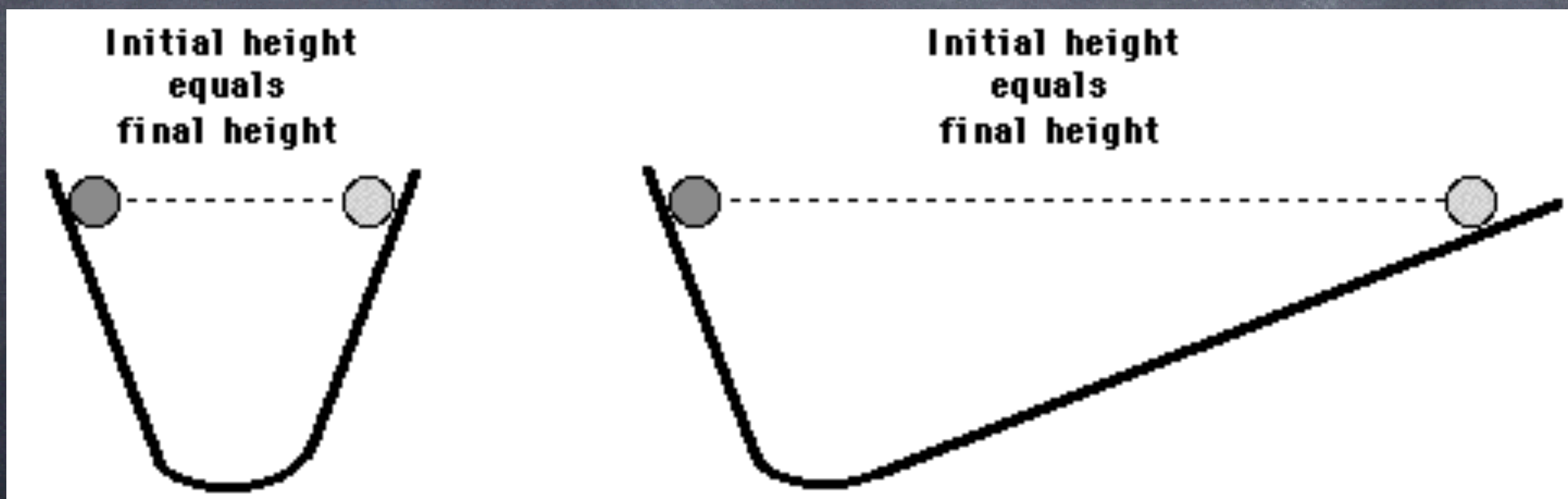
Unit 3: Dynamics

"Why do objects change their motion?"

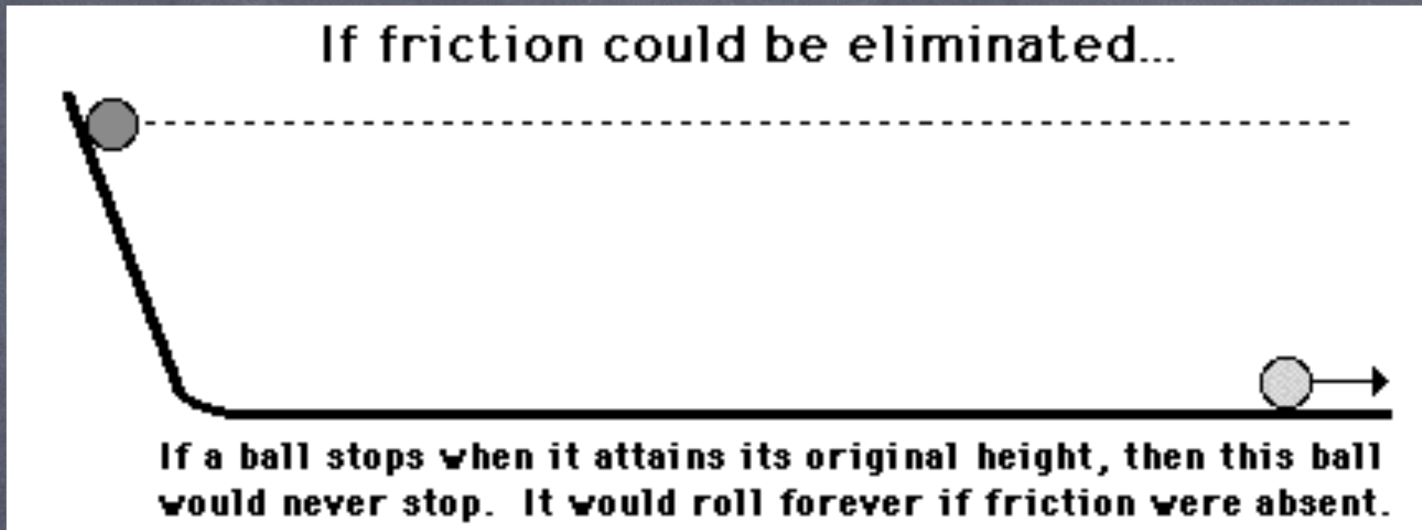
A Brief History of Dynamics

- Aristotle (500 BC): moving objects come to rest because that is their preferred state
  - a force is needed to keep an object moving

- Galileo Galilei (1600 AD): ball rolling experiment



A Brief History of Dynamics



- Sir Isaac Newton (1687 AD): expanded on Galileo's work with his Three Laws of Motion

Newton's
1st Law of Motion

- "Objects in motion tend to stay in motion (at constant velocity) and objects at rest tend to stay at rest, unless acted upon by a net outside force."
  - Objects resist a change in velocity (acceleration).
  - The tendency of an object to resist acceleration is called INERTIA.

Inertia demos:

block and pipe
tablecloth and glass
hammer and block
Seatbelts

Newton's 1st Law of Motion

- How do we measure inertia?
  - Imagine you kicked a boulder and a pebble equally as hard...which resisted a change in motion more?
  - Inertia = Mass
  - More mass -> Greater resistance to change

Newton's 1st Law of Motion

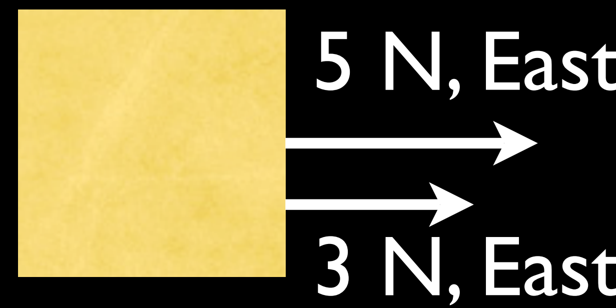
- "Objects in motion tend to stay in motion (at constant velocity) and objects at rest tend to stay at rest, **unless acted upon by a net outside force**."
  - What is a force?
    - A force is a push or a pull that one object exerts on another.
    - A Force is a vector quantity.

Newton's 1st Law of Motion

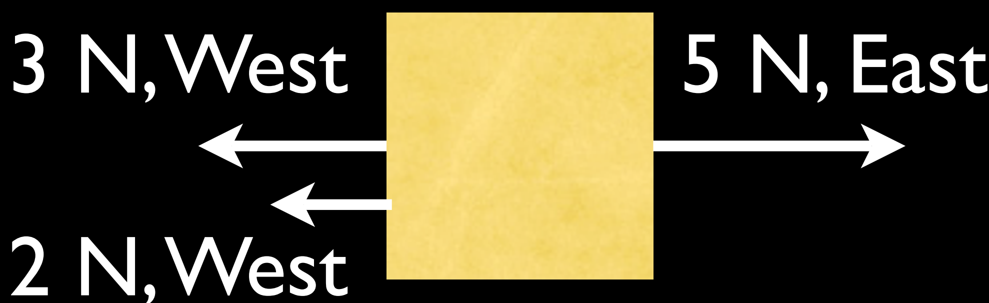
- "Objects in motion tend to stay in motion (at constant velocity) and objects at rest tend to stay at rest, **unless acted upon by a net outside force**."
  - net = vector sum ($\sum$ -> "sigma" = sum of...)
  - When the net force equals zero, the object is in EQUILIBRIUM (acceleration = zero)
  - An object that is accelerating is NOT in equilibrium

Calculating Net Force

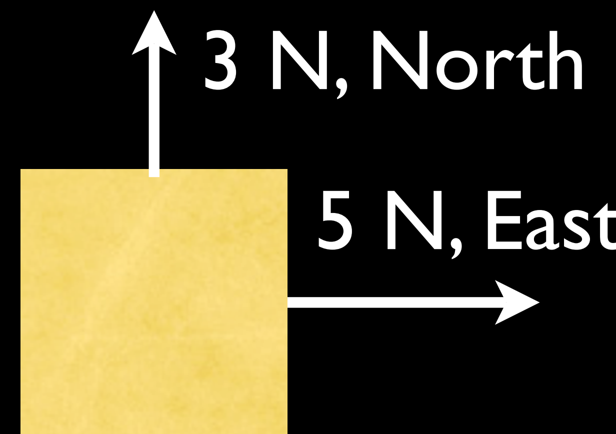
$\sum F =$ 2 N, East



$\sum F =$ 8 N, East



$\sum F =$ 0 N



$\sum F =$ 5.83 N,
31.0° N of E

Newton's Second Law of Motion

- 1st Law: "If $\sum F = 0$, then $a = 0$"
- Antithesis -> "If $\sum F \neq 0$, then $a \neq 0$"

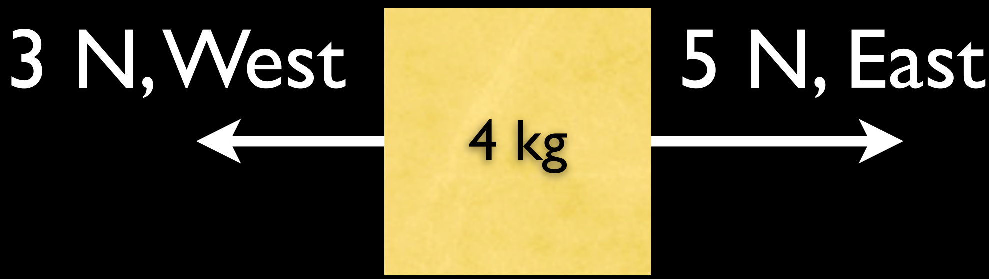
Newton's Second Law $\vec{a} = \frac{\sum \vec{F}}{m}$ or $\sum \vec{F} = m\vec{a}$

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

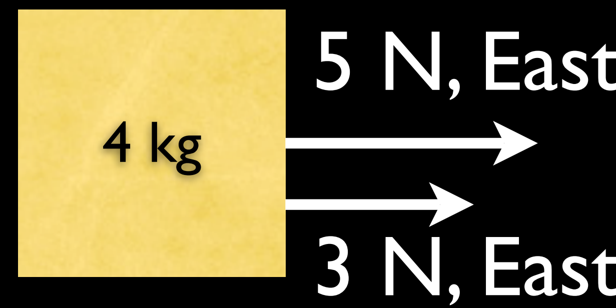
Newton's Second Law of Motion

- A 5-kg box has a net force of 25 N exerted on it. What is the box's acceleration?
- A 4-kg book experiences an acceleration of 3 m/s^2. What is the net force acting on it?
- A 4750-N net force causes a car to accelerate at 5 m/s^2. What is the mass of the car?

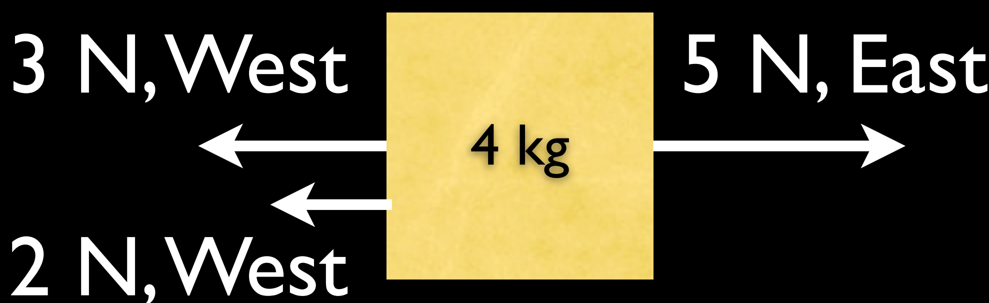
Calculating Acceleration from Net Force



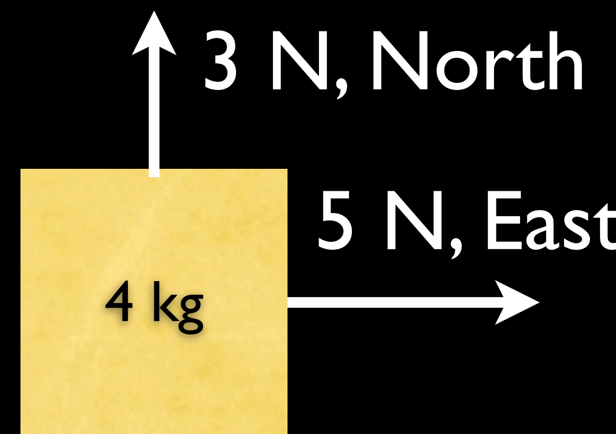
$a = 0.5\ m/s^2$, East



$a = 2\ m/s^2$, East



$a = 0\ m/s^2$ (Equilibrium)



$a = 1.46\ m/s^2$, 31.0° N of E

- Do Now:
  "A 10-kg object has a net force of 20 N acting on it to the right."

  - What is the magnitude and direction of the object's acceleration?

  - Is this object speeding up? Slowing down? Explain.

Without information on the object's initial condition, we have no way of knowing if it is speeding up or slowing down.

Newton's Third Law of Motion

- What happens if you punch a wall as hard as you can?
  - The wall "punches" you back just as hard!
- Newton's 3rd Law -> "Action-Reaction"

Newton's Third Law of Motion

- "For every action there is an equal and opposite reaction."
- "When two objects interact, the force exerted on the first object by the second is EQUAL IN MAGNITUDE and OPPOSITE IN DIRECTION to the force exerted on the second object by the first."

$$\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$$

Newton's Third Law of Motion

Momentum Carts

- Forces ALWAYS come in pairs.
- Identify the reaction force to the following forces:
  - A sprinter pushes to the right on the starting blocks.
  - A bird's wing pushes down on the air.
  - The Earth exerts a gravitational force pulling on the Moon.

- An 80-kg man and his 30-kg daughter are standing on a frozen lake facing each. With their hands they push off against one another. The daughter experiences an acceleration of +4.0 m/s^2.
  (a) What net horizontal force is acting on the daughter?
  (b) What is the father's acceleration?

$$\sum F = ma \quad = (30\ \text{kg})(+4.0\ \text{m/s}^2) \quad = +120\ \text{N}$$

$$a = \frac{\sum F}{m} = \frac{-120\ \text{N}}{80\ \text{kg}} = -1.5\ \text{m/s}^2\ \text{(Father)}$$

- What is the "reaction" force to the Earth's gravitational pull on you?
    - YOUR gravitational pull on the Earth!

$$F_{\text{EARTH ON PERSON}} = F_{\text{PERSON ON EARTH}}$$

$$m_{\text{EARTH}} a_{\text{EARTH}} = m_{\text{PERSON}} a_{\text{PERSON}}$$

Types of Forces

- There are only 3 fundamental forces (all forces that exist can be explained in terms of these):
  - Electroweak Force
    - electrical forces, magnetic forces, contact forces, weak nuclear force
  - Strong Nuclear Force
  - Gravitational Force

Force of Gravity

- A 5-kg object is released from rest near Earth's surface and experiences free fall. What is the magnitude of the net force acting on the object?
  - $\sum F = ma = (5\ \text{kg})(9.8\ \text{m/s}^2) = 49.0\ \text{N}$
- This $\sum F$ is due to one force: gravity
- The force of gravity exerted on an object is also called the object's <u>weight</u>

Definition of Weight

$$\vec{W} = m\vec{g}$$

m = mass of object

$g_{EARTH} = 9.8\ \text{m/s}^2$

Mass vs. Weight

- Be careful when using the terms "mass" and "weight"; they are NOT the interchangeable

Mass (m)

Scalar quantity

Measured in kilograms

Measure of how much matter an object is composed of

Same everywhere!

Weight ($\vec{W}$)

Vector quantity

Measured in Newtons

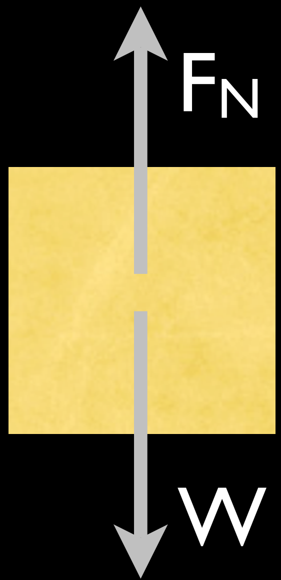
Measure of the force the Earth (or other body) exerts on an object

Depends on where you are (varies with location)!

The Normal Force

- “Normal” = “Perpendicular”
- exerted by any surface (horizontal, vertical, or inclined) in contact with the object
- can vary; depends upon the situation
  - some problems will give you the maximum normal force a surface can exert before breaking...you will then determine if it breaks

- A 35-kg crate rests on a horizontal floor. Determine the magnitude of the normal force the floor exerts on it.



$F_N = 343\ \text{N}$

$W = (35\ \text{kg})(9.8\ \text{m/s}^2) = 343\ \text{N}$

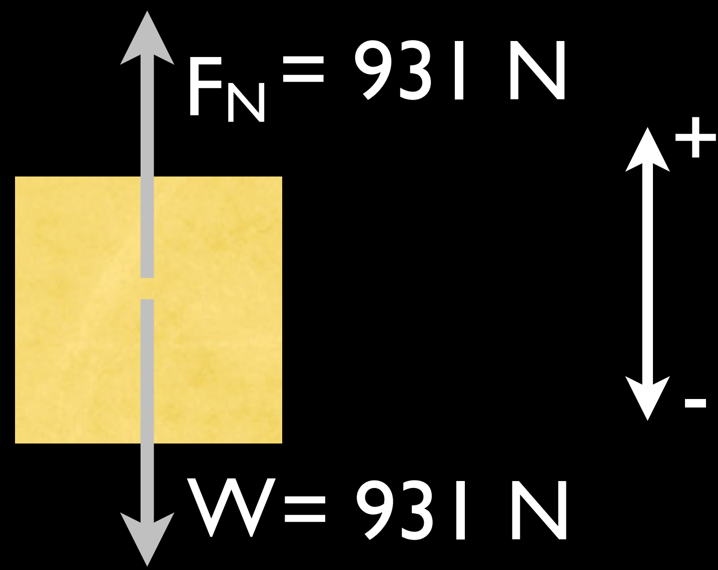
Normal force must balance the force of gravity (weight) if the crate is not accelerating.

- The normal force also tells us an object's "apparent weight", how much it "seems" to weigh due to vertical acceleration.
  - An object in equilibrium will have an apparent weight (F_N) equal to its true weight
  - An object in free fall has a F_N of zero ("feels" weightless)
- The "apparent weight" is what a scale reads

- A 95-kg person stands on a scale in an elevator.
  - (a) What does the scale read (in Newtons) when the elevator is at rest?
  - (b) What does the scale read when the elevator accelerates upward at +1.80 m/s^2?
  - (c) What does the scale read when the elevator travels at a constant velocity?
  - (d) What does the scale read when the elevator accelerates downward at -1.80 m/s^2?

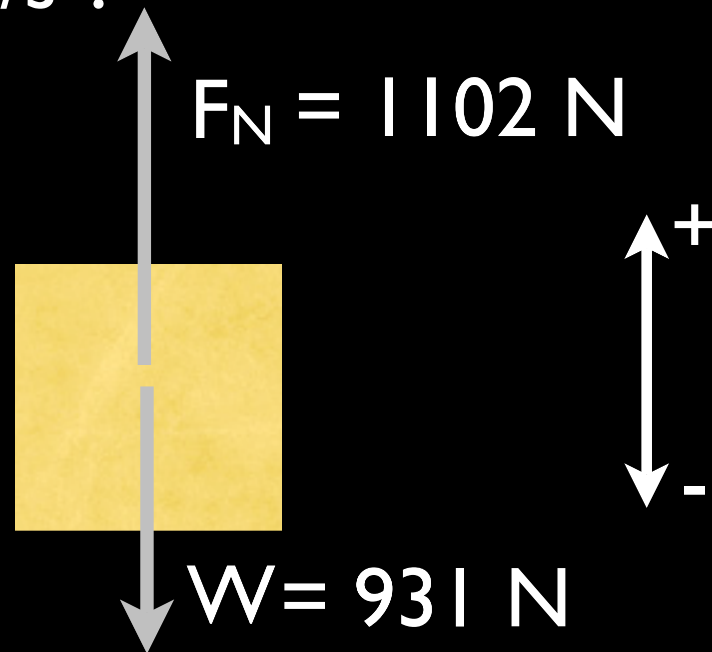
- A 95-kg person stands on a scale in an elevator.
  - (a) What does the scale read (in Newtons) when the elevator is at rest?

$a = 0$,
therefore
$\sum F = 0$



$W = (95\ kg)(9.8\ m/s^2)$
$= 931\ N$

- A 95-kg person stands on a scale in an elevator.
  - (b) What does the scale read when the elevator accelerates upward at +1.80 m/s^2?



$a \neq 0$, so:

$\sum F = ma$

$\sum F = (95\text{ kg})(1.80\text{ m/s}^2)$

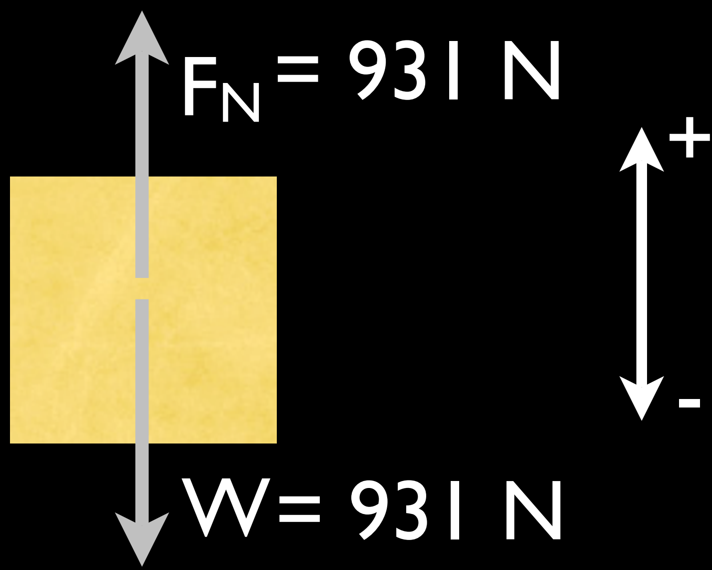
$\sum F = 171\text{ N}$

$171\text{ N} = F_N + W$

$= F_N + (-931\text{ N})$

- A 95-kg person stands on a scale in an elevator.
  - (c) What does the scale read when the elevator travels at a constant velocity?

$a = 0$,
therefore
$\sum F = 0$



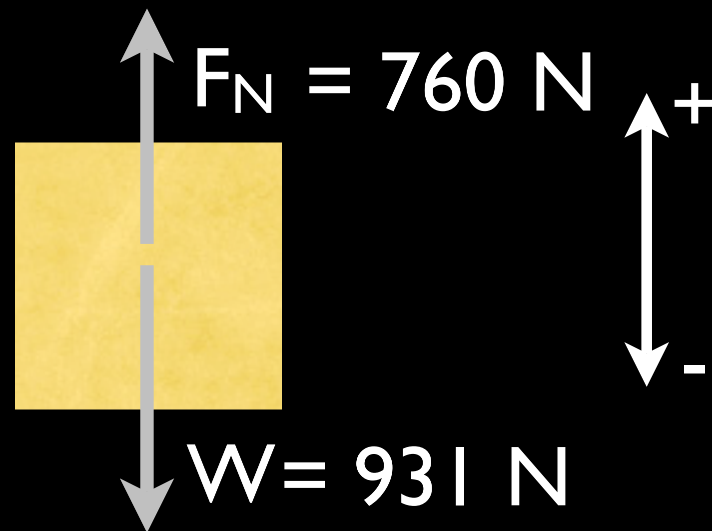
- A 95-kg person stands on a scale in an elevator.
  - (d) What does the scale read when the elevator accelerates downward at -1.80 m/s^2?

$a \neq 0$, so:

$\sum F = ma$

$\sum F = (95\ \text{kg})(-1.80\ \text{m/s}^2)$

$\sum F = -171\ \text{N}$



$-171\ \text{N} = F_N + W$

$= F_N + (-931\ \text{N})$

Force of Friction

- "Friction" is a force exerted by a surface on an object which opposes the relative motion of the object
- **Magnitude** of friction force depends upon:
  - Normal force
  - "Roughness" of both surfaces
- The ratio of F_f to F_N is called the coefficient of friction (μ)
  - μ is the Greek letter mu (pronounced "myoo")
  - Larger μ = "rougher" surfaces (in general)

Static Friction

- Static = stationary (object at rest relative to surface)
- Static friction force varies
  - Resists any attempt to put the object in motion
- Can only become so large (determined by μ)

Definition of Static Friction Force

$$F_f \leq \mu_s F_N$$

μ_s -> Coefficient of Static Friction

Static Friction is at its maximum when $F_{fMAX} = \mu_s F_N$

Kinetic Friction

- Kinetic = motion
- Kinetic friction force is constant regardless of speed (assuming F_N is constant)

Definition of Kinetic Friction Force

$$F_f = \mu_k F_N$$

μ_k -> Coefficient of Kinetic Friction

Comparing μ_s and μ_k

- μ_k will always be smaller than μ_s for a given pair of surfaces
  - It takes more force to get something in motion than to keep it in motion

Table 4.2 Approximate Values of the Coefficients of Friction for Various Surfaces*

Materials	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Glass on glass (dry)	0.94	0.4
Ice on ice (clean, 0 °C)	0.1	0.02
Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Steel on ice	0.1	0.05
Steel on steel (dry hard steel)	0.78	0.42
Teflon on Teflon	0.04	0.04
Wood on wood	0.35	0.3

- A 5-kg wooden box sits at rest on a wooden horizontal floor. What range of values could the static friction force have?
- A 5-kg wooden box slides across a wooden horizontal floor. What is the magnitude of the kinetic friction force?

NOTE: If there is no vertical acceleration, then $F_N = W$.

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Rubber on dry concrete	1.0	0.8
Rubber on wet concrete	0.7	0.5
Steel on ice	0.1	0.05
Steel on steel (dry hard steel)	0.78	0.42
Teflon on Teflon	0.04	0.04
Wood on wood	0.35	0.3

Think and Answer

- Is friction good or bad? What would the world be like without friction?

Force of Friction

- Why does friction exist?
  - Friction is a contact force (electroweak force)
  - Chemical bonds are created between the atoms of the surface and object (cold welding)
  - Bonds created when the object is at rest are generally stronger than the bonds when the object is in motion relative to the surface

Force of Friction

- **Direction** of friction force:
  - Parallel to the surface
  - For objects at rest: directly opposite the force(s) that would cause motion
  - For objects in linear motion: directly opposite to the direction of travel
  - For rolling objects: directly opposite to the relative motion between the object and surface (i.e. in the direction the object is traveling)

The "Nose" Rule: The direction your nose would bend is the direction of the frictional force.