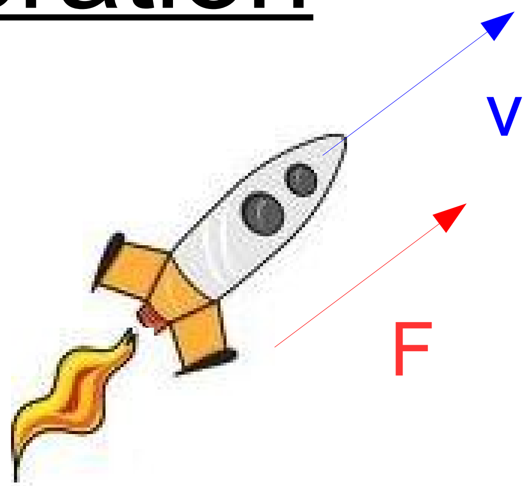
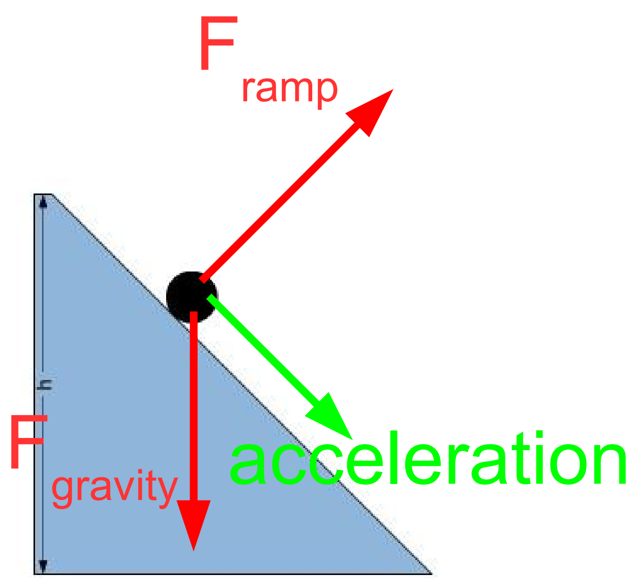
NEWTON'S SECOND LAW

Net Force and Acceleration

- According to Newton:
  - A constant velocity is the “natural state” of motion
  - To <u>accelerate</u> a physical system requires a <u>force</u>
  - The amount of force required to accelerate a system depends on the <u>mass</u> of the system

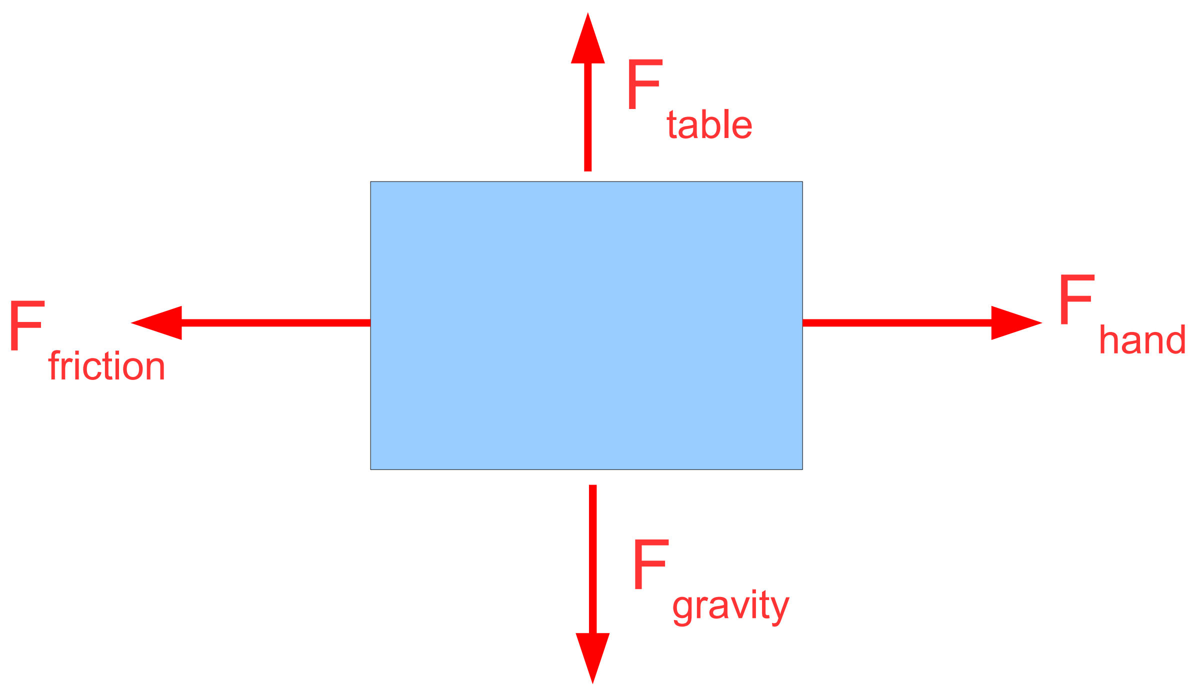


- <u>The catch</u>: A system can have more than one force acting on it
  - But it can only have <u>one</u> acceleration!
  - We must somehow combine all the forces into one
  - This total force is called the “net force”



Free Body Diagrams

- Standard procedure for finding F_{net}
  - Draw the physical system
  - Draw all the forces acting on the system
  - Calculate the net force



IF

$F_{hand} = 30\ N$

$F_{friction} = 20\ N$

THEN

$F_{net} = 10\ N$

(to the right)

Newton's Second Law

- F_{net} causes acceleration according to the following equation:

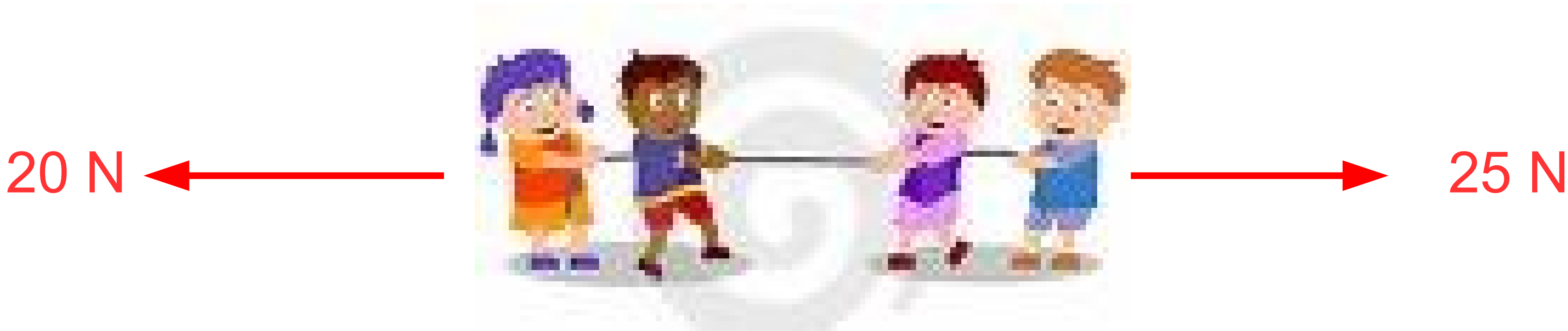
$$a = \frac{F_{net}}{m} \quad \text{OR} \quad F_{net} = m\,a$$

- Notice the units:

$$1\,N = (1\,kg)(1\,\frac{m}{sec^2})$$

We now have a definition for a Newton in terms of mass, length, and time!

Newton's Second Law – Example



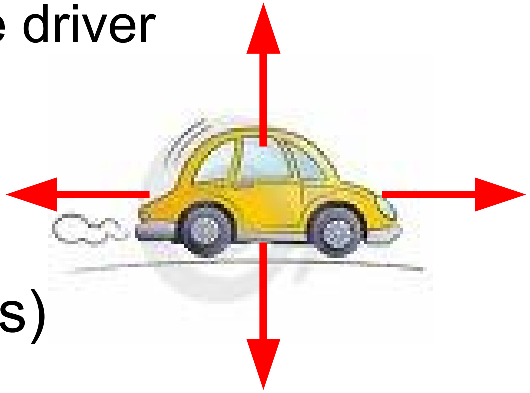
- Tug-of-war (total mass of kids = 100 kg)

- Net Force = 25 N – 20 N = 5 N (to the right)

$$a = \frac{F_{net}}{m} \quad \Rightarrow \quad a = \frac{5\,N}{100\,kg} = 0.05\ \frac{m}{sec^2}$$

Common Obstacles (Watch Out!)

- F_{net} is a sum of all the forces acting on a system
  - It is not a force by itself!
  - You should not draw F_{net} on your free body diagram
- F_{net} only comes from external forces
  - You should not include internal forces in your diagram
  - Example: When drawing a free body diagram for your car, don't draw the force between the seat and the driver
- Objects moving at constant velocity
  - F_{net} must be zero! (Even though object moves)



Mass and Weight

- There is a difference!

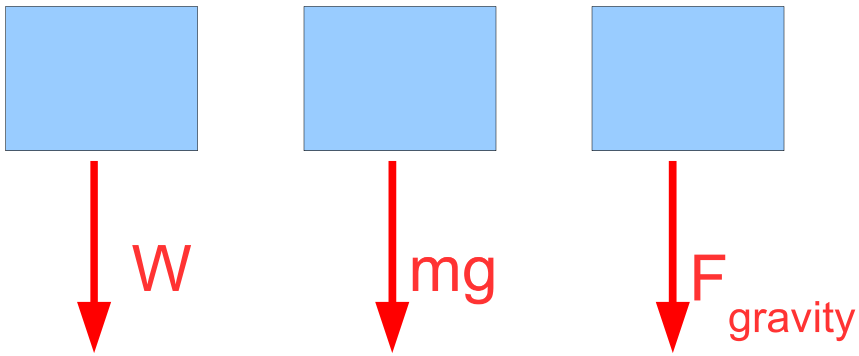
- Mass describes how much matter is in a system
  - Measured in kilograms (NOT pounds!)
  - A physical system's mass is always the same no matter where or when it is measured
- Weight is the force that gravity exerts
  - Measured in Newtons (or pounds)
  - The weight of a system depends on the strength of gravity – your weight is different on the moon

The Force of Weight

- From "free fall" experiments, we know:
  - Gravity accelerates objects downward at g = 10 m/sec^2
  - Gravity is the only force acting in free fall
- So, using Newton's Second Law:

$$F_{net} = m\,a \longrightarrow \boxed{Weight = m\,g}$$

- In free body diagrams:

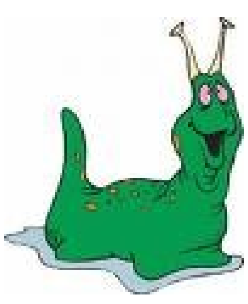


Mass and Weight – Units

- It is common to see kilograms and pounds used interchangeably to describe an object
  - This is not technically correct!
  - Kilograms are a unit of mass
  - Pounds are a unit of weight (like Newtons)

- An object that weighs 100 lb
  - Will also weigh about 450 Newtons
  - Has a mass of about 45 kg

- The English unit of mass is called a “slug”



Mass and Weight – Example

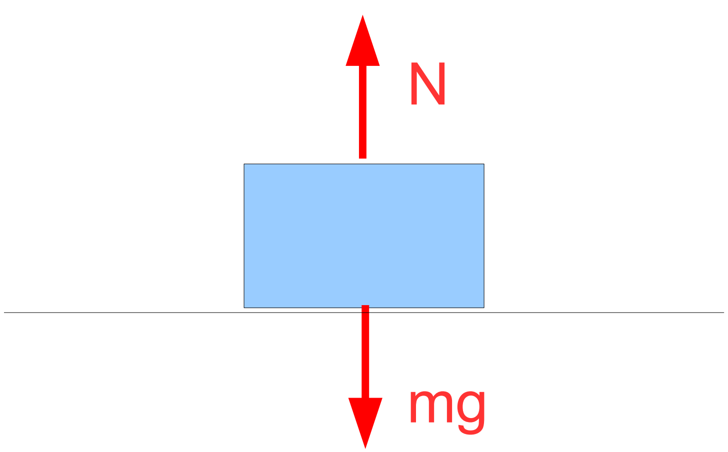
- Two bricks – one made of lead and one made of styrofoam
  - Very different masses
  - Lead brick much harder to lift and shake

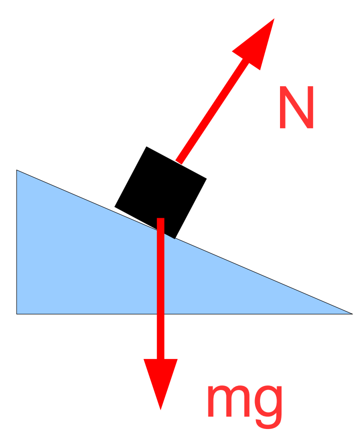
- "Thought experiment" – go to the moon with the bricks
  - Now the lead brick is easier to lift than it was on earth
  - However, it is just as difficult to shake as it was on earth

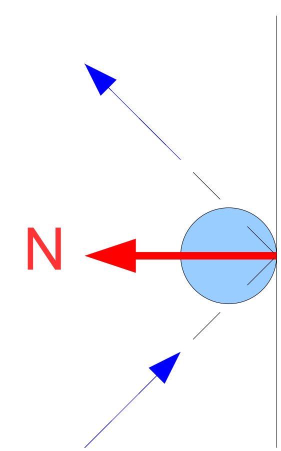
The “Normal” Force

- Objects are usually supported by a surface
  - Floor, table, ground, shelf, etc.
  - Surface must exert a force to balance the weight of the object

- The <u>Normal</u> Force
  - “Normal” means “perpendicular to a surface”
  - This force is created when atoms in a surface are pressed together (they push back on the object)
  - Normal force also exists during collisions

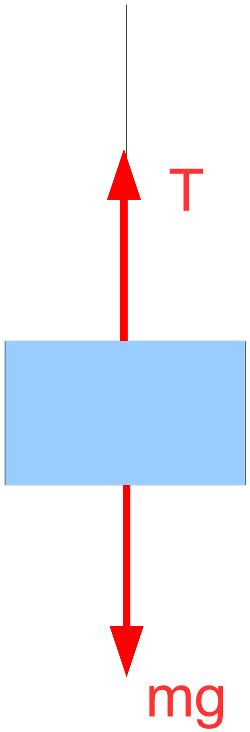






Tension

- Ropes and cables are useful for exerting pulling forces
  - Note that they are incapable of pushing → one-way force!



The molecules in the rope are “stuck together”

When an outside force pulls them apart → they pull back...

...until the rope breaks!

This force is called tension in the rope

Note: Could not support the brick's weight from below with a rope → ropes can't exert normal forces

Simple "Machines"

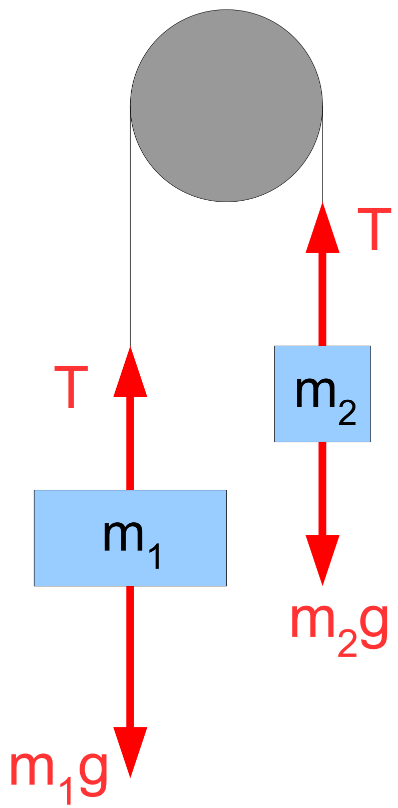
Pulley

Used to change the direction of a force

1) draw free-body diagram(s)

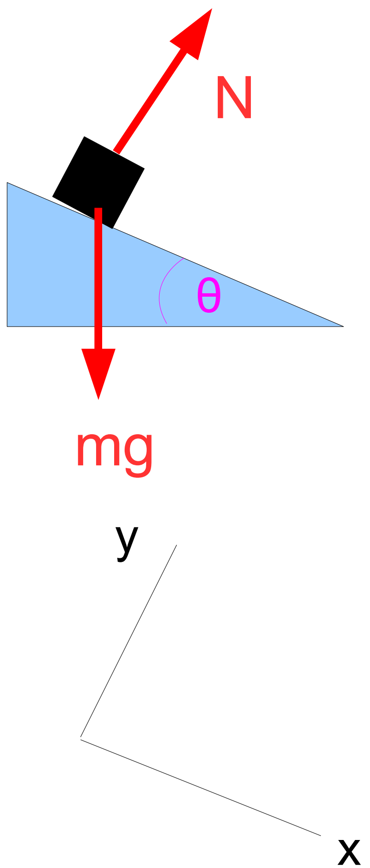
2) apply Newton's 2^{nd} Law

3) calculate acceleration of system



Inclined Plane

Used to control acceleration



1) Set up "tilted" coordinate system

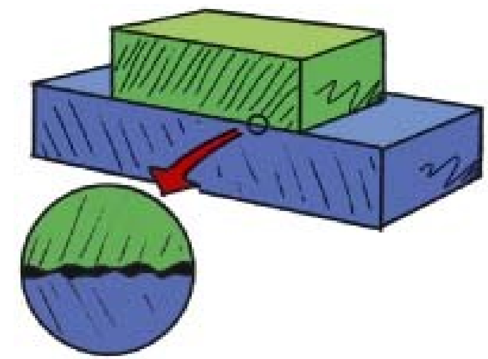
2) calculate components of forces

3) apply Newton's 2^{nd} Law

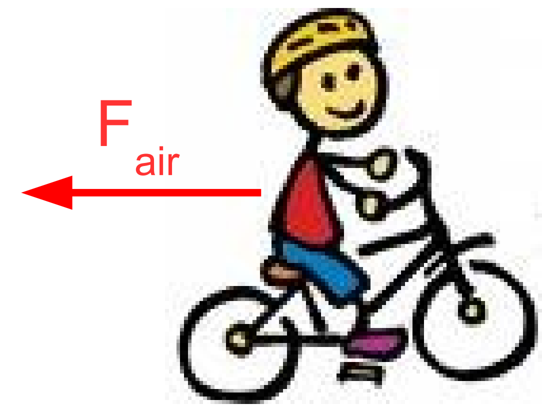
4) calculate acceleration of block

Friction and Air Resistance

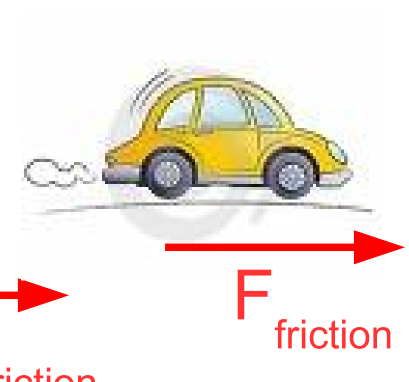
- Friction and air resistance are forces
  - Just like gravity or a push with your hand
  - These forces come from atoms rubbing against each other at the microscopic level

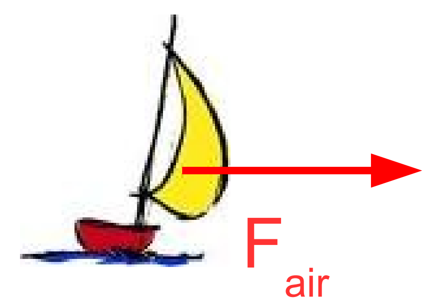


- Often these forces oppose motion
  - Example: Air resistance on a bike ride



- Sometimes these forces create motion
  - Examples:
  - Walking
  - Driving a car
  - Sailboat

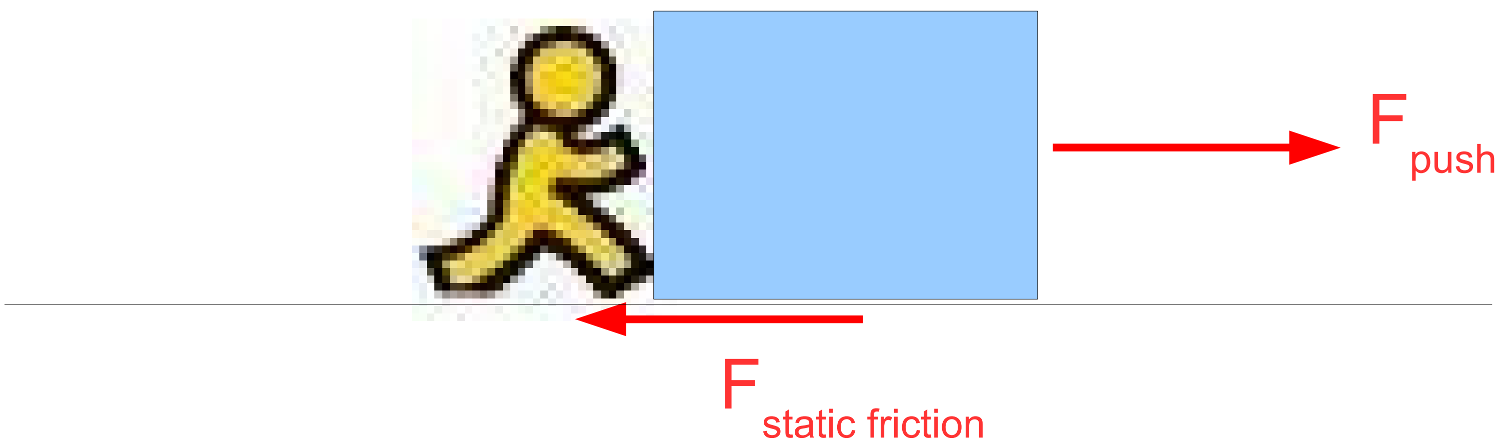




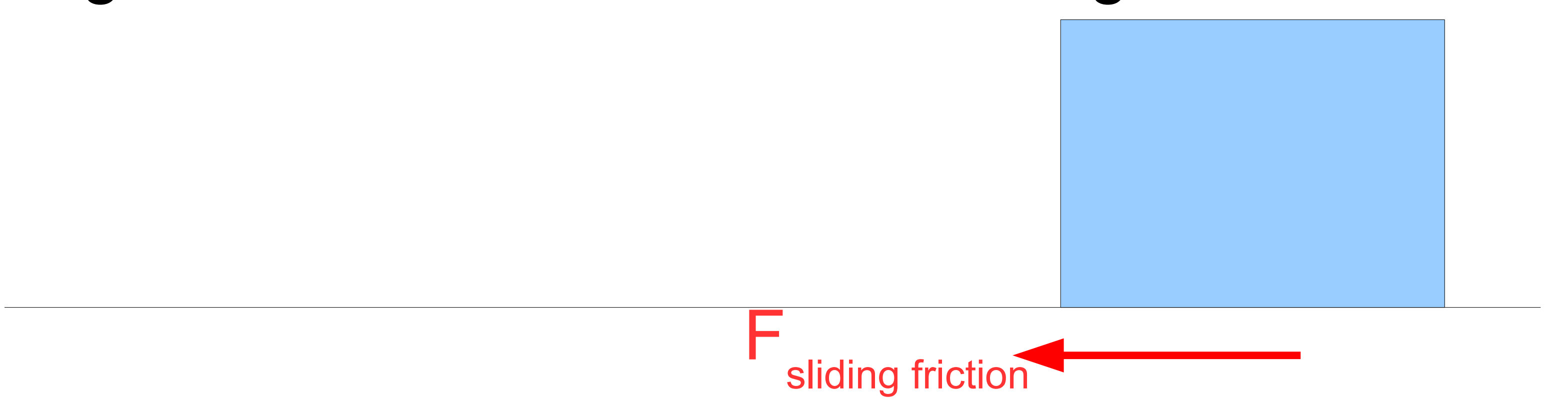
Friction – A Closer Look

- There are two basic types of friction:

- Static friction – holds objects still

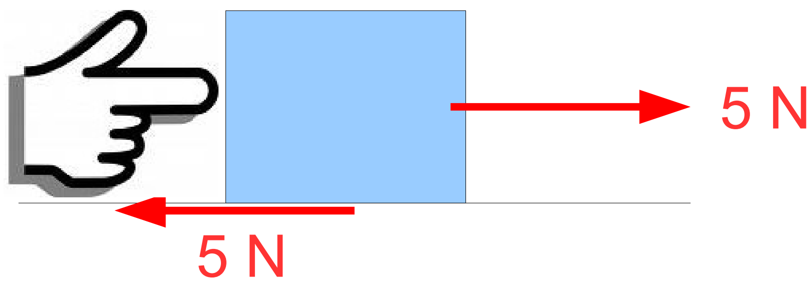


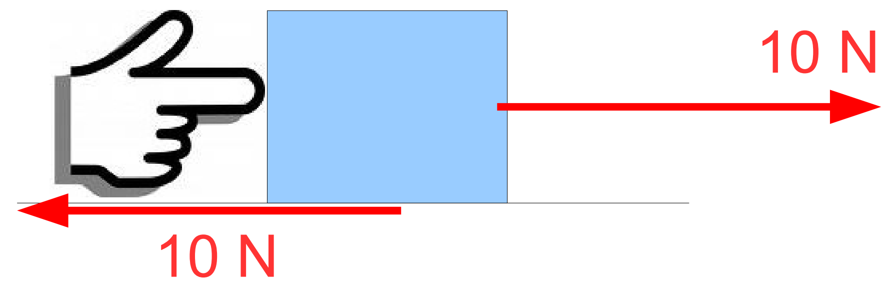
- Sliding friction – when surfaces slide against one another



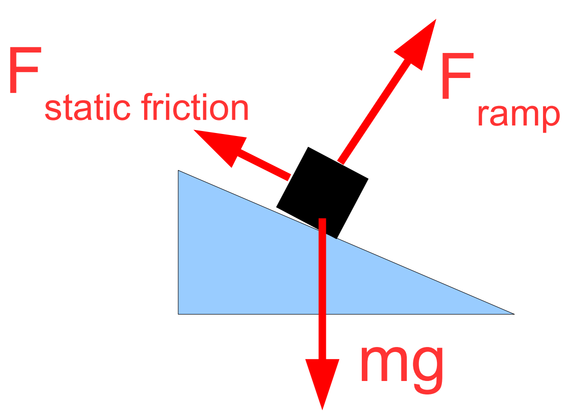
Static Friction

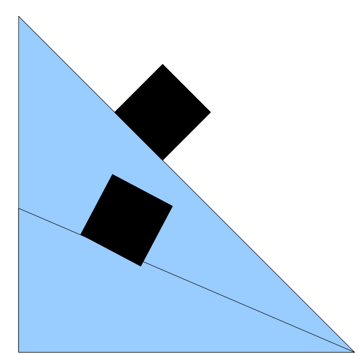
- Exerts a force exactly strong enough to balance out other forces and keep an object from moving





- Static friction has a limit – it can only balance so much force before giving in and allowing the object to slide



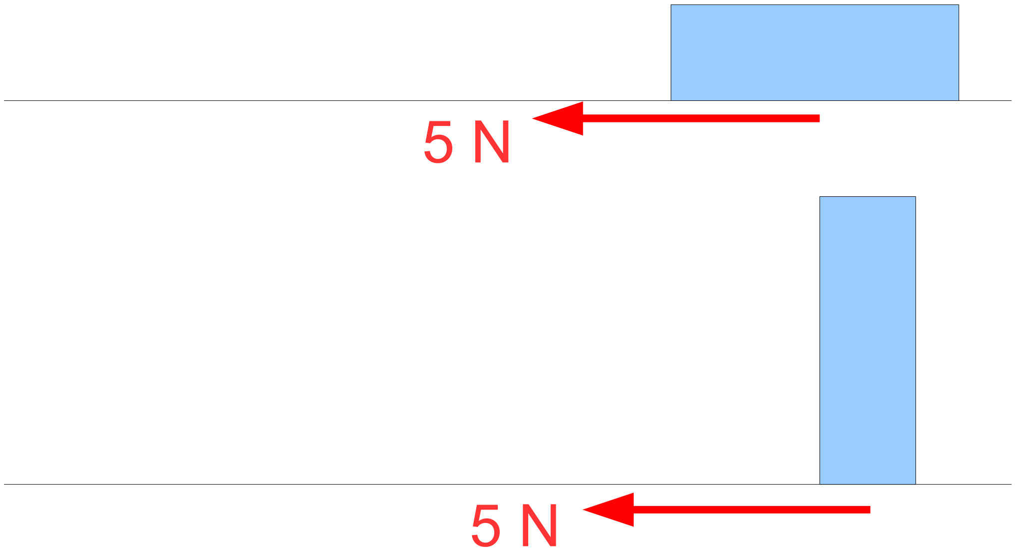


<u>Sliding Friction</u>

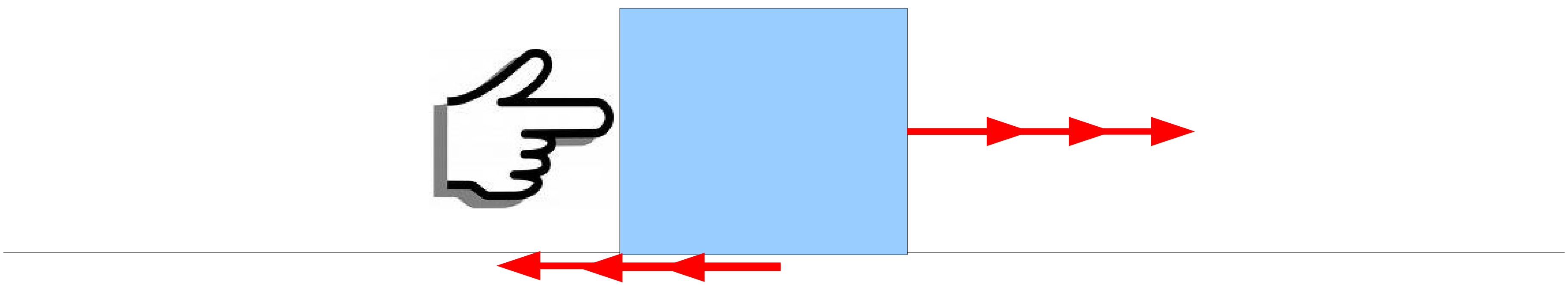
- Also called <u>kinetic</u> friction
  - "Kinetic" means "in motion"

- Strength of friction force depends on size of "normal force"

- Amazingly, the force of sliding friction does <u>NOT</u> depend on:
  - Sliding speed
  - Area of contact



Which is Stronger – Static Friction or Sliding Friction?



- Imagine slowly increasing F_{push} until block starts to slide
  - This tells us the limit of static friction

- If $F_{sliding} > F_{static}$
  - Block would stop immediately
  - Can't be true!

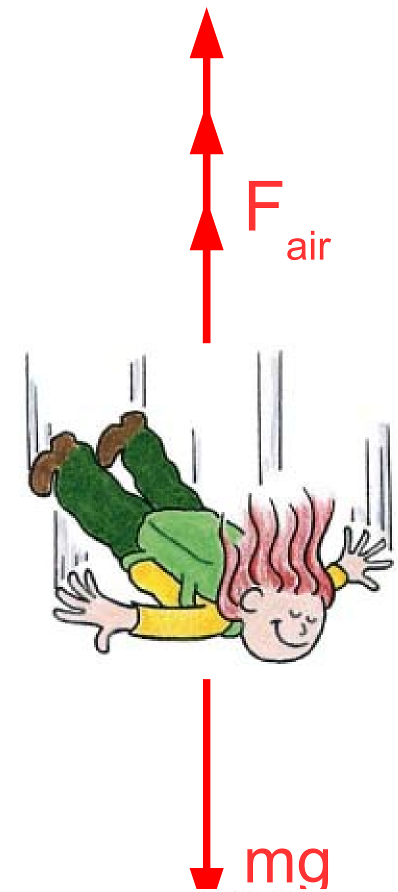
- If $F_{static} > F_{sliding}$
  - Block accelerates
  - Must be true!

Air Resistance – A Closer Look

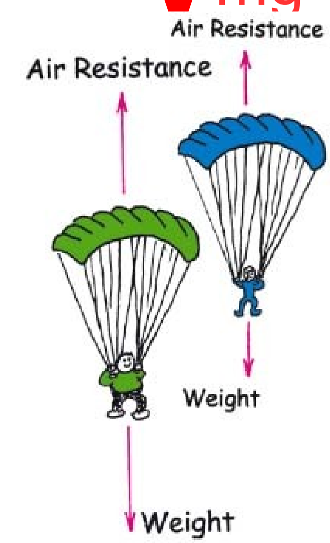
- When moving through air, an object must “push” air molecules out of the way
  - The air molecules push back – this is air resistance!
- How big is the force of air resistance?
  - How many air molecules does an object push?
- Speed
  - Faster objects push more molecules – more air resistance
- Width of object
  - Wide objects must push more air molecules out of the way
  - This is why rockets are designed to be thin

Terminal Velocity

- Start with a constant force (like gravity) accelerating an object through the air
  - As the object gets faster, the force of air resistance gets greater



- Eventually the air resistance force is big enough to balance the weight
  - When this happens, the net force is zero
  - So the acceleration will be zero!
  - The object will move at a constant speed called its "terminal velocity"
  - The terminal velocity can be adjusted by adjusting the width and/or mass of the object



Summary

- Newton's Second Law: $F_{net} = ma$

- Forces cause acceleration
  - Mass resists acceleration

- Weight = mg

- Friction and air resistance are forces!
  - Can resist acceleration of objects or cause it