Course announcement

- Homework set 1 has been posted on eLearn. It will be due on Friday(10/7) at 5PM. Please submit your homework via eLearn. No late homework will be accepted.
- There are 5 points in Homework set 1. The homework points will directly be added to final grades.
- You can view11110PHYS 113301-04and06-07 [元課程]普通物理B on eLearn. It is for your reference.

3	9/27(Tue.)	**Newton's law:** Newton's first and second law I
3	9/30(Fri.)	**Newton's law:** Newton's first and second law II (Homework 1)
4	10/4(Tue.)	**Newton's law:** Newton's third law and Using Newton's law
4	10/7(Fri.)	**Energy:** kinetic energy and work

GENERAL PHYSICS B 1
NEWTON’S LAW

Using Newton’s Laws

2022/10/04

Newton's first and second law

- **Newton's first law of motion:** A body in uniform motion remains in uniform motion, and a body at rest remains at rest, unless acted on by a nonzero net force ($\overrightarrow{F_{net}} \neq 0$) .
- **Newton's second law**: The net force on a body is

$$\overrightarrow{F_{net}} = \frac{d\vec{p}}{dt}$$

When mass is constant, Newton's second law becomes:

$$\overrightarrow{F_{net}} = m\vec{a}$$

- **Newton's third law:** When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

Application of Newton’s second law

Recipe of applying Newton’s second law to analyze motion of an object:

- Draw free body diagram of the object and plot out all the forces.
- Analyzing the net force applying on the object.
- Applying Newton’s law to link the net force to acceleration and thus other quantities of kinetics.

Equation of motion

- Newton's second law provide link between force and acceleration, which is the second derivative of position respect to time. Therefore, one can obtain an equation to describe the behavior of a physical system in terms of its motion as a function of time, which is called equation of motion.

Topics

- Uniform circular motion
- Drag force and terminal speed
- Other example of force and motion
- Newton’s third law

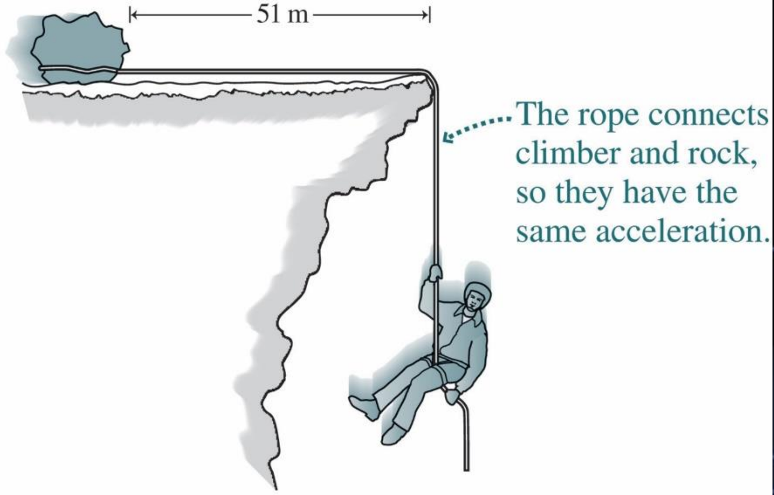
Newton’s law on Multiple Object

Solve problems involving multiple objects by first identifying each object and all the forces and constraints on it.

- Draw a free-body diagram for each object.
- Write Newton’s law for each object.
- Identify connections among the objects, which give common terms in the equations.
- Solve.

Example: Multiple Objects

- Example: A 73-k g climber dangles over the edge of a frictionless ice cliff from a massless rope tied to a 940-kg rock. What is the acceleration of the climber?



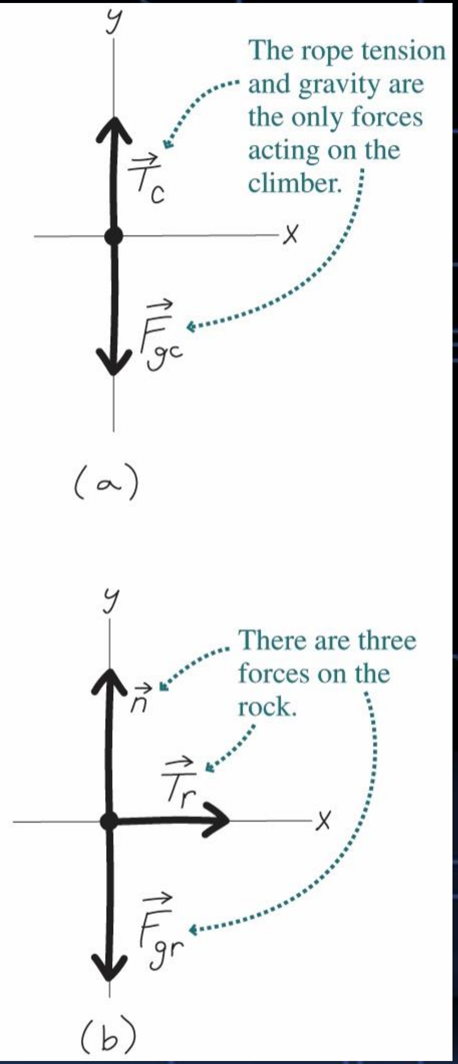
Example: Multiple Objects

- Draw a free-body diagram for the climber and the rock.
- Write Newton's second law for the both objects:

$$\text{climber}: \vec{T}_c + \vec{F}_{gc} = m_c\vec{a}_c$$

$$\text{rock}: \vec{T}_r + \vec{F}_{gr} + \vec{n} = m_r\vec{a}_r$$

- Now write these equations in component form:
  - The accelerations of the climber and rock are equal in magnitude—call that common value a.
  - In the absence of friction, the magnitude of the tension in the massless rope is constant—call that T



Example: Multiple Objects

- We have:

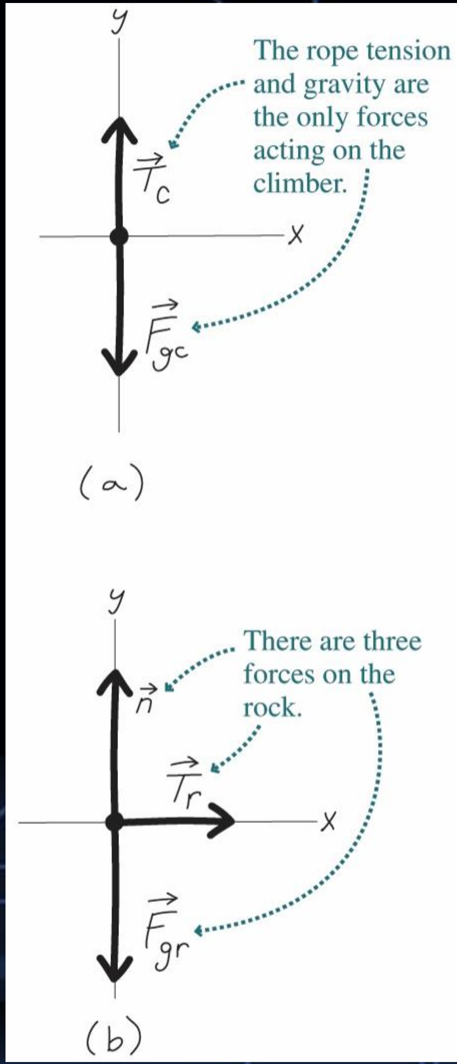
climber, y: $T - m_c g = -m_c a$

rock, x: $T = m_r a$

rock, y: $n - m_r g = 0$

- Solve:

$$a = \frac{m_c g}{m_c + m_r} = \frac{(73\ \text{kg})(9.8\ \text{m/s}^2)}{(73\ \text{kg} + 940\ \text{kg})} = 0.71\ \text{m/s}^2$$

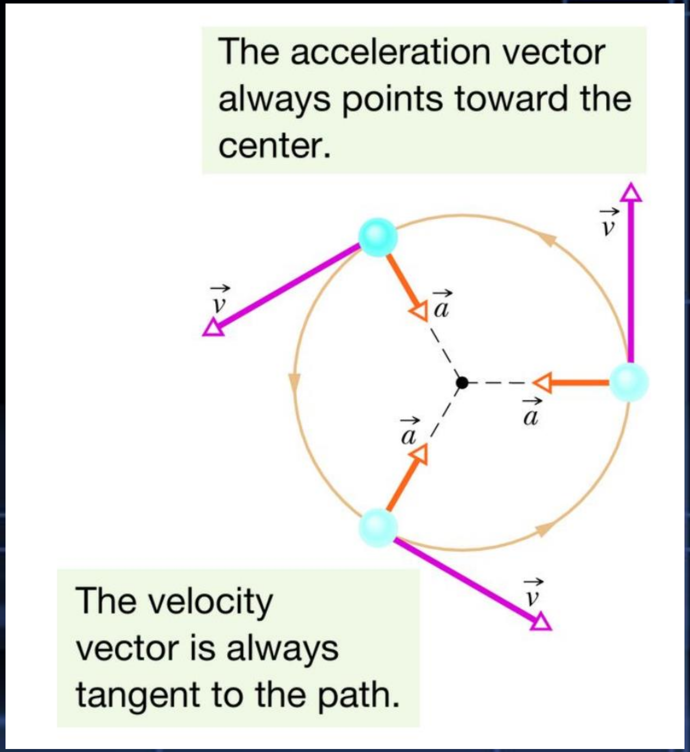


Forces in uniform circular motion

- In a uniform circular motion, it is require to have an acceleration with direction always pointing to center and the magnitude is:

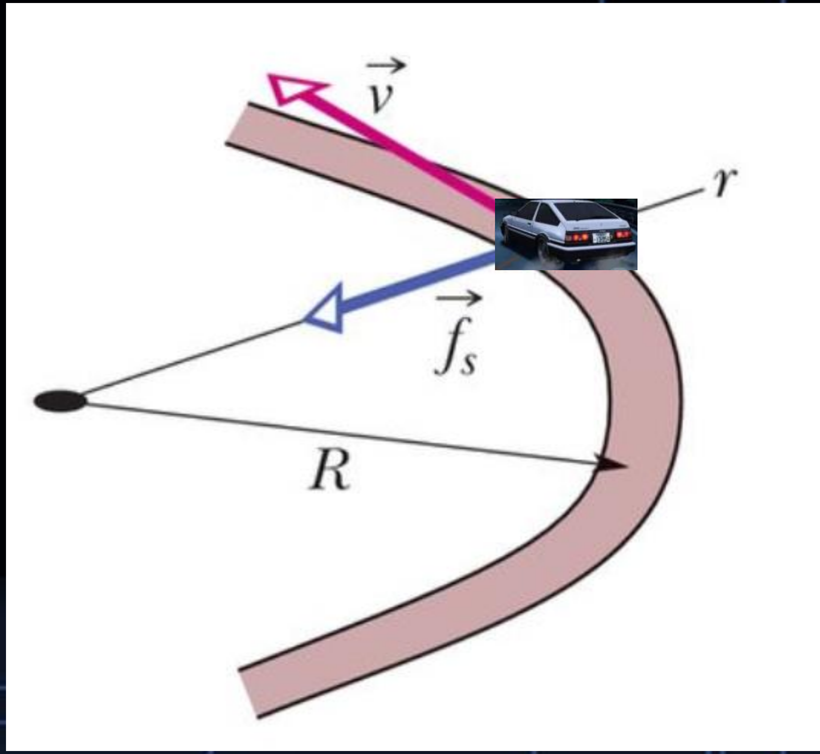
$$a = \frac{v^2}{r}$$

- With Newton's seconds law, there must be a net force exerting on the object with direction pointing to center and magnitude is $\frac{mv^2}{r}$



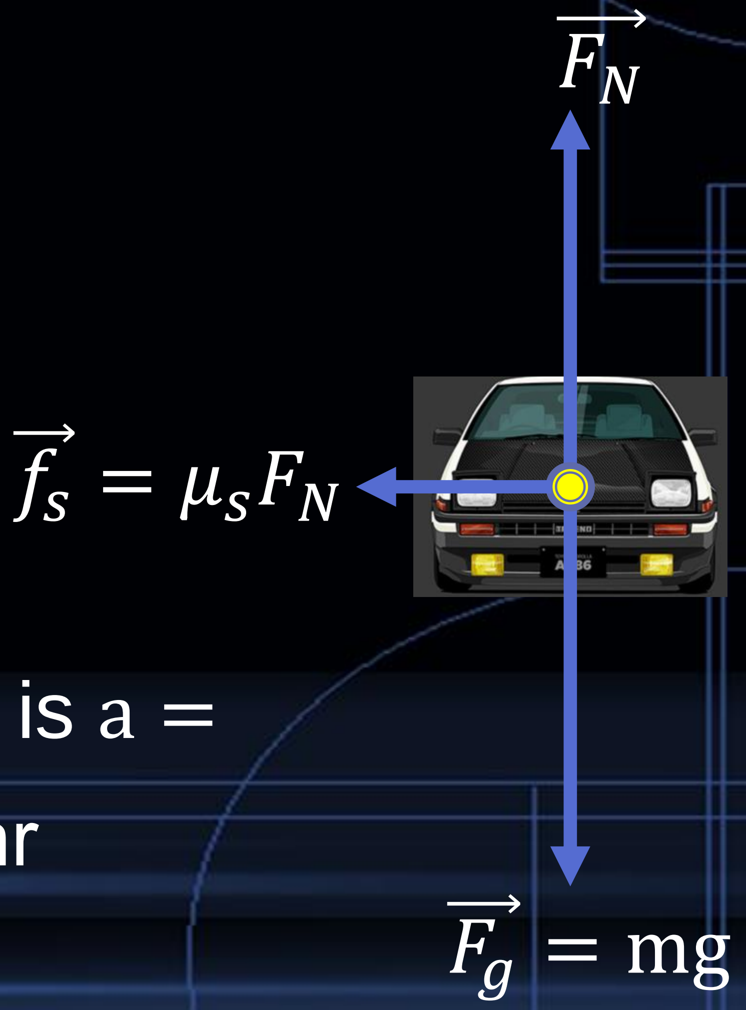
Example: car on a flat curve

- Assuming a car with mass m=1000kg turn on a flat curve. The curve can be approximate as a part of a circle with radius R=50m. The static frictional coefficient $\mu_s = 0.75$. What is the maximum speed of this car can make the turn?



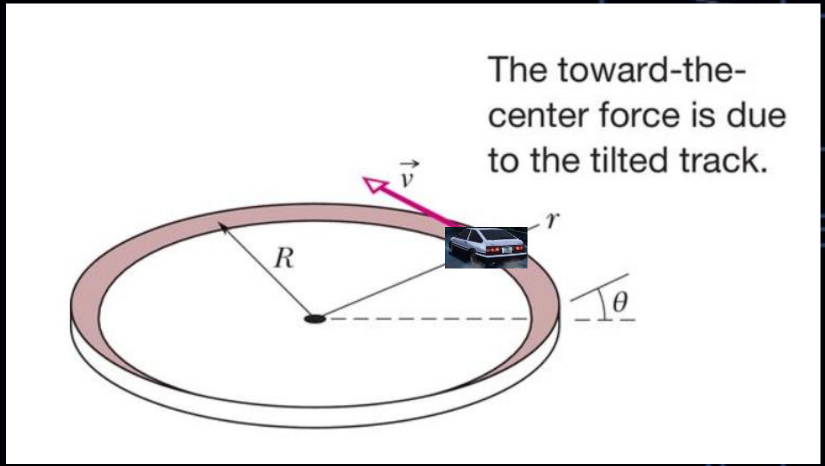
Example: car on a flat curve

- Start with free body diagram right at the maximum speed. The centripetal acceleration is provided by maximum static frictional force.
- In vertical direction normal force is equal to gravitational force: $F_N = mg$
- The maximum centripetal acceleration is $a = \frac{\mu_s F_N}{m} = \frac{{v_{max}}^2}{R} \rightarrow v_{max}$= 19.2m/s=69km/hr



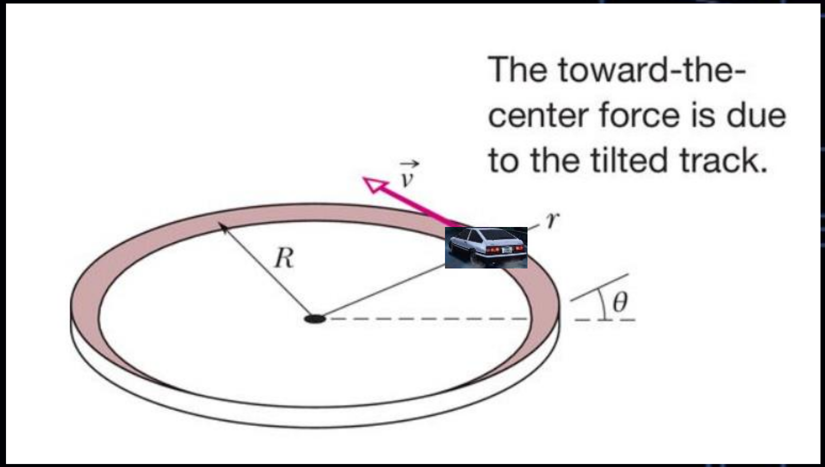
Example 3: car on a frictionless tilted curve

- Assuming a car with mass m=1000kg turn on a frictionless tilted curve. The tilted angle is $\theta = 10^{\circ}$curve can be approximate as a part of a circle with radius R=50m. What is the maximum speed of this car can make the turn?



Example 3: car on a frictionless tilted curve

- Assuming a car with mass m=1000kg turn on a frictionless tilted curve. The tilted angle is $\theta = 10^{\circ}$curve can be approximate as a part of a circle with radius R=50m. What is the maximum speed of this car can make the turn?
- Prediction:



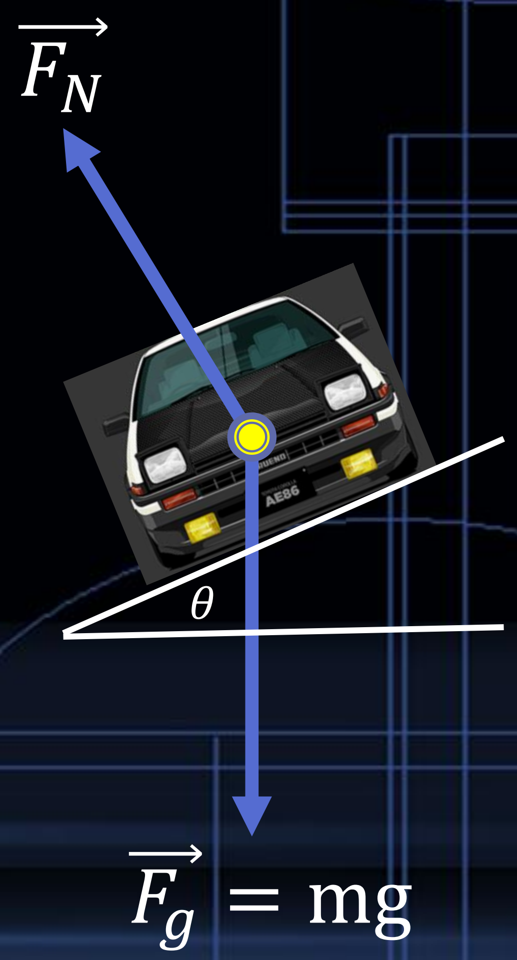
A. Faster than 69km/hr
B. Slower than 69km/hr

Example 2: car on a frictionless tilted curve

- The centripetal acceleration is provided by the horizontal components of normal force. The vertical component of normal force cancels out the gravitational force:

$$F_N \cos\theta = mg$$

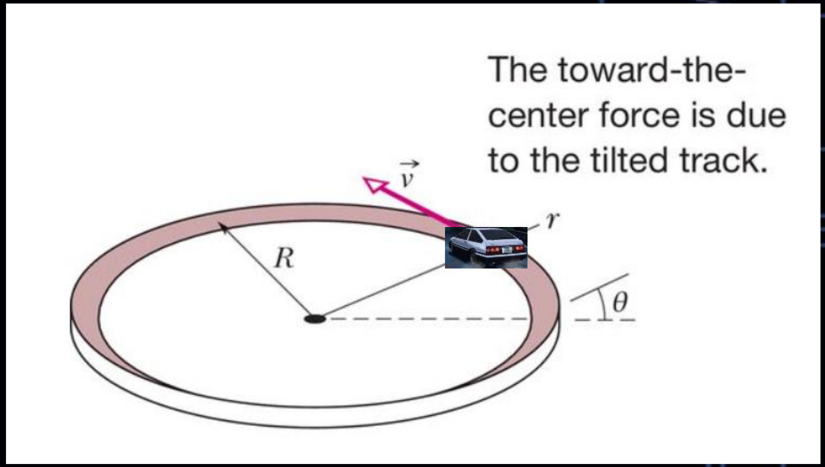
$$F_N sin\theta = \frac{m{v_{max}}^2}{R}$$



- Thus $v_{max} = \sqrt{gRtan\theta} = 33.5km/hr$

Example 3: car on a tilted curve with friction

- Assuming a car with mass m=1000kg turn on a tilted curve. The tilted angle is $\theta = 10^{\circ}$curve can be approximate as a part of a circle with radius R=50m. The static frictional coefficient $\mu_s = 0.75$. What is the maximum speed of this car can make the turn?



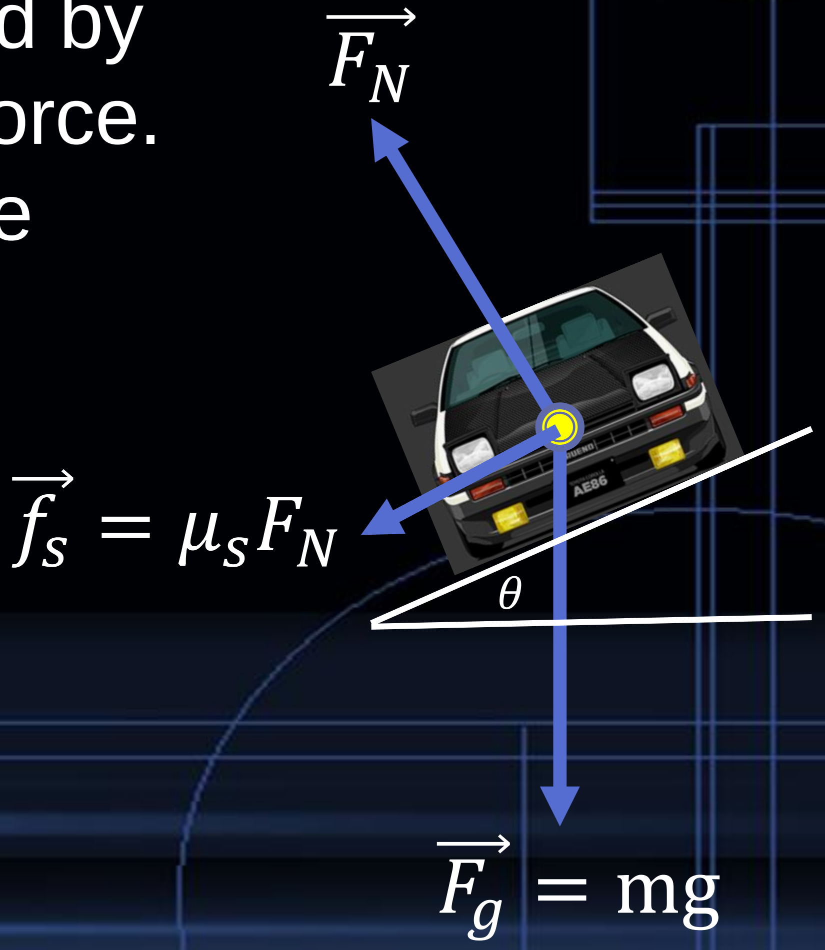
Example 3: car on a frictionless tilted curve

- The centripetal acceleration is provided by the horizontal components of normal force. The vertical component of normal force cancels out the gravitational force:

$$F_N \cos\theta = mg + \mu_s F_N sin\theta$$

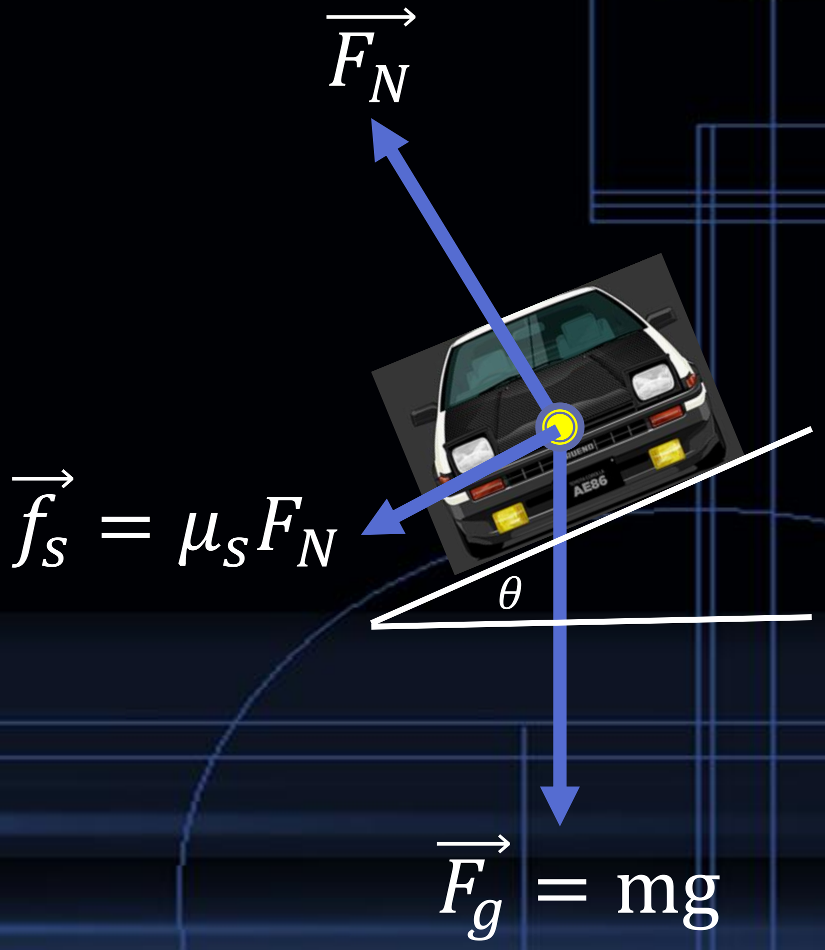
$$F_N sin\theta + \mu_s F_N \cos\theta = \frac{m{v_{max}}^2}{R}$$

Thus $v_{max} = 82.3km/hr$



Think about it…

- Can we let the car go faster?

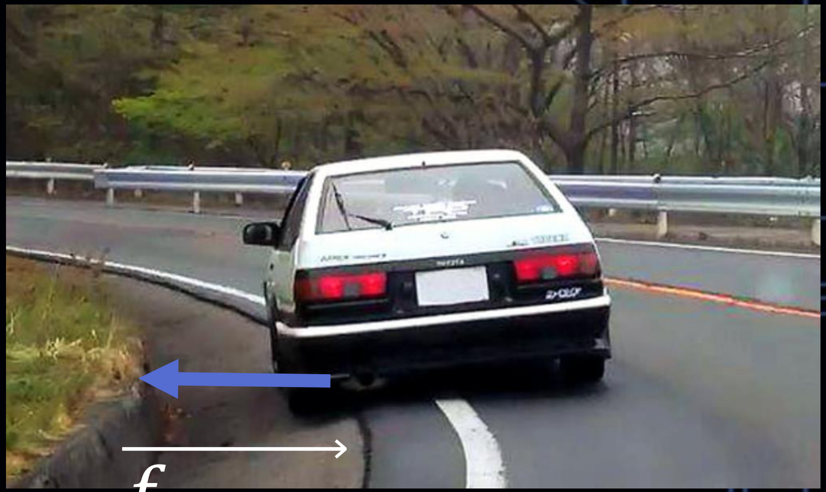


Example 4: car on a curve with extra force

https://www.youtube.com/watch?v=079P6GAaJGQ

Example 4: car on a curve with extra force

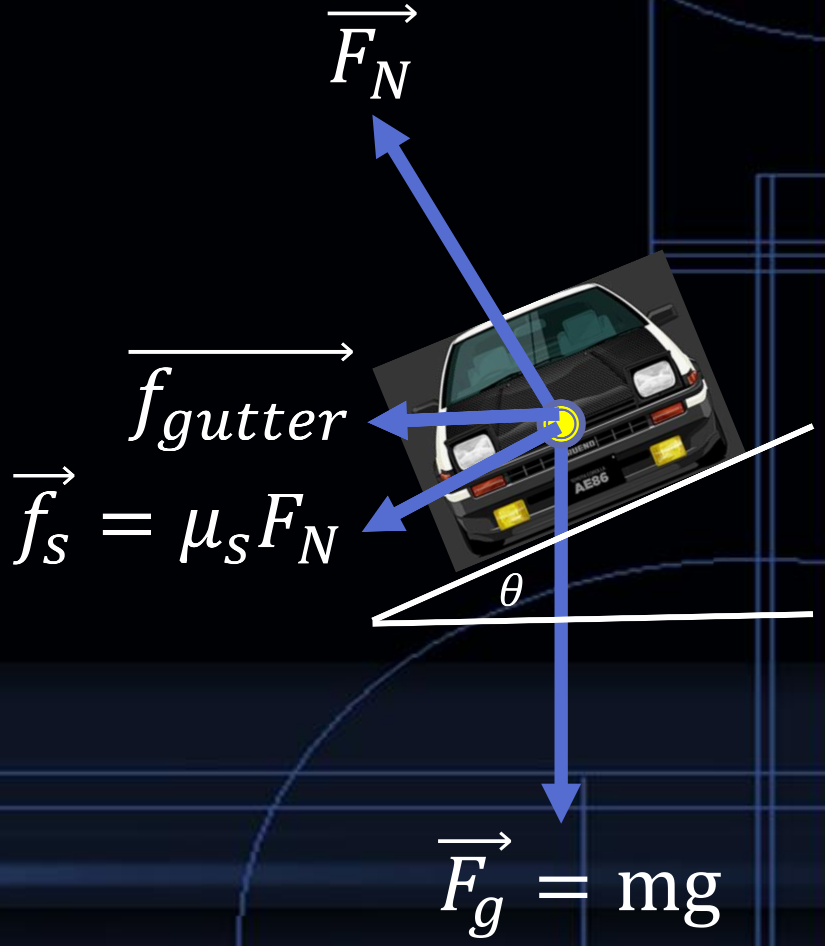
- Assuming the side wall of gutter give an extra centripetal force $f_{gutter} = 1000N$ that pointed to the center of the curve. What is the maximum speed of this car can make the turn?



$\overrightarrow{f_{gutter}}$

Example 4: car on a curve with extra force

- Assuming the side wall of gutter give an extra centripetal force $f_{gutter} = 1000N$ that pointed to the center of the curve. What is the maximum speed of this car can make the turn?



$$F_N \cos\theta = mg + \mu_s F_N sin\theta$$

$$F_N sin\theta + \mu_s F_N \cos\theta + f_{gutter} = \frac{m{v_{max}}^2}{R}$$

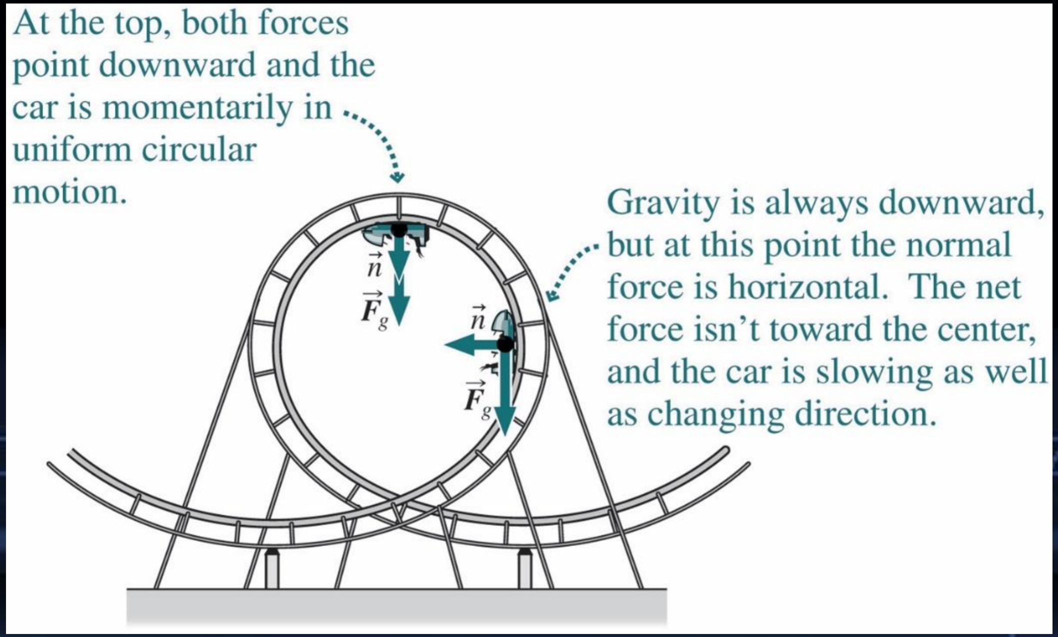
Thus $v_{max} = 86.1km/hr$

Typical result of doing gutter run in real life…

https://www.reddit.com/r/initiald/comments/7jvivj/would_the_load_shift_technique_be_possible_in/

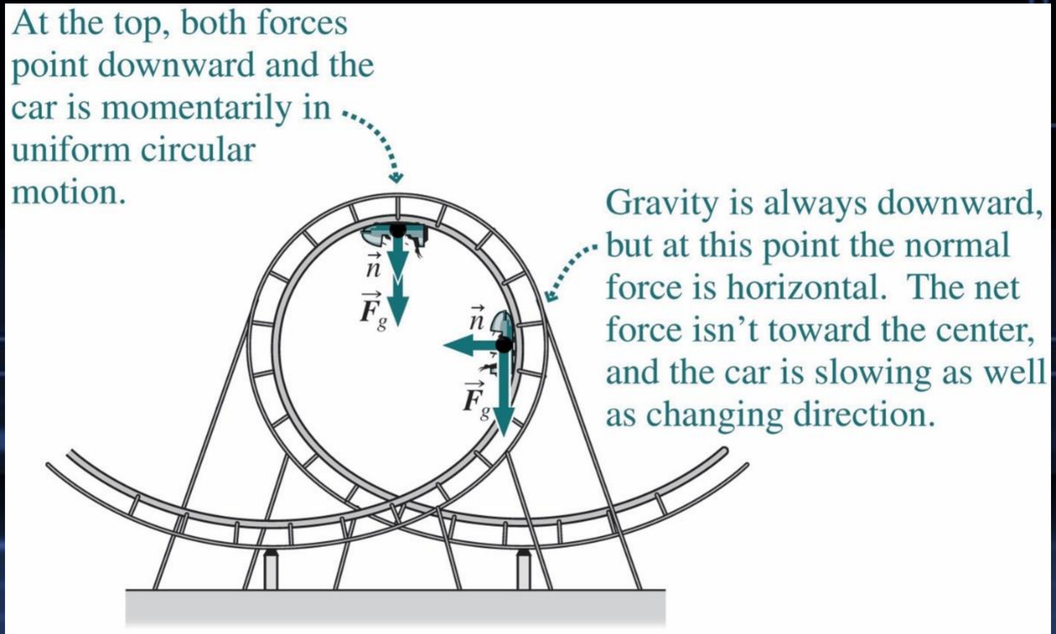
Example: Looping the Loop

- A roller-coaster car is traveling around a circular loop of radius *r*. What **minimum speed** does the car need at the top of the loop so that stays on the track?

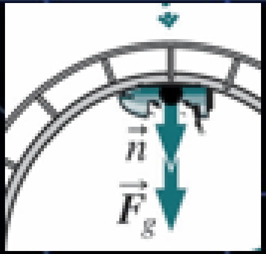


Example: Looping the Loop

- The car experiences the force of gravity and a normal force from the track.
- Gravity is always downward and the normal force is always perpendicular to the track. We assume that the normal force pushes the car away from the track and cannot pull the car toward the track.



Example: Looping the Loop



- At the top of the loop, both forces are downward. Newton's second law gives: $\vec{n} + \vec{F}_g = m\vec{a}$
- In component form (choosing the positive direction downward), we have: $n_y = n,\ F_{gy} = mg \quad \Rightarrow \quad n + mg = \frac{mv^2}{r}$
- Solving for *v*, we obtain: $v = \sqrt{(nr/m) + gr}$
- As the car slows and begins to leave the track, the normal force approaches zero. Therefore, the minimum speed is: $v = \sqrt{gr}$

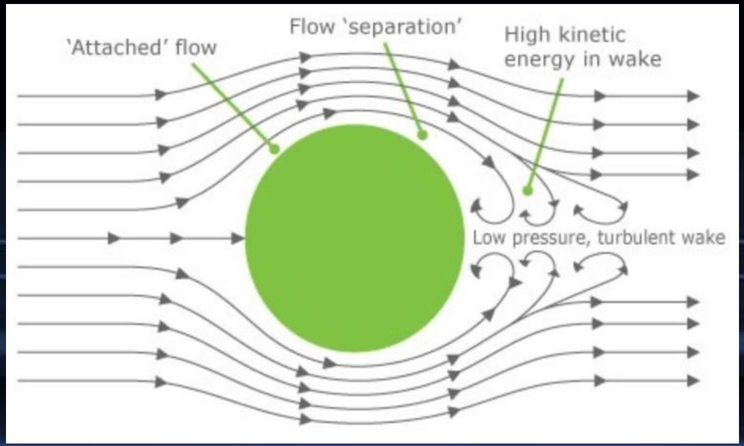
Drag Force

- Previously, we neglect effect of air for most of the motion. Now, let’s consider it.
- When there is a relative velocity between a fluid and a body experiences a drag force $\vec{D}$ that opposes the relative motion and points in the direction in which the fluid flows relative to the body.

Drag Force

where : $\vec{D} = \frac{1}{2} C \rho A v^2$

- v: relative speed between object and fluid.
- A: effective cross-sectional area.
- ρ: the air density (mass per volume).
- C: experimentally determined drag coefficient.



https://www.sciencelearn.org.nz/resources/1346-causes-of-aerodynamic-drag

Free Falling with Drag Force

- A constant velocity (terminal velocity) can be reached when gravitational force is balanced with drag force:

$$\vec{D} - \vec{F_g} = 0 \rightarrow \frac{1}{2} C\rho A v^2 - mg = 0$$

$$v_t = \sqrt{\frac{2mg}{C\rho A}}$$

Motion of a mass on a spring

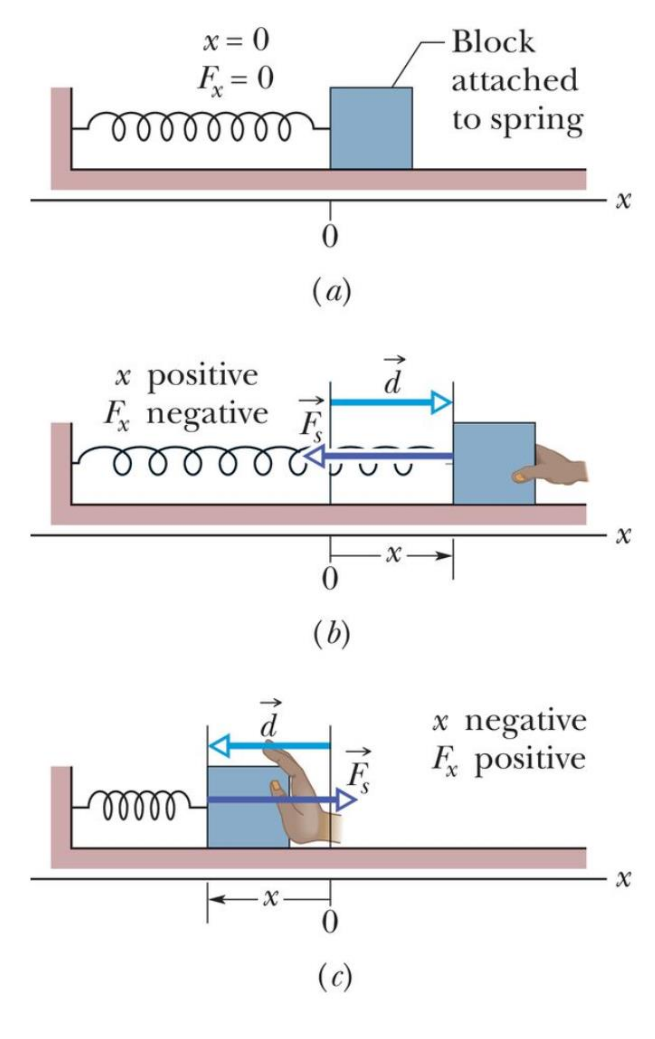
- The spring force is given by $\vec{F_s} = -k\vec{d}$
- The equation of motion is:

$$m\frac{d^2x}{dt^2} = -kx$$

- The function form that can satisfy this differential equation is

$$x(t) = Asin(\omega t + \varphi) + Bcos(\omega t + \varphi)$$

Assuming $x(t) = x_0$ is the end point.



Motion of a mass on a spring

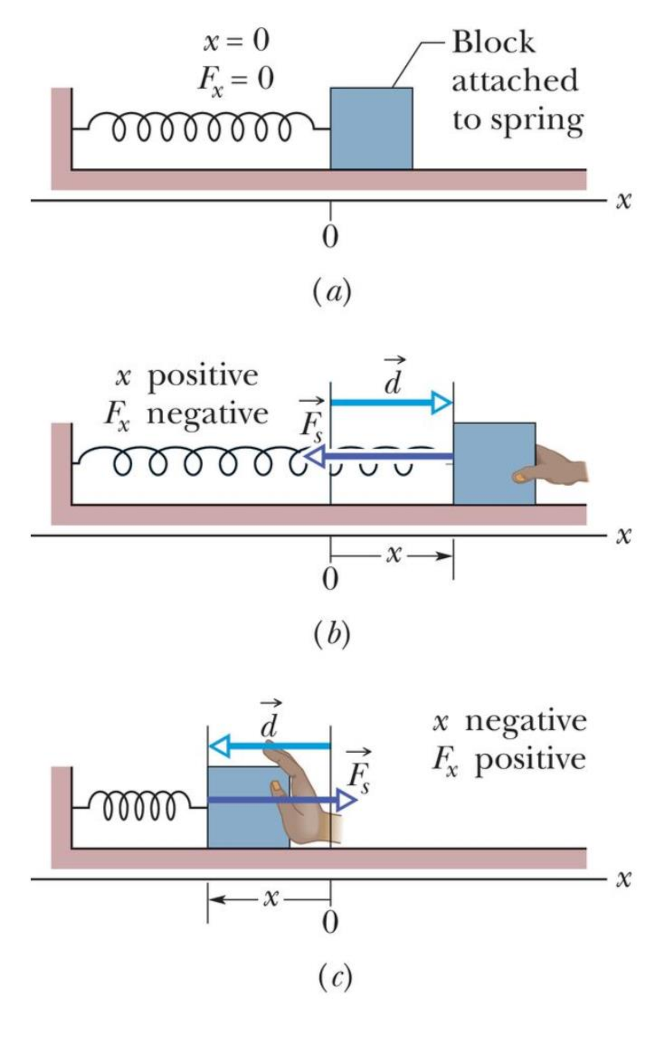
Assuming a hand pull the mass to $x(t=0)=x_0$ and the hand release the mass. By plug in the solution and compare results.

One can get $x(t)=x_0 cos(\omega t)$

where $\omega=\sqrt{\frac{k}{m}}$

And period $T=\frac{2\pi}{\omega}=2\pi\sqrt{\frac{m}{k}}$

(We will talk about it on Chapter 13)



Summary

- Newton's laws are a universal description of motion, in which uniform motion occurs in the absence of a net force.
- All Newton's law problems are handled using the same steps:
  - Identify all the forces acting on the object or objects of interest.
  - Draw one or more free-body diagrams.
  - Write Newton's law in vector form for each object:
    - Equate the net force to the mass times the acceleration.
  - Establish a coordinate system.
  - Write Newton's law in component form.
  - Solve for the quantities of interest.