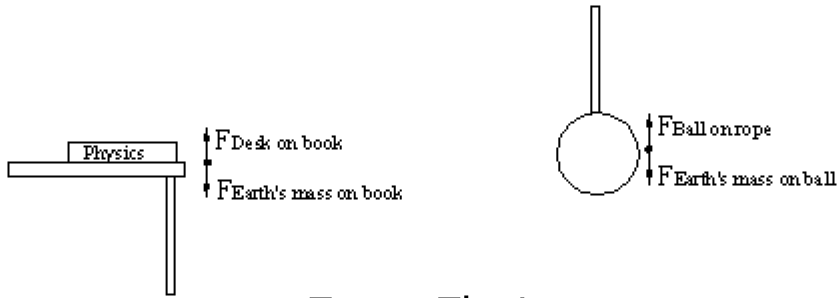
Physics

Lesson Plan #6
Forces
David V. Fansler
Beddingfield High School

Force and Motion

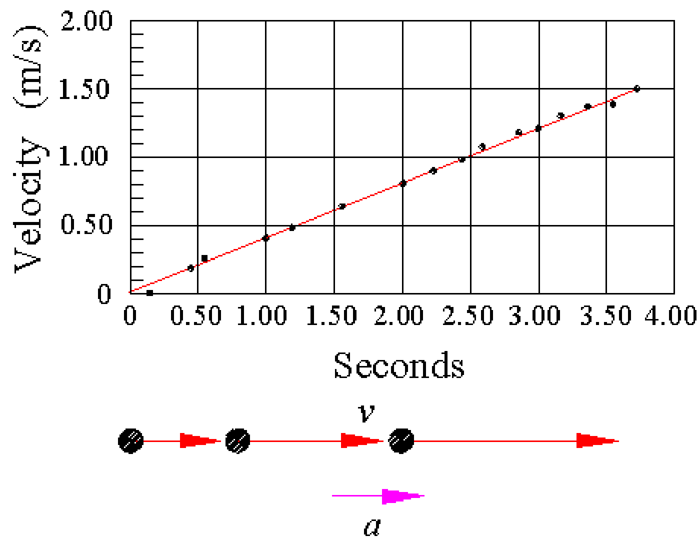
Objective – Define a force and differentiate between contact forces and long-range forces; Recognize the significance of Newton's second law of motion and use it to solve motion problems; Explain the meaning of Newton's first law and describe an object in equilibrium

- All objects have forces working on them
    - Pushing a book across a table
    - Pulling a book across a table
    - The object is called the **system**
    - The world around the object that exerts forces on it is called the **environment**
    - ***F*** represents a force vector
        - Since it is a vector, it has both magnitude and direction
        - *F* represents the magnitude
- Contact Forces vs. Long-Range Forces
    - Contact forces occur because of contact
        - Book lying on a desk
        - Your hand pushing the book
        - Walking – pushing against the floor
        - Wind
    - Long-Range forces occur without contact
        - Magnets
        - Gravity (the only one we will consider)
- Agents
    - All forces have a specific, identifiable, immediate cause called the agent
        - For a book on a desk, there is the agent of the earth's gravity pulling the book down, and the force of the desk pushing up on the book
        - If you can not name an agent, the force does not exists
    - Agents can be identified by drawing a picture of the system and identify everywhere the system touches the environment
        - Circle the system
        - Identify the contact forces
        - Then add long-range forces



Forces Fig. 1

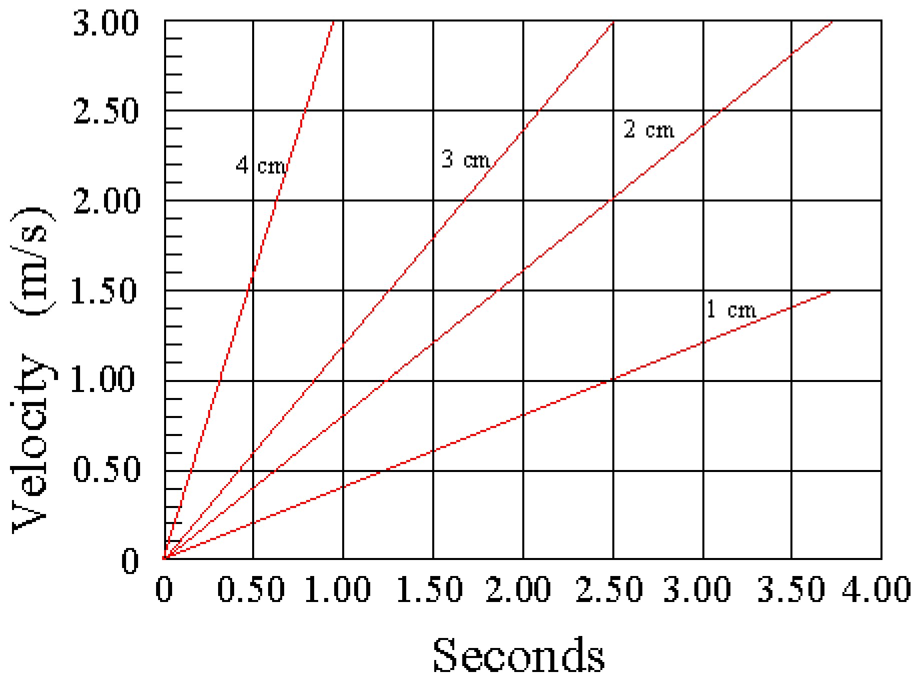
- Newton's Three Laws of Motion
    - 1st Law – an object at rest will remain at rest and an object in motion will remain in motion in a straight line and constant speed unless acted on by an outside force
        - If a system has no net force on it, then its velocity will not change
    - 2nd Law – a change of motion of an object upon by an outside force is directly proportional to the force and inversely proportional to the mass of the object
        - Acceleration of an object equals the net force on that object divided by its mass
    - 3rd Law – for every action there is an equal and opposite reaction
        - All forces come in pairs that are equal in magnitude and opposite in direction
- Newton's 2nd Law
    - If we were to pull a cart with a rubber band, stretching it 1 cm, then plotting the velocity vs. time we would get a graph similar to



Forces Fig. 2

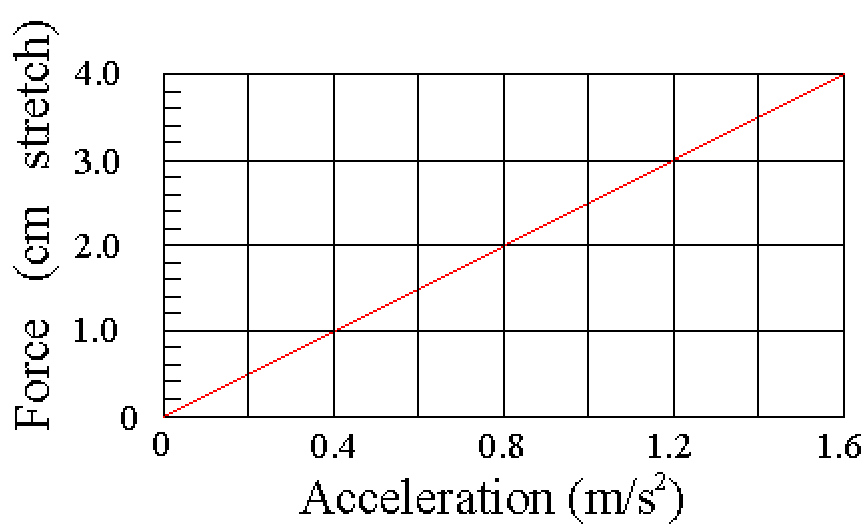
        - From this graph we can determine the acceleration of the cart

- If we were to perform the same experiment with the rubber band stretched to 2 cm and then 3 cm and so and plot these on a v-t graph we could determine the acceleration of each run



Forces Fig. 3

- If we then plot the stretch of the rubber band vs. the acceleration we would get a graph like:

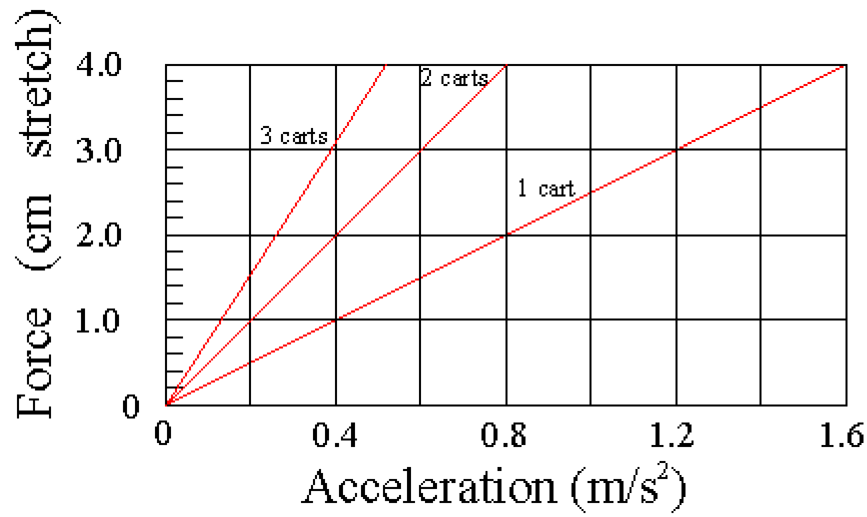


Forces Fig. 4

- Note that fig 4 is a force-acceleration graph and that acceleration and force are proportional – the larger the force the greater the acceleration

- A linear relationship that goes through the origin is represented by $F=ka$ where k is the slope of the line

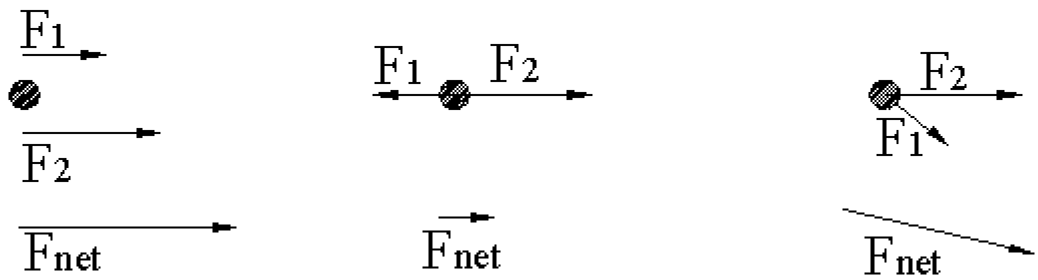
- What happens when the mass increases?
  - Double the weight of the cart, then triple the weight



Forces Fig. 5

  - Notice that the slope of the line increases for each cart added
    - Acceleration is reduced by ½ by adding a second cart
    - Acceleration is reduced to 1/3 by adding a third cart
    - The greater the number of carts, the greater the force needed to produce the same acceleration
    - The slopes of the lines is dependent on the number of carts or mass of the carts
    - If mass is defined as the slope of the F-a graph, then $m = F/a$ or $F = ma$

- Combining forces
  - What if multiple rubber bands were connected to exert forces on a cart?
    - Forces could act in the same direction, opposite directions, or at angles to one another
  - In a **free-body diagram** the system is represented by a dot and arrows extending from the dot represent the forces on the system



Forces Fig. 6

    - Using what we learned before on adding vectors to find the resultant, the above figures should look familiar
  - The vector sum of two or more forces on an object is called the **net force**
    - The acceleration of object is proportional to the net force exerted on the object and inversely proportional to the mass of the object being accelerated
    - This is Newton's Second Law and can be expressed as $a = \frac{F_{net}}{m}$

- Measuring Force: The Newton
  - 1kg accelerated at 1 m/s^2
    - Force of gravity on a nickel – 0.05N
    - Force of gravity on 1 lb of sugar – 4.5 N
    - Force of gravity on 150-lb person – 668 N
    - Force of accelerating car – 3,000 N
    - Force of a rocket motor - 5,000,000 N

Problems

- Newton's First Law of Motion
  - What is the motion of an object with no net force on it
    - Depends on the surface (therefore friction)
    - Deep pile carpet it would slow down quickly
    - Hard surface such as a bowling ally a ball would roll for a long ways
    - If you could remove the friction it would go forever
  - An object at rest will remain at rest and an object in motion will remain in motion in a straight line and constant speed, if and only if the net force acting on that object is zero
  - **Inertia** – tendency of an object to resist change
    - Newton's first law is often called the Law of Inertia
  - Equilibrium – when the net force on an object is zero
    - Can be at rest or at constant velocity

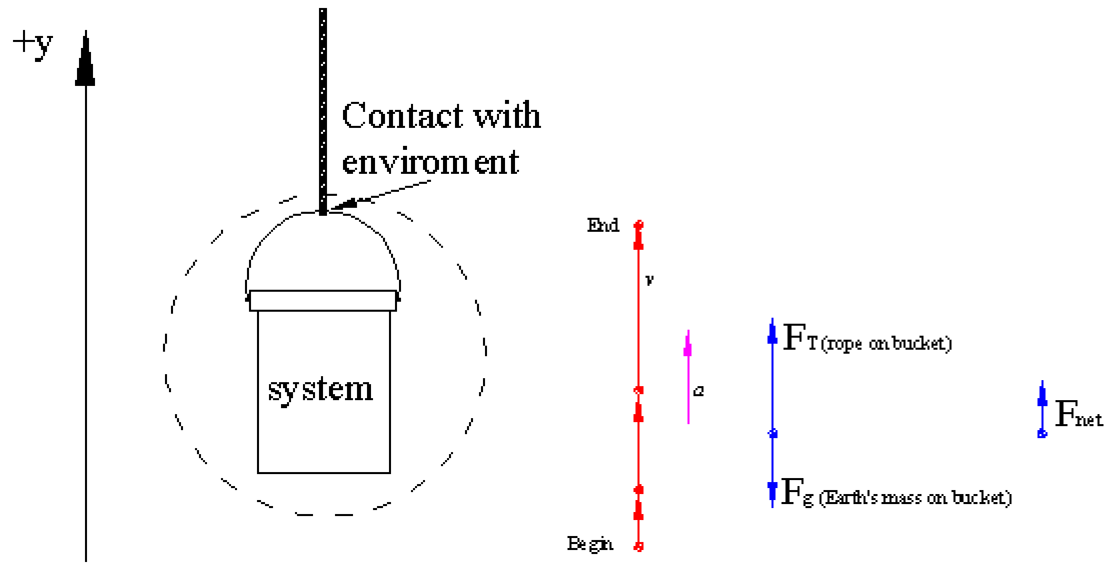
- Newton's 1st law says that any changes in net force will cause a change in equilibrium – change in velocity, or acceleration

- Types of forces

Some Types of Forces			
Force	**Symbol**	**Definition**	**Direction**
Friction	$\boldsymbol{F}_f$	The contact force that acts to oppose sliding motion between surfaces	Parallel to the surface and opposite the direction of sliding
Normal	$\boldsymbol{F}_N$	The contact force exerted by a surface on an object	Perpendicular to and away from the surface
Spring	$\boldsymbol{F}_{sp}$	A restoring force, that is, the push or pull a spring exerts on an object	Opposite the displacement of the object at the end of the spring
Tension	$\boldsymbol{F}_T$	The pull exerted by a string, rope, or cable when attached to a body and pulled taut	Away from the object and parallel to the string, rope, or cable at the point of attachment
Thrust	$\boldsymbol{F}_{thrust}$	A general term for the forces that move objects such as rockets, planes, cars and people	In the same direction as the acceleration of the object barring any resistive forces
Weight	$\boldsymbol{F}_g$	A long-range force due to gravitational attraction between two objects, generally the Earth and an object	Straight down towards the center of Earth

- Constructing a Free-Body Diagram
  - A rope is lifting a bucket at an increasing speed. How can the forces on the bucket be related to the change in speed?
    - Choose a coordinate system defining the positive direction of velocity (or gravity)
    - Locate every point at which the environment touches the system
    - Draw a motion diagram including the velocity and acceleration. The bucket is moving upward, so the direction of direction of $\boldsymbol{v}$ is upward. The speed is increasing so the direction of $\boldsymbol{a}$ is upward. Indicate "begin" and "end".
    - Draw the free-body diagram. Replace the bucket by a dot and draw arrows to represent $\boldsymbol{F}_{\text{T(rope on bucket)}}$ and $\boldsymbol{F}_{\text{g(Earth's mass on bucket)}}$
    - When done:
      - Velocity is increasing in the upward direction, so acceleration is upward
      - According to Newton's 2nd law, $\boldsymbol{F}_{\text{net}}$ and $\boldsymbol{a}$ are in the same direction
    - Therefore, vector addition of the positive represent $\boldsymbol{F}_{\text{T}}$ and the negative $\boldsymbol{F}_{\text{g}}$ results in a positive $\boldsymbol{F}_{\text{net}}$

- Draw an arrow showing $\boldsymbol{F}_{\text{net}}$



Forces Fig. 7

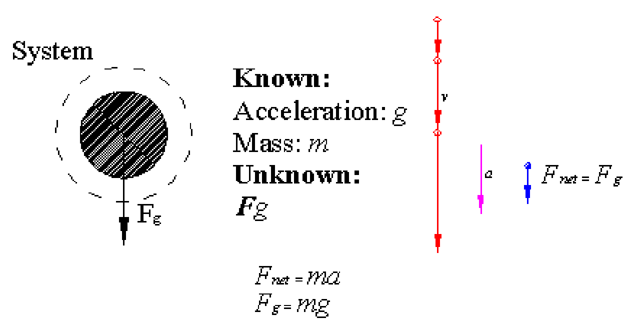
Practice problems

- Common Misconceptions about Force
  - **When a ball has been thrown, the force of the hand that threw it remains on it** – no, the force of the hand is a contact force, therefore, once the contact is broken, the force is no longer exerted.
  - **A force is needed to keep an object moving** – no, if there is no net force, then the object keeps moving with unchanged velocity (which implies unchanged direction since velocity is a vector). If friction is a factor, then there is a net force and the object's velocity will change
  - **Inertia is a force** – no, inertia is the tendency of an object to resist changing its velocity. Forces are exerted on objects by the enviroment; they are not properties of the object.
  - **Air does not exert a force** – ever stuck your hand out the window of a moving car? Air exerts a huge force, but because it is balanced on all sides, it usually exerts no net force unless an object is moving. You can also experience this force when you remove the air from one side such as with a suction cup. A suction cup is hard to remove because of the large unbalanced force of the air on the other side.
  - **The quantity *ma* is a force** - The equals sign in $F = ma$ does not define *ma* as a force – rather, the equal sign means that experiments have shown that the two sides of the equation are equal

Using Newton's Laws

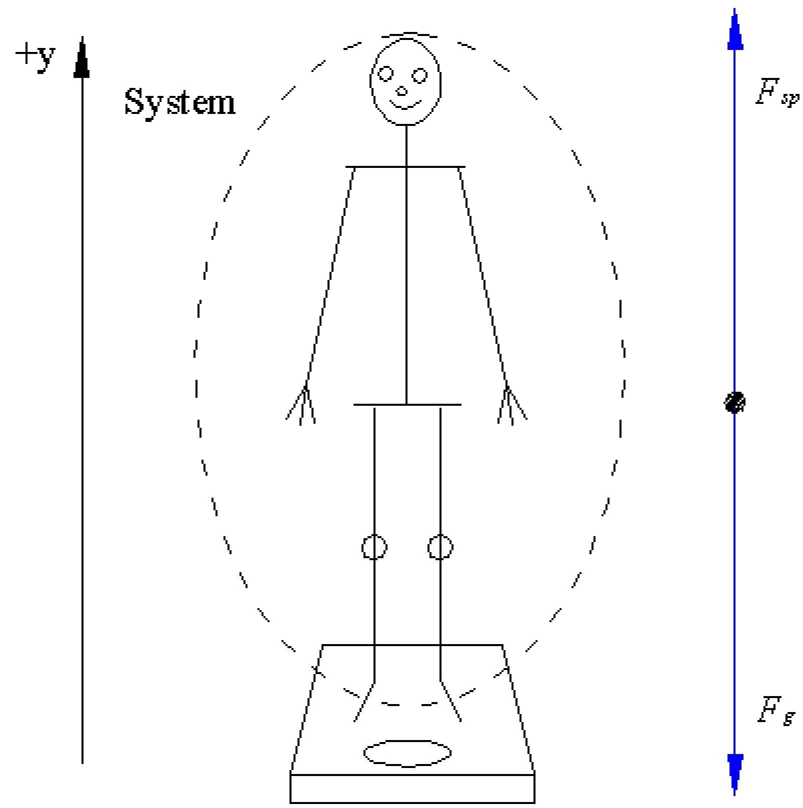
Objectives: Describe how the weight and the mass of an object are related; Differentiate between the gravitational force weight and what is experienced as apparent weight; Define the friction force and distinguish between static and kinetic friction; Describe simple harmonic motion and explain how the acceleration due to gravity influences such motion

- Using Newton's Second Law
  - The acceleration of object is proportional to the net force exerted on the object and inversely proportional to the mass of the object being accelerated
    - Newton once named this the "law of nature" because he thought it would hold true for all motion
      - Fails as objects approach the speed of light
      - Fails for objects the size of an atom
  - Man once believed that the heavier an object the faster it would fall
    - We know now that this is false – air resistance was the cause of the wrong thinking
    - Galileo dropped balls from the Leaning Tower of Pisa to test Aristotle's belief that the heavier an object the faster it falls.
      - He timed two cannon balls falling – then tied them together and dropped them again – according to Aristotle they should have fallen twice as fast – which they did not
      - Galileo therefore theorized that all objects, regardless of weight would gain speed at the same rate, meaning they have the same downward acceleration.
  - What is the weight force ***Fg*** exerted on an object of mass *m*?
    - Consider a ball free falling
      - Air friction can be ignored
      - Nothing is touching the ball so there are no contact forces
      - Only ***Fg*** is acting on the ball and the ball's acceleration is *g*
      - Newton's 2nd Law becomes ***Fg=mg***
      - Both the force and acceleration are downward
      - The weight of the object is therefore equal to its mass times the acceleration it would have if it were freely falling.



Forces Fig. 8

- What do scales measure – mass or weight?
    - When you step on a scale, the scale exerts an upward force on you equal and opposite to your weight, so the net force is 0
    - Either a spring is stretched an amount proportional to your weight, or a load cell is compressed proportional to your weight.
    - In either case the magnitude of the spring or load cell, $\boldsymbol{F_{sp}}$, is equal to your weight $\boldsymbol{F_g}$
    - The weight that a scale shows is proportional to your mass and the acceleration due to gravity – so your weight would be different on a planet with a different acceleration due to gravity.



$\boldsymbol{a} = 0,\ \boldsymbol{F_{net}} = 0$

$\boldsymbol{F_{sp}} - \boldsymbol{F_g} = 0$

$\boldsymbol{F_{sp}} = \boldsymbol{F_g}$

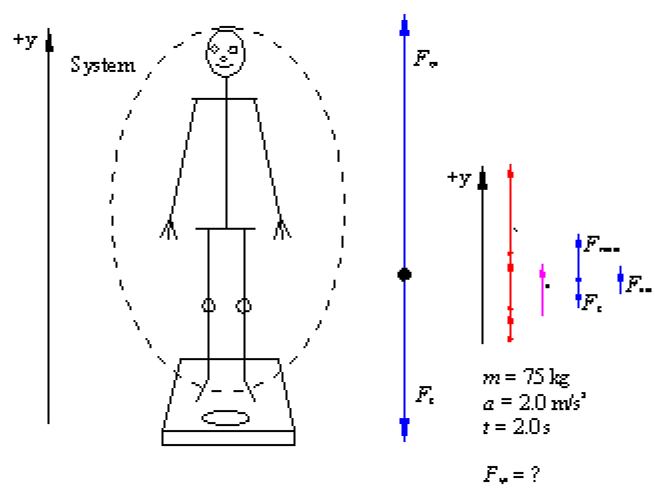
Forces Fig. 9

- Problem Solving Strategy
    - Force and Motion – when using Newton's laws to solve force and motion problems, use the following strategy
        - Read the problem carefully. Visualize the situation and create the pictorial model with a sketch.
        - Circle the system and choose the coordinate system.
        - Decided which quantities are know and which quantity you need to find. Assign symbols to the known and unknown quantities.

- Create the physical model, which includes the a motion diagram showing the direction of the acceleration, and a free-body diagram, which includes the net force.
- To calculate your answer, use Newton's laws to link acceleration and net force.
- Rearrange the equation to solve for the unknown quantity, $\boldsymbol{a}$ or $\boldsymbol{F}_{net}$. Newton's 2nd law involves vectors, so the equation must be solved separately in the x and y directions.
- Substitute the known quantities with their units in the equation and solve.
- Check your results to see if they are reasonable.

Example Problems

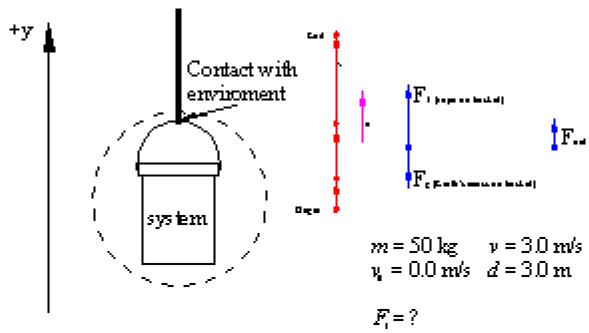
- **Weighing yourself in an elevator:** Your mass is 75 kg. You stand on a scale in an elevator which is going up. Starting from rest, the elevator accelerates a 2.0 m/s^2 for 2.0s, then continues at a constant speed. What does the scale read during the acceleration? Is it larger than, equal to or less than the scale reading when the elevator is at rest?
  - First, sketch the problem



Forces Fig.10

  - We know that $\boldsymbol{F}_{net}$ is the sum of the positive force of the scale on you, $\boldsymbol{F}_{scale}$, and the negative weight force, $\boldsymbol{F}_g$, so $\boldsymbol{F}_{net} = \boldsymbol{F}_{scale} - \boldsymbol{F}_g$.
  - Solve for $\boldsymbol{F}_{scale}$, and substitute ma for $\boldsymbol{F}_{net}$ and mg for $\boldsymbol{F}_g$.
    - $\boldsymbol{F}_{scale} = ma - (m\text{-}g) = ma + mg = m(a+g)$
    - $\boldsymbol{F}_{scale} = 75\text{ kg}(2.0\text{m/s}^2 + 9.80\text{m/s}^2)$
    - $\boldsymbol{F}_{scale} = 885\text{ kg m/ s}^2 = 885\text{ N} = 890\text{N}$
  - Are the units correct? kg m/ s^2 = N
  - Does the sign make sense
  - Is the magnitude realistic? At rest $\boldsymbol{F}_{scale} = ma$, or 75 kg x 9.80 m/s^2 = 735 N = 740 N, so the value of $\boldsymbol{F}_{scale}$ when accelerating in the elevator is greater than when at rest.

- **Lifting a bucket:** A 50 kg bucket is being lifted by a rope. The rope is guaranteed not to break if the tension is 500 N or less. The bucket started at rest, and after being lifted 3.0 m, it is moving at 3.0 m/s. Assuming that the acceleration is constant, is the rope in danger of breaking?
    - First, sketch the problem
    - Establish a coordinate system with positive axis up
    - Draw a motion diagram including ***v*** and ***a***
    - Draw the free-body diagram. Position the force vectors with their tails on the dot.



Forces Fig.11

- The net force is the vector sum of $\boldsymbol{F_T}$ (positive) and $\boldsymbol{F_G}$ (negative).
    - $\boldsymbol{F_{net}} = \boldsymbol{F_T} - \boldsymbol{F_g}.$
- Rearrange the equation so $\boldsymbol{F_T} = \boldsymbol{F_{net}} + \boldsymbol{F_g} = ma + \text{mg}$
- We know what the mass of the bucket is, as well as g
- a is unknown, for which we need to solve for
    - using our old friend $v^2 = v_0^2 + 2a(d - d_0)$ we can solve for a
    - Because v_0 is zero, and d_0 is zero, then a = $v^2/2d$
- $\boldsymbol{F_T} = m(a+g) = m(\frac{v^2}{2d} + g)$
- $\boldsymbol{F_T} = 50g(\frac{(3.0m/s)^2}{2(3.0m)} + 9.80m/s^2)$
- $\boldsymbol{F_T} = 50g(\frac{9.0m^2/s^2}{6.0m} + 9.80m/s^2)$
- $\boldsymbol{F_T} = 50g(1.5m/s^2 + 9.80m/s^2)$
- $\boldsymbol{F_T} = 50g(11.3m/s^2) = 565kg \bullet m/s^2 = 570N$
- The rope is in danger of breaking
- Checking your answer
    - Are the units correct? Did we end up with kg·m/s^2 which is N?
    - Does the sign make sense? Since the bucket was rising, it should be positive.
    - Is the magnitude realistic? The weight of the bucket is 490 N, so the answer being slightly larger is expected.

Practice Problems

- Apparent Weight
  - What is weight? What does a bathroom scale measure?
  - Weight is defined as $\boldsymbol{F}_g = mg$ so $\boldsymbol{F}_g$ changes with g
  - g varies with your distance from the center of the Earth, but for all practical purposes it is constant at the Earth's surface at 9.80 m/s^2
  - Standing on a scale, there is one contact force – the scale pushing you upward – your weight.
  - If someone were to push down on your shoulders, then the weight would increase, but it would not be your weight since there were other contact forces at play.
  - How about when you ride an elevator?
    - At rest, $\boldsymbol{F}_{net}$ is 0, so your true weight is shown
    - When going up, your weight reads more
    - When going down, your weight reads less
    - This change is called the apparent weight
  - If the elevator cable were to break, and the elevator were to fall at g, then the scale would read 0 since you and the scale would accelerate with $a = -g$. Your apparent weight would be 0 – you would be weightless. Weightless does not mean you do not weight anything – just that there are no contact forces pushing up on you. Weightlessness means that your apparent weight is 0 – right up to the point the elevator hit the bottom!

- The Friction Force
  - We all are familiar with friction – falling while running on a concrete driveway produces friction between your hand and the concrete. Someone giving you a nuggy burns because of the friction. Friction is needed to stop a car or bike; friction is the enemy of a car engine and why an engine must have oil.
  - Static & Kinetic Friction
    - When you try to push a heavy object and it does not move – Newton's 2nd law tells us it should move – unless there is another horizontal force equal and opposite to your force acting on the crate
    - That force is called **static friction** – it is exerted on one surface by another when there is no relative motion between the two surfaces
    - If you continue to add force to the crate, the force of static friction also increases – but there is a limit to how much static friction force two surfaces can generate
    - Once enough force is applied, the crate moves – but friction is still acting because if you stop pushing the crate stops
    - When the crate is moving, the friction between it and the floor becomes **kinetic friction force** – that is the force exerted on one surface by another when there is relative motion.
  - A model for friction
    - First we should note that friction forces are complicated, but we can take a simplified model that has been proven by experiment

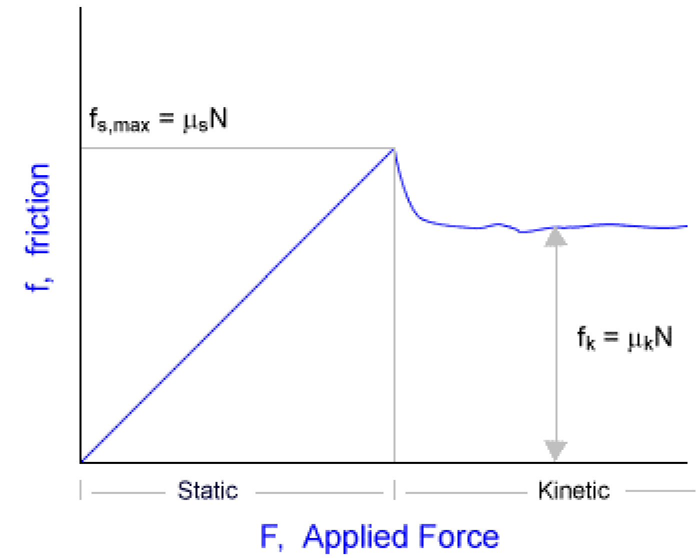
            - Model assumes that friction depends of the surfaces in contact
            - Model does not depend on the surface area
            - Model does not depend on the speed of their relative motion
            - The magnitude of the friction force is proportional to the magnitude of the force pushing one surface against the other.
                - That force, perpendicular to the surface, is the normal force, $\boldsymbol{F}_N$
    - $\boldsymbol{F}_{f,\text{ kinetic}} = \boldsymbol{\mu}_k \boldsymbol{F}_N$, where $\boldsymbol{\mu}_k$ is a proportionality constant called the kinetic coefficient of friction
    - The static friction force is related to the normal force by this expression: $0 \le F_{f,static} \le \mu_s F_N$
        - $\boldsymbol{\mu}_s$ is the static coefficient of friction
        - The equation states that the static friction force can vary from 0 to $\mu_s F_N$, where $\mu_s F_N$ is the maximum static friction that must be balanced before motion can begin
    - The equations $\boldsymbol{F}_{f,\text{ kinetic}} = \boldsymbol{\mu}_k \boldsymbol{F}_N$, and $0 \le F_{f,static} \le \mu_s F_N$ are magnitudes of the forces only – the forces themselves, $\boldsymbol{F}_N$ and $\boldsymbol{F}_f$, are at right angles to each other - **ignore the direction for friction problems!**
    - Below is a table of some coefficients of friction – while all are less than 1, there are some greater than 1 – drag racers will have coefficients as large as 5.0

-

Typical Coefficients of Friction		
Surface	$\boldsymbol{\mu}_s$	$\boldsymbol{\mu}_k$
Rubber on concrete	0.80	0.65
Rubber on wet concrete	0.60	0.40
Wood on wood	0.50	0.20
Steel on steel (dry)	0.78	0.58
Steel on steel (with oil)	0.15	0.06
Teflon on steel	0.04	0.04

- Below is a graph of friction vs. force
    - When a force is applied to the object, the static friction starts pushing back with an equal amount of force. This continues until $F_{s,max} = \mu_s F_N$ (that is until the maximum static friction which equals the coefficient of static friction times the normal force has been reached)
    - Notice the sudden drop in friction as the object starts to move and that the friction becomes more or less stable at $F_k = \mu_k F_N$ (where the kinetic friction force equals the coefficient of kinetic friction times the normal force)

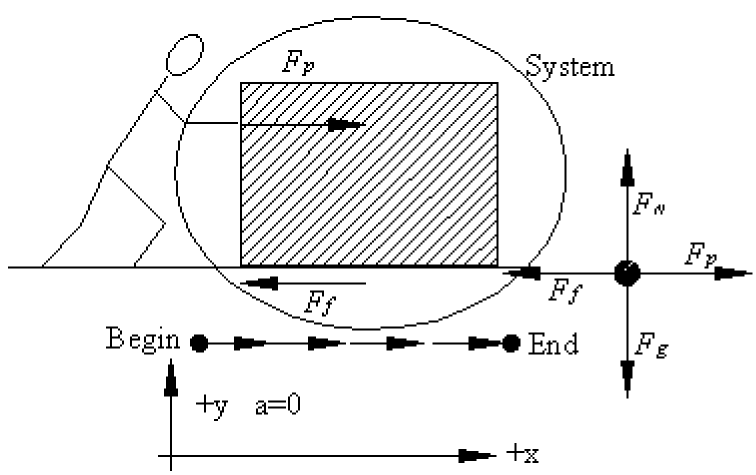
- Once the object starts moving, the minimum amount of force that can be applied to keep the object moving at constant velocity is Fk, which is dependent on the coefficient of kinetic friction and the normal force (the weight of the object).



Example Problem

You push a 25 kg wooden box across a wooden floor at a constant speed of 1.0 m/s. How much force do you exert on the box?

First we need to draw a picture of the system
Then we add all the agents (forces) to the picture
Then we circle the system
Draw a motion diagram indicating constant *v* and *a* = 0
Then we set up a coordinate system
Then we draw the free-body diagram by placing all the forces on the dot, which represents the system



Forces Fig. 12

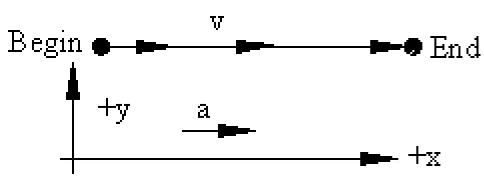
$F_{net} = F_{pt}(-F_f) = F_p - F_f$ since $f_{net} = 0$ the $F_p = F_f$

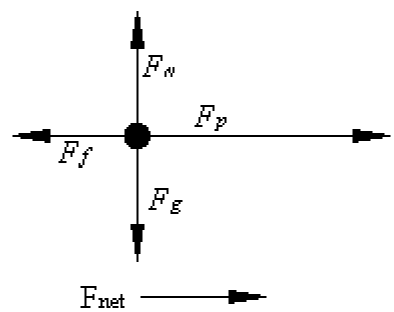
Known	*Unknown*
m = 25 kg	F_p
v = 1.0 m/s	
$a = 0$ m/s^2	
$\mu_k = 0.20$	

In the y direction we know there is no acceleration, so $F_N = Fg = mg$
In the x direction, because there is no acceleration, then the pushing force, $Fp = Ff = \mu_k mg$

For our calculations:
$Fp = Ff = \mu_k mg$
$Fp = (0.20)(25\ \text{kg})(9.80\ \text{m/s}^2)$
$Fp = 49$ N
Does the answer make sense?
The units work since kg x m/s^2 = N, the positive sign agrees with the diagram. Is the magnitude realistic? Without having lived in a world of N, I am not sure I could gage that.

What if we doubled the force on the box – what is the resulting acceleration?
Sketching the free-body diagram again, this time we shown an increasing v and the direction of a.





Forces Fig.13

Known	*Unknown*
m = 25 kg	a = ?
v = 1.0 m/s	
$\mu_k = 0.20$	
$F_p = 2(49\text{N}) = 98$ N	

Friction force is the same, it is independent of velocity.

y direction: $F_N = Fg = mg$, $F_N = mg$
x direction: $F_p - F_f = ma$

There is a net horizontal force, the crate is accelerating.

$F_f = \mu_k F_N = \mu_k mg$

We need to apply Newton's laws separately in two directions.

$$a = \frac{F_{net}}{m} = \frac{F_p - F_f}{m} = \frac{F_p - \mu_k mg}{m} = \frac{F_p}{m} - \mu_k mg$$

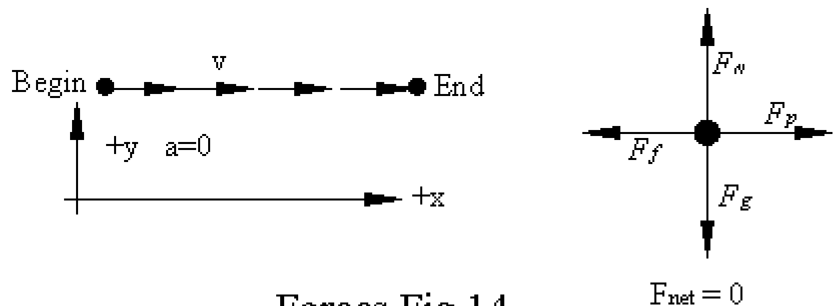
$$a = \frac{98\ N}{25\ kg} - (0.20)(9.80\ m/s^2)$$

$$a = 2.0\ m/s^2$$

Practice problems

14. A boy exerts a 36 N horizontal force as he pulls a 52 N sled across a cement sidewalk at constant speed. What is the coefficient of kinetic friction between the sidewalk and the metal sled runners, ignoring air resistance?

Known	*Unknown*
weight = 52 N	μ_k = ?
v = constant	
$a = 0$ m/s^2	
F_p = 36 N	



Forces Fig.14

Since there is no acceleration, then the pulling force is equal to the force of friction, 36 N.

To calculate the force of friction, we know that

$F_f = \mu_k F_N$ which rearranges to $\mu_k = F_f/F_N$ = 36 N/52 N = 0.69

So 0.69 is the coefficient of friction

15. Suppose the sled runs on packed snow. The coefficient of friction is only 0.12. A person weighing 650 N sits on the sled, what is the amount of force needed to move the sled at constant velocity?

Known	*Unknown*
$\mu_k = 0.12$	F_p = ?
weight of sled = 52 N	
weight of body = 650 N	
a = 0	

y-direction – since there is no acceleration the $F_N = F_g$

x-direction – since there is constant velocity

$Fp = \mu_k F_N = \mu_k F_g = \mu_k mg = (0.12)(52\ N + 650\ N) = 84.24\ N = 84\ N$

16. Consider doubled force pushing the crate in the above example problem. How long would it take for the velocity to reach 2.0 m/s?

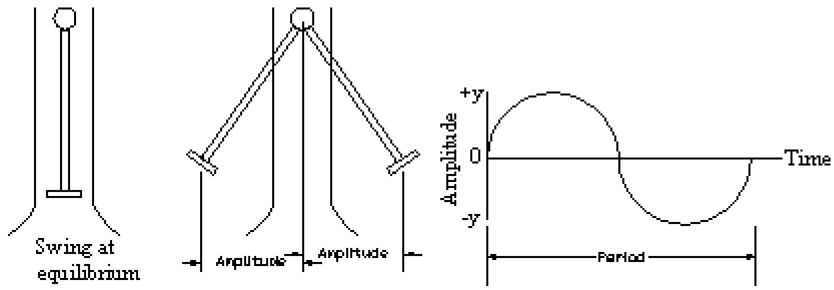
Known	*Unknown*
m = 25 kg	t = ?
v = 1.0 m/s	
μ_k = 0.20	
F_p = 2(49N) = 98 N	
a = 2.0 m/s	

$$a = \frac{\Delta v}{\Delta t} \; or \; t = \frac{\Delta v}{a} = \frac{2m/s - 1m/s}{2.0m/s^2} = \frac{1m/s}{2.0m/s^2} = .5s$$

- Causes of Friction
  - All surfaces have some roughness to them
  - When high points touch, a bond is formed. This bond must be overcome when your try to move one piece against the other – static friction.
  - As you move one surface over another – the high points again try to bond – this produces a weaker bond known as kinetic friction
  - Details of this process are still not totally understood and currently subject to research
- Air Drag and Terminal Velocity
  - As an object moves through air or any other fluid, the fluid exerts a friction like force – called drag.
  - As velocity increases, so does the drag.
  - When an objected is dropped, it accelerates until the drag = g, giving a net force of 0 and an acceleration of 0 m/s. This balance point is called **terminal velocity**
    - Ping pong ball 9 m/s
    - Basketball 20 m/s
    - Baseball 42 m/s
    - Sky diver – slowest is 60 m/s, with chute open 5 m/s

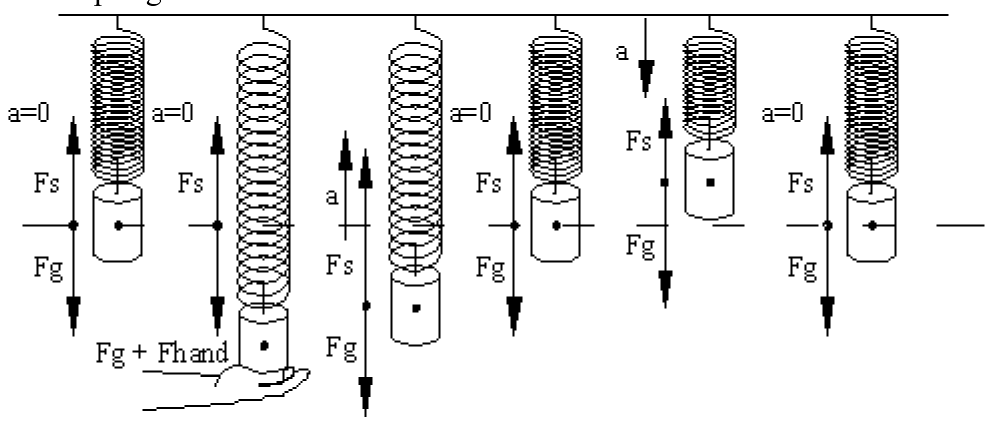
- Periodic Motion
  - A swing at rest is at equilibrium, as is a guitar string at rest, that is the net force is 0. When you push the swing, or pluck the string you set up a condition in which the object in motion, the net force in no longer 0 and the object moves back toward equilibrium. In both the swing and guitar string, the motion will overshoot the point of equilibrium, reverse directions and again move back toward equilibrium.
  - If the force which restores the equilibrium is directly proportional to the displacement of the object the result is **simple harmonic motion**
  - Two terms describe simple harmonic motion
    - T – period, how long (in time) it takes the object to repeat one complete cycle of motion

- Amplitude – maximum distance the object moves from equilibrium.



Forces Fig.15

- Mass on a Spring

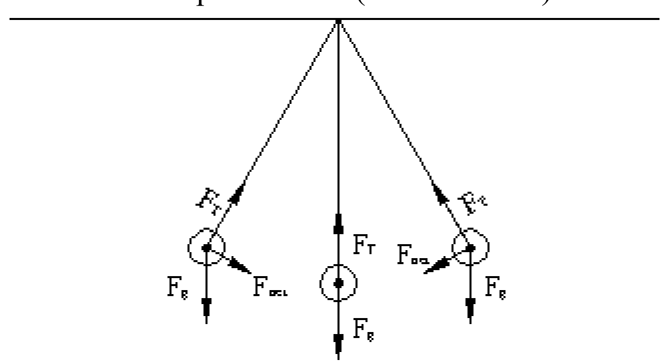


Forces Fig.16
Simple Harmonic Motion

- When a mass is hung on a spring, the system comes to equilibrium where Fg = Fsp. The upward force of the spring is directly proportional to the stretch of the spring. This is in accordance with Hooke's Law – Hooke described mathematically how a spring should behave.
- When the mass is pulled down and held steady, the force exerted by the spring now equals the force holding the mass down, plus Fg
- When the mass is released the Fsp is now greater than Fg, so the mass accelerates upward
- As it mass reaches the equilibrium point, Fsp equals Fg and a =0, but the mass's inertia keeps the mass moving upwarded
- The mass reaches it's maximum height when Fg slows and stops the upward direction
- The mass then falls until it reaches the equilibrium point once more – where the inertia continues the object downward and we are back to step 3. This simple harmonic oscillation will continue, with decreasing amplitude until it comes to rest with Fsp = Fg.

- The period of oscillation (T) is dependent on the mass of the weight and the strength of the spring – amplitude is not a factor.

- The Pendulum
  - Pendulums demonstrate simple harmonic motion
  - Basically a mass suspended by a string or length of rod.
  - When the mass is pulled back, the mass will oscillate back and forth through the equilibrium point
  - The string or rod exerts a force F_T on the mass, while gravity exerts weight (Fg) on the mass. The vector sum of these two forces produces the net force.
  - Note that Fnet is a restoring force in that it is opposite the displacement of the mass
  - Period of a pendulum is give as $T = 2\pi\sqrt{\frac{l}{g}}$
  - Note that for a given gravity, the only factor to affect the period is the length.
  - Pendulum clocks are based on this function
    - If a clock runs slow, then what would you need to do to the mass on the pendulum? (move it up)
    - IF a clock runs fast, the what would you need to do to the mass on the pendulum? (move it down)



Forces Fig.17
Simple Harmonic Motion - The Pendulum

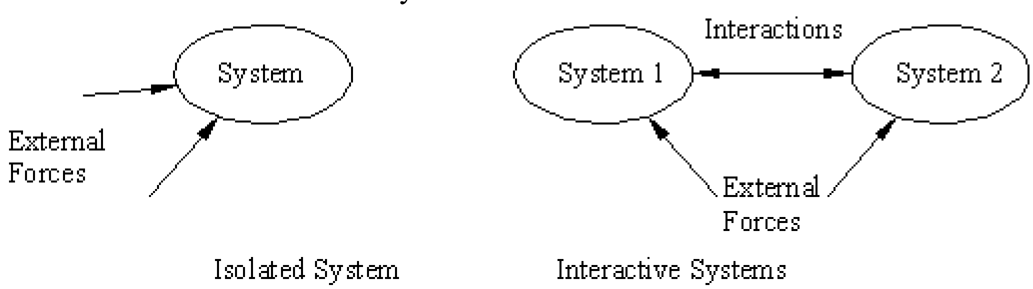
- Resonance
  - You learned that when swinging you could swing higher by leaning back and pumping your legs at a certain point in your oscillations.
  - You also learned when to push a friend in a swing to increase their amplitude.
  - If you have ever jumped on a trampoline or diving board, you also add small amounts of force at the proper time to increase the amplitude the same concept applies
  - Such an increase of amplitude is called mechanical resonance

            - The period of time between applications of force is equal to the period of oscillation.
        - Mechanical resonance can be good – or bad
            - Rocking a car to get out of a snow bank
            - Jumping on a trampoline or diving board
            - Theater balconies have been damaged by people jumping up and down in resonance with the balcony have caused damage
            - A bridge in Washington State once fell because of resonance set off by wind
            - Soldiers will break formation when crossing bridges in order to not set up a resonance

Interaction Forces

Objectives: Explain the meaning of interaction pairs of forces and how they are related by Newton's 3rd law; List the four fundamental forces and illustrate the environment in which each can be observed; Explain the tension in ropes and strings in terms of Newton's 3rd law.

- Identifying Interaction Forces
    - We have learned that when a net force acts on an object that $a = \frac{F_{net}}{m}$. Also that forces are exerted on objects by agents, and forces can be contact or long-range. Where does the force come from? Pull on a rope it pulls back – which is the agent and the object?
    - Systems and the environment
        - So far we have studied closed systems, where only the forces immediately present are considered.
        - But what about systems that interact with each other

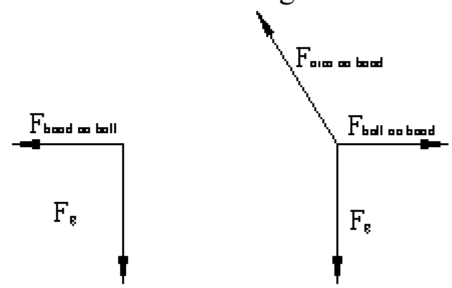


Forces Fig.18

    - Take a baseball being caught by a catcher
        - Dealing with two systems – the ball and the catcher's hand
        - Forces involved
            - External forces would be
                - On the ball, Fg
                - On the hand, Fg and the arm connected to the hand
            - Internal forces
                - Hand on the ball ($F_{\text{hand on ball}}$)

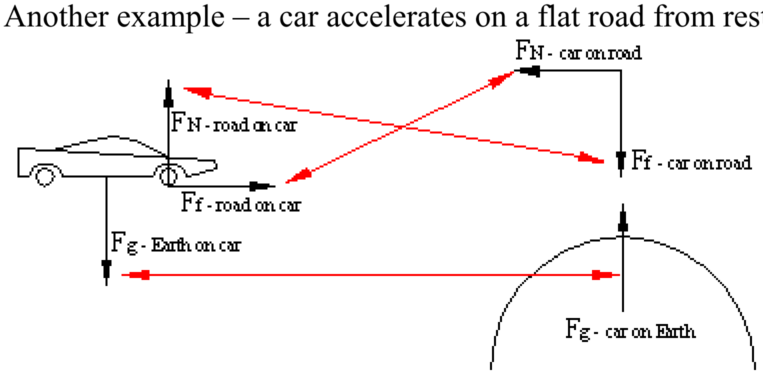
- Ball on the hand ($F_{\text{ball on hand}}$)
- These are interactive forces
- Also noted at A on B and B on A

- While this suggests that one causes the other, one cannot exist without the other
  - What is the direction and magnitude of the forces?



Forces Fig.19

- Newton's Third Law
  - According to Newton, an **interactive pair** is two forces which have opposite directions and the same magnitude.
  - In the case of the ball being caught by the catcher, the two forces would be the $F_{\text{ball on hand}}$ and the $F_{\text{hand on ball}}$ which would be written as $F_{\text{hand on ball}} = - F_{\text{ball on hand}}$
  - This is a clear example of Newton's 3rd law – for every action there is an equal and opposite reaction
  - Another example – a car accelerates on a flat road from rest

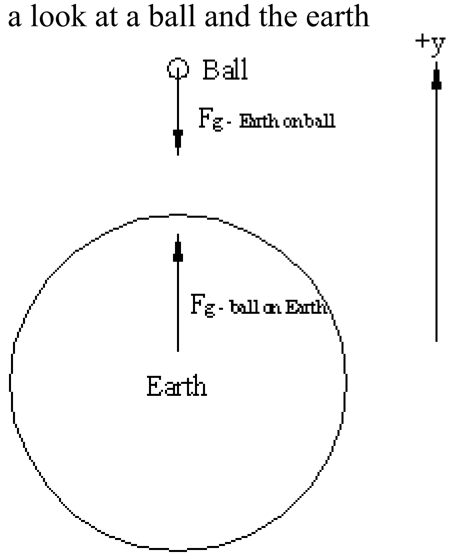


Two Systems with interactive pairs
Forces Fig.20

- The car touches the road, so that gives us a F_N of road on the car and the car on the road
- Gravity – there is gravity on the car from the earth (pulling the car down) and gravity on the earth from the car (pulling the earth up)
- There is friction force of the tire on the road and the friction force of the road on the tire

- You must be careful when looking at forces – the turning of the wheels exert a backward force on the road – but this is not what makes the car go forward
  - The force is backwards – the wrong direction
  - The force is exerted on the road – not the car
  - Thus it is the forward force of the road on the car that propels the car forward.
  - Without the interaction between the tires and road the car would not move
    - Ever tried to drive on ice?
    - No friction, no movement
    - The coefficient of friction for the tire has not changed, the coefficient of friction for the road has.

- Since the road is pushing the car forward, is the car really pulling the earth upward? Take a look at a ball and the earth



Forces Fig.21

When a softball with a mass of 0.18 kg is dropped, its acceleration toward Earth is equal to g, the acceleration due to gravity. What is the force on Earth due to the ball, and what is the Earth's acceleration? The mass of the Earth is 6.0 x 10^{24} kg.

Known	*Unknown*
m_{ball} = 0.18 kg	$F_{Earth\ on\ ball}$ = ?
m_{Earth} = 6.0 x 10^{24} kg	a_{Earth} = ?
g = 9.80 m/s^2	

$F_{Earth\ on\ ball} = m_{ball}$ x - 9.80 m/s^2 = 0.18 kg x 9.80 m/s^2 = -1.8 N

Since for ever force there is a counter force of the opposite direction and same direction:

$F_{Earth\ on\ ball}$ = - $F_{Earth\ on\ ball}$ = -(-1.8 N) = 1.8 N

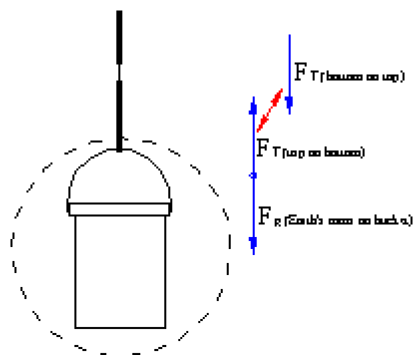
$$a_{\text{Earth}} = \frac{F_{net}}{m_{Earth}} = \frac{1.8\ N}{6.0\ x\ 10^{24}\ kg} = 2.9\ x\ 10^{-25}\ m/s^2$$

Check you answer:

Do the units work out?

Is the magnitude of the acceleration of the earth reasonable – yes since the earth is so large and the softball is so small

- The four fundamental forces of nature
  - So far we have seen a number of contact interactions and one long range interaction – are they all different or the result of the same force?
  - There are currently 4 different forces science recognizes
    - Gravity – long range – all objects attract each other due to their gravitation fields relative to their mass
    - Electromagnetic Interactions – include magnets, static charges and electrical forces. This is the force that holds atoms and molecules together – so indirectly is responsible for all contact forces.
    - Strong nuclear interaction between protons and neutrons hold the nucleus together
    - Weak nuclear interaction is seen in radioactive decay.
- Forces of Ropes and Strings
  - So given a bucket hanging on a rope, where are all the forces?



Forces Fig.22

  - Suppose we take the situation above – a bucket hanging on a rope that is about to break. There are tensions inside the rope.
    - Specifically the rope is held together by electromagnetic forces between the molecules and atoms of the rope.
    - At any one point, the tension forces are pulling in equally in both directions.
    - Since the bucket is in equilibrium, the net force on the bucket is zero
    - So $F_{T(\text{top on bottom})} = -Fg$, or $F_{T(\text{bottom on top})} = Fg$
    - Thus the tension in the rope is the weight of the objects below it
  - How about a rope in a tug of war?

- Suppose both teams are pulling with 500 N, then what is the force on the rope?
- Suppose the rope were to break, then what force would be on each piece of the rope? (500 N)
- Since each team is pulling 500 N, there is an equilibrium, where the force of the left team equals the force of the right team, giving a net force of 0