball is shot into a circular tube that is lying flat (horizontal) on a tabletop. When the Ping-Pong ball leaves the track, which path will it follow?



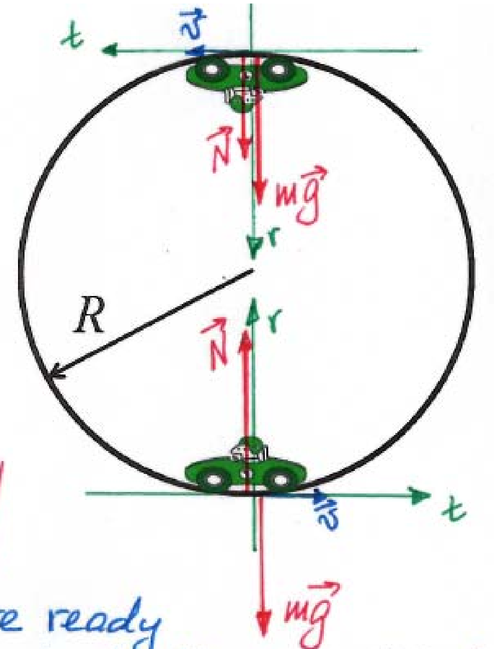
Once the ball leaves the tube, there is no longer a force to keep it going in a circle. Therefore, it simply continues in a straight line, as Newton's First Law requires!

Follow-up: What physical force provides the centripetal acceleration?

Example Loop the Loop

a) To make the loop-the-loop at a constant speed, what minimum speed does the car need?

b) Find an apparent weight at the bottom.



a) Draw a free body diagram for a car at the top

N. 2nd law for a radial direction:

$$\sum_i F_r = m a_r \quad \leftarrow a_r = \frac{v^2}{R}$$

$$N + mg = m\frac{v^2}{R} \Rightarrow \left\| v = \sqrt{\frac{R}{m}(N+mg)} \right\|$$

The critical speed occurs when we are ready to start falling down, i.e. losing contact with the wall (N=0).

$$v_{min} = \sqrt{\frac{R}{m}(\cancel{N} + mg)} = \sqrt{g \cdot r}$$

b) apparent weight -? (i.e N-?) at the bottom.

$$\sum_i F_r = m a_r \Rightarrow N - mg = m\frac{v^2}{R} \Rightarrow \left\| N = mg + m\frac{v^2}{R} \right\|$$

Thus, N > mg. You would feel heavier (similar to a case when a person is in an elevator)

Demo success

Demo fail

http://phys23p.sl.psu.edu/phys_anim/mech/

ConcepTest — Going in Circles

You're on a Ferris wheel moving in a vertical circle. When the Ferris wheel is at rest, the normal force N exerted by your seat is equal to your weight *mg*. How does N change at the top of the Ferris wheel when you are in motion?

A) N remains equal to *mg*

B) N is smaller than *mg*

C) N is larger than *mg*

D) none of the above

$$mg - N = m\frac{v^2}{R}$$

$$mg - m\frac{v^2}{R} = N$$

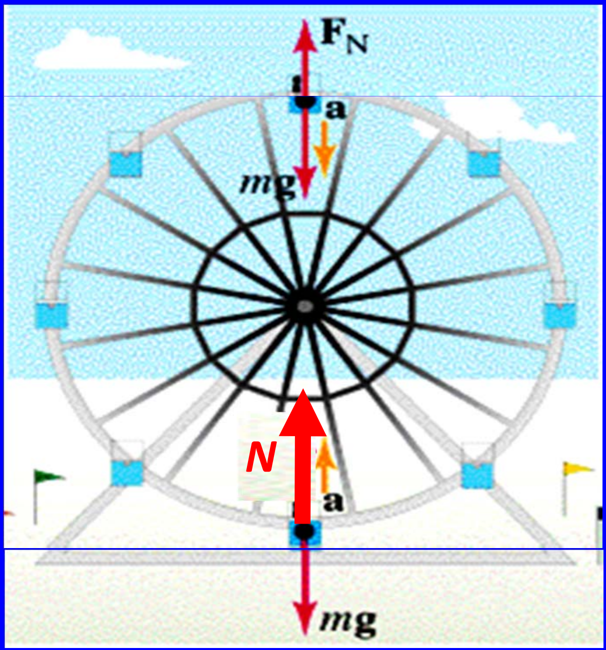
You are in circular motion, so there has to be a centripetal force pointing *inward*. At the top, the only two forces are *mg* (down) and *N* (up), so *N* must be smaller than *mg*.

Follow-up: Where is N larger than *mg*?

Bottom

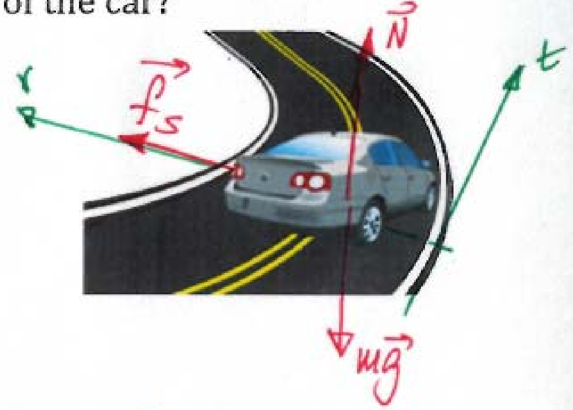
$$N - mg = m\frac{v^2}{R}$$

$$N = mg + m\frac{v^2}{R}$$



Example Car on a circular flat road

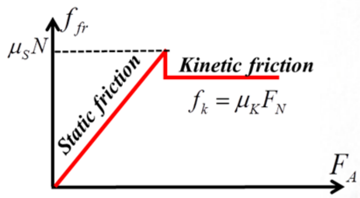
What is the maximum speed with which a 1200-kg car can round a turn of radius 80 m ona flat road if the coefficient of static friction between tires and road is 0.65? Is the result independent of the mass of the car?



- The radial force required to keep the car in the curved path is supplied by the force of static friction between the tires and the road.

The max static friction force is

$$f_s^{max} = \mu_s \cdot N = \mu_s \cdot mg$$



In this case the car would be on a verge of skidding. Let's find the speed corresponding to this centripetal force (f_s^{max}) and that would be the max speed.

- N. 2nd law in the r direction

$$\sum F_r = ma_r \Rightarrow f_s^{max} = m\frac{v_{max}^2}{R}$$

$$\mu_s \cdot m \cdot g = m \cdot \frac{v_{max}^2}{R} \Rightarrow \left\| v_{max} = \sqrt{\mu_s \cdot gR} \right\| = \sqrt{0.65 \cdot 9.8\,m/s^2 \cdot 80\,m} = 22.6\ m/s$$

It's independent of the car's mass.

ConcepTest *Going in Circles*

A skier goes over a small round hill with radius *R*. Because she is in circular motion, there has to be a *centripetal force.* At the top of the hill, what is F_c of the skier equal to?

A) $F_c = N + mg$

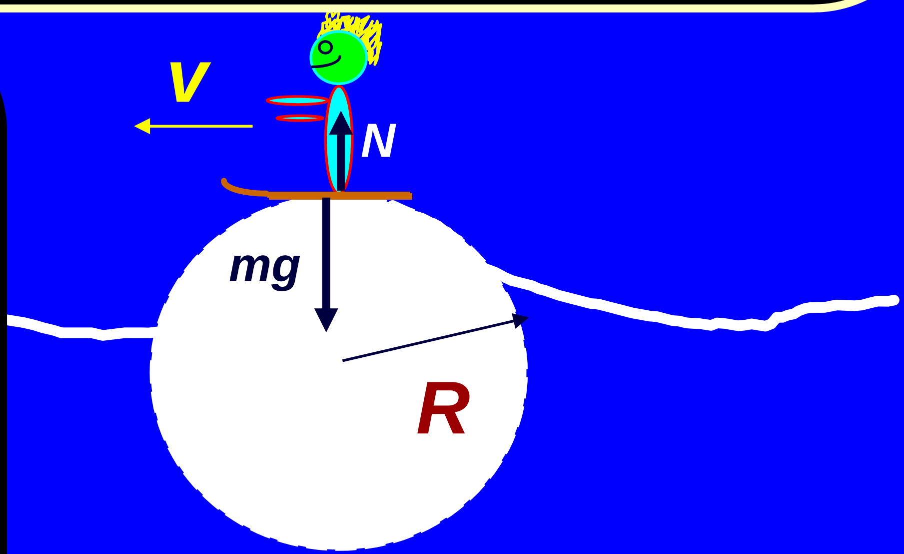
B) $F_c = mg - N$

C) $F_c = T + N - mg$

D) $F_c = N$

E) $F_c = mg$

F_c points toward the center of the circle (*i.e.*, downward in this case). The weight vector points down and the normal force (exerted by the hill) points up. The magnitude of the net force, therefore, is $F_c = mg - N$.



Follow-up: What happens when the skier goes into a small dip? $F_c = N - mg$


Thank you
Bye Bye For Now

ConcepTest *Around the Curve*

You drive your car too fast around a curve and the car starts to skid. What is the correct description of this situation?

A) car's engine is not strong enough to keep the car from being pushed out

B) friction between tires and road is not strong enough to keep car in a circle

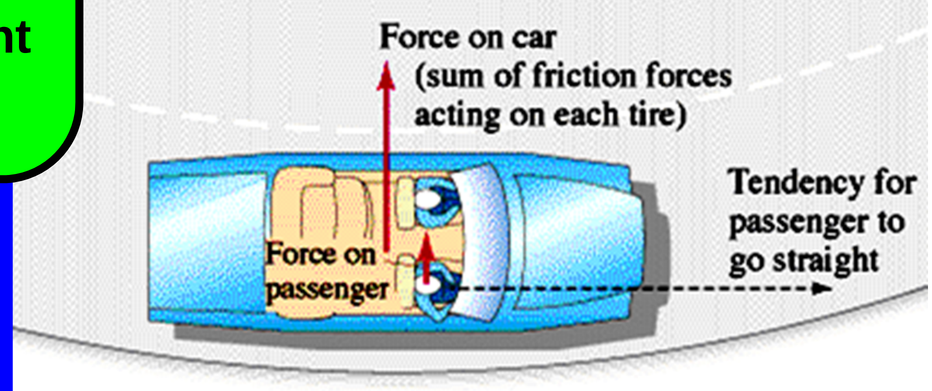
C) car is too heavy to make the turn

D) a deer caused you to skid

E) none of the above

The friction force between tires and road provides the centripetal force that keeps the car moving in a circle. If this force is too small, the car continues in a straight line!

$$f_s = \frac{mv^2}{R}$$



Follow-up: What could be done to the road or car to prevent skidding?