IB Physics – Fall 2013 – Final Exam Study Guide

Scalars vs. Vectors

- Scalars are quantities that are fully described by a magnitude (or numerical value) alone.
  - Distance
  - Speed
- Vectors are quantities that are fully described by both a magnitude and a direction.
  - Displacement
  - Velocity
  - Acceleration
- Examples of scalar and vector quantities

Distance vs. Displacement

- Distance is a scalar quantity that refers to "how much ground an object has covered" during its motion.
- Displacement is a vector quantity that refers to "how far out of place an object is"; it is the object's overall change in position.
- Examples of distance and displacement

Speed vs. Velocity

- Speed is a scalar quantity that refers to "how fast an object is moving." Speed can be thought of as the rate at which an object covers distance. A fast-moving object has a high speed and covers a relatively large distance in a short amount of time. Contrast this to a slow-moving object that has a low speed; it covers a relatively small amount of distance in the same amount of time. An object with no movement at all has a zero speed.
- Velocity is a vector quantity that refers to "the rate at which an object changes its position." Imagine a person moving rapidly - one step forward and one step back - always returning to the original starting position. While this might result in a frenzy of activity, it would result in a zero velocity. Because the person always returns to the original position, the motion would never result in a change in position. Since velocity is defined as the rate at which the position changes, this motion results in zero velocity. If a person in motion wishes to maximize their velocity, then that person must make every effort to maximize the amount that they are displaced from their original position. Every step must go into moving that person further from where he or she started. For certain, the person should never change directions and begin to return to the starting position.
- Velocity is a vector quantity. As such, velocity is *direction aware*. When evaluating the velocity of an object, one must keep track of direction. It would not be enough to say that an object has a velocity of 55 mi/hr. One must include direction information in order to fully describe the velocity of the object. For instance, you must describe an object's velocity as being 55 mi/hr, **east**. This is one of the essential differences between speed and velocity. Speed is a scalar quantity and does not *keep track of direction*; velocity is a vector quantity and is *direction aware*.
- The average speed during the course of a motion is often computed using the following formula:

$$\text{Average Speed} = \frac{\text{Distance Traveled}}{\text{Time of Travel}}$$

- In contrast, the average velocity is often computed using this formula

$$\text{Average Velocity} = \frac{\Delta\,\text{position}}{\text{time}} = \frac{\text{displacement}}{\text{time}}$$

- Since a moving object often changes its speed during its motion, it is common to distinguish between the average speed and the instantaneous speed. The distinction is as follows.
  - Instantaneous Speed - the speed at any given instant in time.
  - Average Speed - the average of all instantaneous speeds; found simply by a distance/time ratio.

Acceleration

- Acceleration is a vector quantity that is defined as the rate at which an object changes its velocity. An object is accelerating if it is changing its velocity.
- Sometimes an accelerating object will change its velocity by the same amount each second. This is referred to as a constant acceleration since the velocity is changing by a constant amount each second. An object with a

constant acceleration should not be confused with an object with a constant velocity. Don't be fooled! If an object is changing its velocity -whether by a constant amount or a varying amount - then it is an accelerating object. And an object with a constant velocity is not accelerating.

- Since accelerating objects are constantly changing their velocity, one can say that the distance traveled/time is not a constant value. A falling object for instance usually accelerates as it falls.
- The average acceleration (a) of any object over a given interval of time (t) can be calculated using the equation:

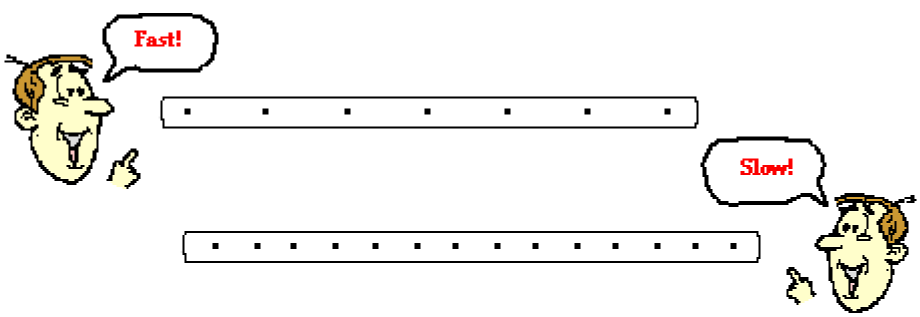
$$\text{Ave. acceleration} = \frac{\Delta\text{velocity}}{\text{time}} = \frac{v_f - v_i}{t}$$

- Acceleration values are expressed in units of velocity/time. Typical acceleration units include the following:
  - m/s/s
  - mi/hr/s
  - km/hr/s
  - m/s^2
- Since acceleration is a vector quantity, it has a direction associated with it. The direction of the acceleration vector depends on two things:
  - whether the object is speeding up or slowing down
  - whether the object is moving in the + or - direction

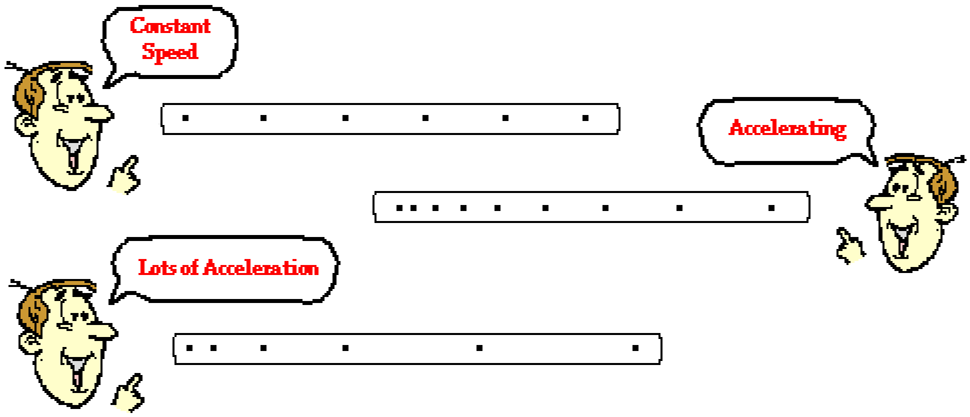
Direction (+ or -)	Velocity (Speeding up or Slowing down)	Acceleration (+ or -)
+	Speeding up	+
+	Slowing down	-
-	Speeding up	-
-	Slowing down	+

❖ **Motion Diagrams**

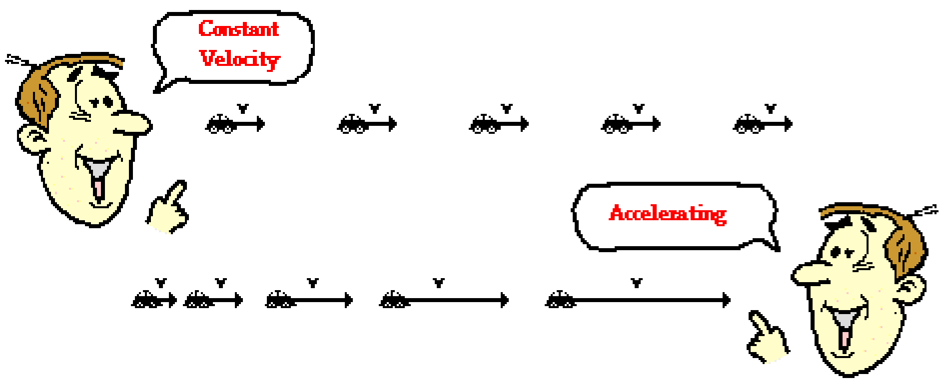
- Particle Model
  - The distance between dots on a particle model represents the object's position change during that time interval. A large distance between dots indicates that the object was moving fast during that time interval. A small distance between dots means the object was moving slowly during that time interval. Particle models for a fast- and slow-moving object are depicted below.



  - Particle models also reveal if the object is moving with a constant velocity or accelerating. A changing distance between dots indicates a changing velocity and thus acceleration. A constant distance between dots represents a constant velocity and therefore no acceleration. Particle for objects moving with a constant velocity and with an accelerated motion are shown below.



- Vector Diagrams
  - Vector diagrams are diagrams that depict the direction and relative magnitude of a vector quantity by a vector arrow. Vector diagrams can be used to describe the velocity of a moving object during its motion.
  - In a vector diagram, the magnitude of a vector quantity is represented by the size of the vector arrow. If the size of the arrow in each consecutive frame of the vector diagram is the same, then the magnitude of that vector is constant. The diagrams below depict the velocity of a car during its motion. In the top diagram, the size of the velocity vector is constant, so the diagram is depicting a motion of constant velocity. In the bottom diagram, the size of the velocity vector is increasing, so the diagram is depicting a motion with increasing velocity - i.e., acceleration.



  - Vector diagrams can be used to represent any vector quantity. In future studies, vector diagrams will be used to represent a variety of physical quantities such as acceleration, force, and momentum. Be familiar with the concept of using a vector arrow to represent the direction and relative size of a quantity. It will become a very important representation of an object's motion as we proceed further in our studies of the physics of motion.

Position vs. Time Graphs

- Meaning of shape
  - Curved line: Accelerating (speeding up or slowing down) object
  - Diagonal line: Constant velocity (speed)
  - Horizontal line: Object is at rest (not moving)
- Meaning of slope
  - Average velocity of object (Absolute value of average velocity is the average speed)
  - Positive slope: Positive average velocity
  - Negative slope: Negative average velocity
- Determining the slope
  - Slope = $\frac{\Delta d}{\Delta t} = \frac{d_f - d_i}{t_f - t_i}$

- **Velocity vs. Time Graphs**
  - Meaning of shape
    - Diagonal line: Constant acceleration
      - Speeding up – Moving away from x-axis
      - Slowing down – Moving towards the x-axis
    - Horizontal line: Constant velocity
    - Above the x-axis – Positive direction
    - Below the x-axis – Negative direction
  - Meaning of slope
    - Average acceleration
    - Positive slope: Positive average acceleration
    - Negative slope: Negative average acceleration
  - Determining the slope
    - Slope = $\frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$
  - Determining the area
    - Area = A = displacement of object
    - Base (B): time and height (h): velocity
    - $A_{rectangle} = B \cdot h$
    - $A_{triangle} = \frac{1}{2} B \cdot h$
    - $A_{trapezoid} = A_{rectangle} + A_{triangle}$

- **Kinematic Equations**
  - What are they?
    1. $d_f = d_i + \bar{v}t$
    2. $v_f = v_i + \bar{a}t$
    3. $d_f = d_i + v_i t + \frac{1}{2}\bar{a}t^2$
    4. $v_f^2 = v_i^2 + 2\bar{a}(d_f - d_i)$
  - Define their variables?
    - Initial position: d_i
    - Final position: d_f
    - Initial velocity: v_i
    - Final velocity: v_f
    - Average velocity: $\bar{v}$
    - Average acceleration: $\bar{a}$
    - Time: t
  - When can each be used?

Variables (G or E)	$d_f = d_i + \bar{v}t$	$v_f = v_i + \bar{a}t$	$d_f = d_i + v_i t + \frac{1}{2}\bar{a}t^2$	$v_f^2 = v_i^2 + 2\bar{a}(d_f - d_i)$
d_i	X		X	X
d_f	X		X	X
v_i		X	X	X
v_f		X		X
$\bar{v}$	X			
$\bar{a}$		X	X	X
t	X	X	X	

Free Fall

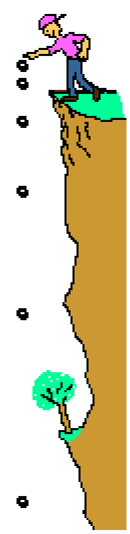
- A free falling object is an object that is falling under the sole influence of gravity. Any object that is being acted upon only by the force of gravity is said to be in a state of free fall. There are two important motion characteristics that are true of free-falling objects:
- Free-falling objects do not encounter air resistance.
- All free-falling objects (on Earth) accelerate downwards at a rate of 9.8 m/s^2 (often approximated as 10 m/s^2 for *back-of-the-envelope* calculations)

Acceleration due to gravity

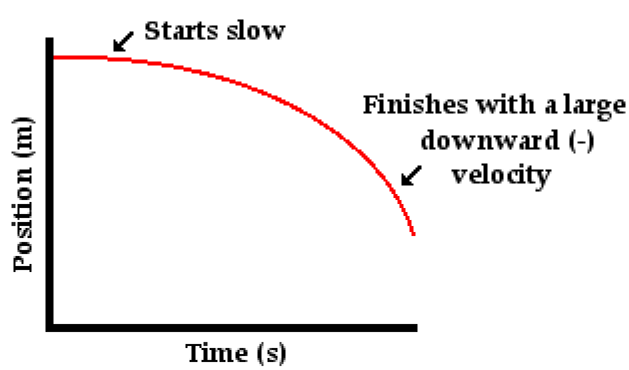
- A free-falling object is an object that is falling under the sole influence of gravity.
- A free-falling object has an acceleration of 9.8 m/s^2, downward (on Earth). This numerical value for the acceleration of a free-falling object is such an important value that it is given a special name. It is known as the acceleration of gravity - the acceleration for any object moving under the sole influence of gravity.
- A matter of fact, this quantity known as the acceleration of gravity is such an important quantity that physicists have a special symbol to denote it - the symbol g. The numerical value for the acceleration of gravity is most accurately known as 9.8 m/s^2.

Representing Free Fall

- Motion Diagram
  - Because free-falling objects are accelerating downwards at a rate of 9.8 m/s^2, a dot diagram of its motion would depict an acceleration. The dot diagram at the right depicts the acceleration of a free-falling object. The position of the object at regular time intervals - say, every 0.1 second - is shown. The fact that the distance that the object travels every interval of time is increasing is a sure sign that the ball is speeding up as it falls downward. Recall that if an object travels downward and speeds up, then its acceleration is downward.

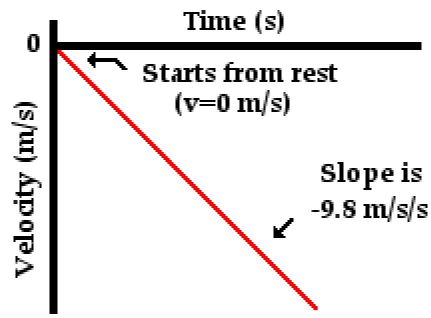


- Position vs. Time Graph
  - A position versus time graph for a free-falling object is shown below.



  - Observe that the line on the graph curves. As learned earlier, a curved line on a position versus time graph signifies an accelerated motion. Since a free-falling object is undergoing an acceleration ($g = 9.8\ m/s^2$), it would be expected that its position-time graph would be curved. A further look at the position-time graph reveals that the object starts with a small velocity (slow) and finishes with a large velocity (fast).

- Velocity vs. Time Graph
  - A velocity versus time graph for a free-falling object is shown below.



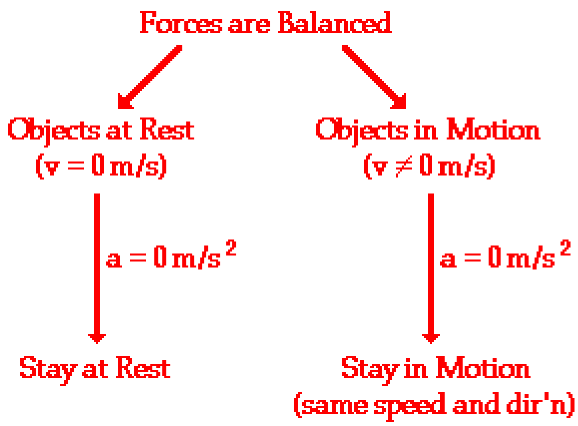
  - Observe that the line on the graph is a straight, diagonal line. As learned earlier, a diagonal line on a velocity versus time graph signifies an accelerated motion. Since a free-falling object is undergoing an acceleration (g = 9.8 m/s^2, downward), it would be expected that its velocity-time graph would be diagonal.
  - A further look at the velocity-time graph reveals that the object starts with a zero velocity (as read from the graph) and finishes with a large, negative velocity; that is, the object is moving in the negative direction and speeding up. An object that is moving in the negative direction and speeding up is said to have a negative acceleration.
  - Since the slope of any velocity versus time graph is the acceleration of the constant, negative slope indicates a constant, negative acceleration. This analysis of the slope on the graph is consistent with the motion of a free-falling object - an object moving with a constant acceleration of 9.8 m/s^2 in the downward direction.

- **<u>Free Fall: Common Misconceptions</u>**

  - The acceleration of a free-falling object (on earth) is 9.8 m/s^2. This value (known as the acceleration of gravity) is the same for all free-falling objects regardless of how long they have been falling, or whether they were initially dropped from rest or thrown up into the air.
  - Yet the questions are often asked "doesn't a more massive object accelerate at a greater rate than a less massive object?" "Wouldn't an elephant free-fall faster than a mouse?" This question is a reasonable inquiry that is probably based in part upon personal observations made of falling objects in the physical world. After all, nearly everyone has observed the difference in the rate of fall of a single piece of paper (or similar object) and a textbook. The two objects clearly travel to the ground at different rates - with the more massive book falling faster.
  - The answer to the question (doesn't a more massive object accelerate at a greater rate than a less massive object?) is absolutely not! That is, absolutely not if we are considering the specific type of falling motion known as free-fall. Free-fall is the motion of objects that move under the sole influence of gravity; free-falling objects do not encounter air resistance. More massive objects will only fall faster if there is an appreciable amount of air resistance present.

Newton's First Law

- In a previous chapter of study, the variety of ways by which motion can be *described* (words, graphs, diagrams, numbers, etc.) was discussed. In this unit (Newton's Laws of Motion), the ways in which motion can be *explained* will be discussed. Isaac Newton (a 17th century scientist) put forth a variety of laws that explain why objects move (or don't move) as they do. These three laws have become known as Newton's three laws of motion. The focus of Lesson 1 is Newton's first law of motion - sometimes referred to as the **law of inertia**.
- Newton's first law of motion is often stated as
  - An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force.
  - There are two parts to this statement - one that predicts the behavior of stationary objects and the other that predicts the behavior of moving objects. The two parts are summarized in the following diagram.



  - The behavior of all objects can be described by saying that objects tend to "keep on doing what they're doing" (unless acted upon by an unbalanced force). If at rest, they will continue in this same state of rest. If in motion with an eastward velocity of 5 m/s, they will continue in this same state of motion (5 m/s, East). If in motion with a leftward velocity of 2 m/s, they will continue in this same state of motion (2 m/s, left). The state of motion of an object is maintained as long as the object is not acted upon by an unbalanced force. All objects resist changes in their state of motion - they tend to "keep on doing what they're doing."
- Inertia: the resistance an object has to a change in its state of motion.
  - Galileo, a premier scientist in the seventeenth century, developed the concept of inertia. Galileo reasoned that moving objects eventually stop because of a force called friction.
  - Isaac Newton built on Galileo's thoughts about motion. Newton's first law of motion declares that a force is not needed to keep an object in motion. Slide a book across a table and watch it slide to a rest position. The book in motion on the table top does not come to a rest position because of the *absence* of a force; rather it is the *presence* of a force - that force being the force of friction - that brings the book to a rest position. In the absence of a force of friction, the book would continue in motion with the same speed and direction - forever! (Or at least to the end of the table top.) A force is not required to keep a moving book in motion. In actuality, it is a force that brings the book to rest.
- Mass as a Measure of the Amount of Inertia
  - All objects resist changes in their state of motion. All objects have this tendency - they have inertia. But do some objects have more of a tendency to resist changes than others? Absolutely yes! The tendency of an object to resist changes in its state of motion varies with mass. Mass is that quantity that is solely dependent upon the inertia of an object. The more inertia that an object has, the more mass that it has. A more massive object has a greater tendency to resist changes in its state of motion
- Balanced vs. Unbalanced Forces
  - Since these two forces are of equal magnitude and in opposite directions, they balance each other. The book is said to be at **equilibrium**. There is no unbalanced force acting upon the book and thus the book maintains its state of motion.
  - If there is an unbalanced force an object changes its state of motion; therefore is not at equilibrium and subsequently accelerates. Unbalanced forces cause accelerations.

The Meaning of Force

- A **force** is a push or pull upon an object resulting from the object's *interaction* with another object. Whenever there is an *interaction* between two objects, there is a force upon each of the objects. When the *interaction* ceases, the two objects no longer experience the force. Forces only exist as a result of an interaction.
- For simplicity sake, all forces (interactions) between objects can be placed into two broad categories:
  - contact forces, and
  - forces resulting from action-at-a-distance
- Force is a quantity that is measured using the standard metric unit known as the **Newton**. A Newton is abbreviated by an "N." To say "10.0 N" means 10.0 Newton of force. One Newton is the amount of force required to give a 1-kg mass an acceleration of 1 m/s/s. Thus, the following unit equivalency can be stated:

$$1 \text{ Newton} = 1 \text{ kg} * \frac{\text{m}}{\text{s}^2}$$

- A force is a vector quantity. As learned in an earlier unit, a vector quantity is a quantity that has both magnitude and direction. To fully describe the force acting upon an object, you must describe both the magnitude (size or numerical value) and the direction.

Types of Forces

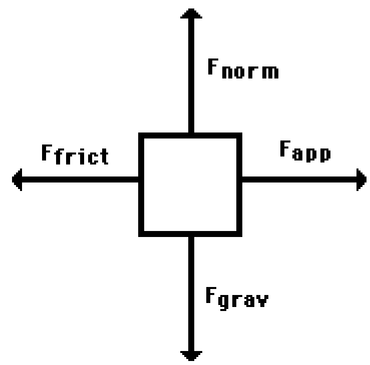
- A force is a push or pull acting upon an object as a result of its interaction with another object. There are a variety of types of forces. Previously in this lesson, a variety of force types were placed into two broad category headings on the basis of whether the force resulted from the contact or non-contact of the two interacting objects.

Contact Forces	Action-at-a-Distance Forces
Frictional Force	Gravitational Force
Tension Force	Electrical Force
Normal Force	Magnetic Force
Air Resistance Force	
Applied Force	
Spring Force	

Type of Force *(and Symbol)*	**Description of Force**
Applied Force F_{app}	An applied force is a force that is applied to an object by a person or another object. If a person is pushing a desk across the room, then there is an applied force acting upon the object. The applied force is the force exerted on the desk by the person.
Gravity Force (also known as Weight) F_{grav}	The force of gravity is the force with which the earth, moon, or other massively large object attracts another object towards itself. By definition, this is the weight of the object. All objects upon earth experience a force of gravity that is directed "downward" towards the center of the earth. The force of gravity on earth is always equal to the weight of the object as found by the equation: **$F_{grav} = m * g$** where g = 9.8 N/kg (on Earth) and m = mass (in kg) (Caution: do not confuse weight with mass.)
Normal Force F_{norm}	The normal force is the support force exerted upon an object that is in contact with another stable object. For example, if a book is resting upon a surface, then the surface is exerting an upward force upon the book in order to support the weight of the book. On occasions, a normal force is exerted horizontally between two objects that are in contact with each other. For instance, if a person leans against a wall, the wall pushes horizontally on the person.
Friction Force F_{frict}	The friction force is the force exerted by a surface as an object moves across it or makes an effort to move across it. There are at least two types of friction force - sliding and static friction. Thought it is not always the case, the friction force often opposes the motion of an object. For example, if a book slides across the surface of a desk, then the

	desk exerts a friction force in the opposite direction of its motion. Friction results from the two surfaces being pressed together closely, causing intermolecular attractive forces between molecules of different surfaces. As such, friction depends upon the nature of the two surfaces and upon the degree to which they are pressed together. The maximum amount of friction force that a surface can exert upon an object can be calculated using the formula below: $$F_{frict} = \mu \bullet F_{norm}$$
Air Resistance Force F_{air}	The air resistance is a special type of frictional force that acts upon objects as they travel through the air. The force of air resistance is often observed to oppose the motion of an object. This force will frequently be neglected due to its negligible magnitude (and due to the fact that it is mathematically difficult to predict its value). It is most noticeable for objects that travel at high speeds (e.g., a skydiver or a downhill skier) or for objects with large surface areas.
Tension Force F_{tens}	The tension force is the force that is transmitted through a string, rope, cable or wire when it is pulled tight by forces acting from opposite ends. The tension force is directed along the length of the wire and pulls equally on the objects on the opposite ends of the wire.
Spring Force F_{spring}	The spring force is the force exerted by a compressed or stretched spring upon any object that is attached to it. An object that compresses or stretches a spring is always acted upon by a force that restores the object to its rest or equilibrium position. For most springs (specifically, for those that are said to obey "Hooke's Law"), the magnitude of the force is directly proportional to the amount of stretch or compression of the spring.

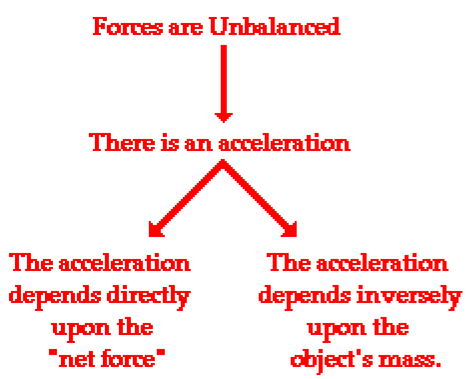
- **<u>Drawing Free-Body Diagrams</u>**
  - Free-body diagrams are diagrams used to show the relative magnitude and direction of all forces acting upon an object in a given situation. These diagrams will be used throughout our study of physics. The size of the arrow in a free-body diagram reflects the magnitude of the force. The direction of the arrow shows the direction that the force is acting. Each force arrow in the diagram is labeled to indicate the exact type of force. It is generally customary in a free-body diagram to represent the object by a box and to draw the force arrow from the center of the box outward in the direction that the force is acting.



  - The free-body diagram above depicts four forces acting upon the object. Objects do <u>not</u> necessarily always have four forces acting upon them. There will be cases in which the number of forces depicted by a free-body diagram will be one, two, or three. There is no hard and fast rule about the number of forces that must be drawn in a free-body diagram. The only ***rule*** for drawing free-body diagrams is to depict all the forces that exist for that object in the given situation. Thus, to construct free-body diagrams, it is extremely important to know the various types of forces. If given a description of a physical situation, begin by using your understanding of the force types to identify which forces are present. Then determine the direction in which each force is acting. Finally, draw a box and add arrows for each existing force in the appropriate direction; label each force arrow according to its type.

- **Determining the Net Force**
  - In the statement of Newton's first law, the unbalanced force refers to that force that does not become completely balanced (or canceled) by the other individual forces. If either all the vertical forces (up and down) do not cancel each other and/or all horizontal forces do not cancel each other, then an unbalanced force exists. The existence of an unbalanced force for a given situation can be quickly realized by looking at the free-body diagram for that situation. Note that the actual magnitudes of the individual forces are indicated on the diagram.
  - It is commonly said that in each situation there is a ***net force*** acting upon the object. The net force is the vector sum of all the forces that act upon an object. That is to say, the net force is the sum of all the forces, taking into account the fact that a force is a vector and two forces of equal magnitude and opposite direction will cancel each other out. At this point, the rules for summing vectors (such as force vectors) will be kept relatively simple.

- **Newton's Second Law**
  - Newton's second law of motion pertains to the behavior of objects for which all existing forces are not balanced. The second law states that the acceleration of an object is dependent upon two variables - the net force acting upon the object and the mass of the object. The acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object. As the force acting upon an object is increased, the acceleration of the object is increased. As the mass of an object is increased, the acceleration of the object is decreased.



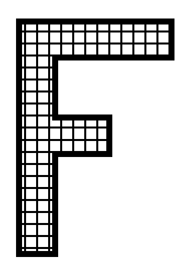
  - Newton's second law of motion can be formally stated as follows:
    - The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.
    - This verbal statement can be expressed in equation form as follows:

$$a = F_{net} / m$$

    - The above equation is often rearranged to a more familiar form as shown below. The net force is equated to the product of the mass times the acceleration.

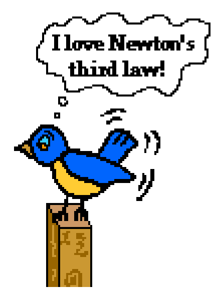
$$F_{net} = m * a$$

  - In this entire discussion, the emphasis has been on the *net force*. The acceleration is directly proportional to the *net force*; the *net force* equals mass times acceleration; the acceleration in the same direction as the *net force*; an acceleration is produced by a *net force*. The NET FORCE. It is important to remember this distinction. Do not use the value of merely "any 'ole force" in the above equation. It is the net force that is related to acceleration



- **Newton's Third Law**
  - A force is a push or a pull upon an object that results from its interaction with another object. Forces result from interactions! Remember, some forces result from ***contact interactions*** (normal, frictional, tensional, and applied forces are examples of contact forces) and other forces are the result of action-at-a-distance interactions (gravitational, electrical, and magnetic forces). According to Newton, whenever objects A and B interact with each other, they exert forces upon each other. When you sit in your chair, your body exerts a downward force on the chair and the chair exerts an upward force on your body. There are two forces resulting from this interaction - a force on the chair and a force on your body. These two forces are called ***action*** and ***reaction*** forces and are the subject of Newton's third law of motion.
  - Formally stated, Newton's third law is: For every action, there is an equal and opposite reaction.
  - The statement means that in every interaction, there is a pair of forces acting on the two interacting objects. The size of the forces on the first object equals the size of the force on the second object. The direction of the force on the first object is opposite to the direction of the force on the second object. Forces always come in pairs - equal and opposite action-reaction force pairs.

  - A variety of action-reaction force pairs are evident in nature.
    - According to Newton's third law, for every action force there is an equal (in size) and opposite (in direction) reaction force. Forces always come in pairs - known as "action-reaction force pairs." Identifying and describing action-reaction force pairs is a simple matter of identifying the two interacting objects and making two statements describing ***who is pushing on whom*** and in what direction**.**
    - Consider the propulsion of a fish through the water. A fish uses its fins to push water backwards. But a push on the water will only serve to accelerate the water. Since forces result from mutual interactions, the water must also be pushing the fish forwards, propelling the fish through the water. The size of the force on the water equals the size of the force on the fish; the direction of the force on the water (backwards) is opposite the direction of the force on the fish (forwards). For every action, there is an equal (in size) and opposite (in direction) reaction force. Action-reaction force pairs make it possible for fish to swim.
    - Consider the flying motion of birds. A bird flies by use of its wings. The wings of a bird push air downwards. Since forces result from mutual interactions, the air must also be pushing the bird upwards. The size of the force on the air equals the size of the force on the bird; the direction of the force on the air (downwards) is opposite the direction of the force on the bird (upwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for birds to fly**.**



    - Consider the motion of a car on the way to school. A car is equipped with wheels that spin. As the wheels spin, they grip the road and push the road backwards. Since forces result from mutual interactions, the road must also be pushing the wheels forward. The size of the force on the road equals the size of the force on the wheels (or car); the direction of the force on the road (backwards) is opposite the direction of the force on the wheels (forwards). For every action, there is an equal (in size) and opposite (in direction) reaction. Action-reaction force pairs make it possible for cars to move along a roadway surface.