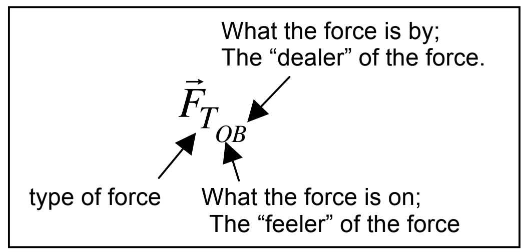
Unit 3, Introduction to Forces
Reading 2, Force Diagrams

Name______________________________

Date_________________Period________

The analysis of a problem in dynamics usually involves the selection and analysis of the relevant forces acting on some object under consideration. An important first step in this analysis process is to carefully select the object of interest that will be the focus of our analysis. For purposes of this analysis, we will refer to the object (or set of objects) under consideration as the **system,** and everything else in the environment that might in any significant way affect the system as the **surroundings**. This analysis process can often times be greatly simplified by utilizing a technique of constructing **force diagrams** (also called free-body diagrams) to assist you in selecting the relevant forces and appropriately representing these forces with **vector** notation.

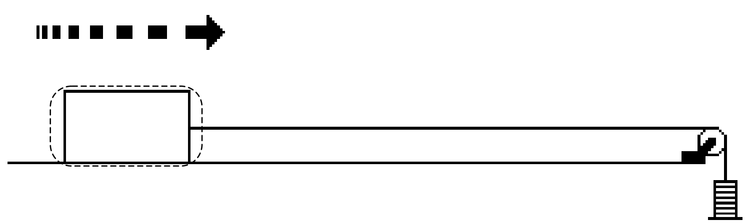
For the purpose of developing a force diagram, all forces will be categorized as either **contact** or **long range** forces. **Contact forces** are all forces acting on the system that result from the contact between the system and its surroundings. These forces include forces of static and kinetic friction, tension forces and normal forces. **Long range** forces result from the interaction of the system with some other body through a force field of some kind, such as magnetic, electric, or gravitational fields.



Each force acting on a system will be labeled using the following system of labels. We will use the symbol $\vec{F}$ to represent the force. The arrow above the F indicates that force is a vector quantity because it has a direction associated with it. We will also use a system of subscripts to indicate the type of force being described, the system that is experiencing the force, and the object that is exerting the force. We will use the following set of subscripts for the various types of forces that we are likely to encounter in this course:

Type of force	Symbol
Normal	N
Gravitational	G
Friction	f
Tension	T
Electrostatic	E
Magnetic	M
Any other Push or Pull	P

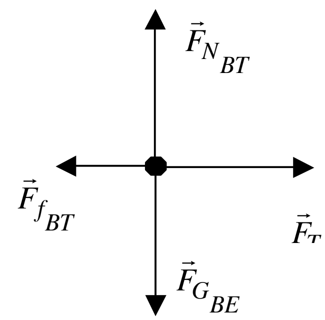
After describing the type of force with the first subscript, the next two subscripts indicate, in order, the object that experiences the force (the victim or "feeler" of the force) and the object that exerts the force (the agent or "dealer" of the force). When describing the feeler and dealer of the force, you can invent a symbol that is descriptive of the object involved. Typically this will be the first letter of the name of the object.



Consider the forces acting on a block being pulled along a horizontal tabletop by a string that is attached to a mass hanger after passing over a pulley. Notice first that the block makes direct contact with both the surface that it is sliding on and with the string.. As the block slides along the surface, it experiences a force opposing its motion because of its contact with the tabletop known as the frictional force. There is also a perpendicular (normal) force that is the result of the table pushing upward against the block to hold it up. There is another contact force (tension force) applied to the block through the string. These forces are all examples of contact forces that result from events that occur at the system boundary. Finally, the system experiences an interaction with the earth by way of a long range gravitational force. This attractive force results from the long range interaction between the block and the earth by way of the earth's gravitational field. This force is often called the weight of the object.

For this example it can be difficult to keep track of each of the forces and their relationships to one another. An analysis of relevant forces is much more meaningful when the sketch of the system is accompanied by vector representations for the relevant forces. After drawing a dashed line around the object or set of objects that you have defined as your system, you will make a diagram that represents the forces acting on that system. This diagram is known as a **force diagram** (sometimes called a free-body diagram). Start by drawing a dot that represents the center of the system. Then draw an arrow to represent each of the forces acting on the system. The arrows should be drawn in proportion to the magnitude of the force. Each of the forces will also be labeled with subscripts that describe the type of force, and the victim (feeler) of the force, and the agent (dealer) of the force. If we let the subscript B represent the block, T the tabletop, S the string, and E the earth, the following designations would represent the relevant forces acting on the block and would be labeled as follows:

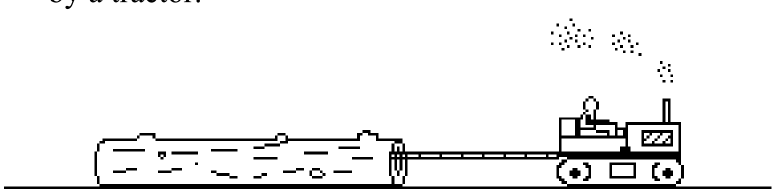
Force	Label
The gravitational force on the block by the earth	$\vec{F}_{G_{BE}}$
The normal force on the block by the table	$\vec{F}_{N_{BT}}$
The friction force on the block by the table	$\vec{F}_{f_{BT}}$
The tension force on the block by the string	$\vec{F}_{T_{BS}}$



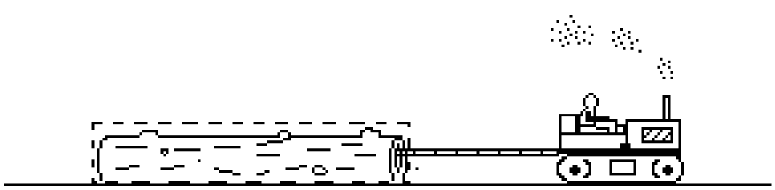
The following steps should be followed when analyzing the forces acting on a system

1. Sketch a physical diagram of the system and its surroundings.
2. Enclose the system within a system boundary, designated by a dashed line.
3. Shrink the system to a point at the center of coordinate axes with one axis parallel to the direction of motion.
4. Represent each relevant force that acts from outside of the boundary of the system by an arrow labeled with the appropriate symbols.

To illustrate this process, consider the forces acting on a log being pulled at a constant speed to the right by a tractor.



Step 1
Sketch a diagram of the system and its surroundings.

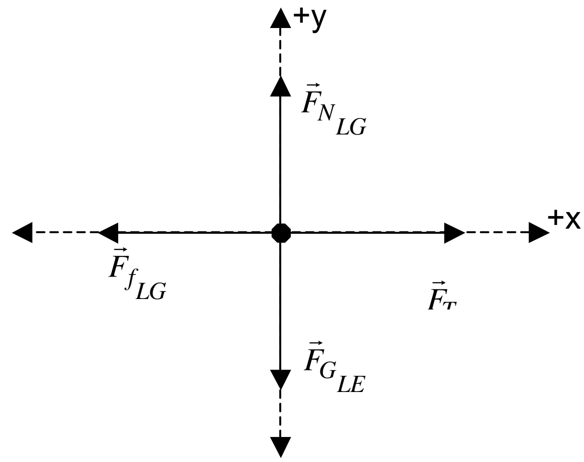


Step 2
Since the log is the system we are trying to analyze, enclose the system (log) within a closed boundary, shown by a dashed line.

Step 3
For this analysis, the shape of the object is unimportant, so to simplify the diagram we will shrink the log to a point. Place it at the intersection of a set of coordinate axes with one of the axes parallel to the direction of motion.

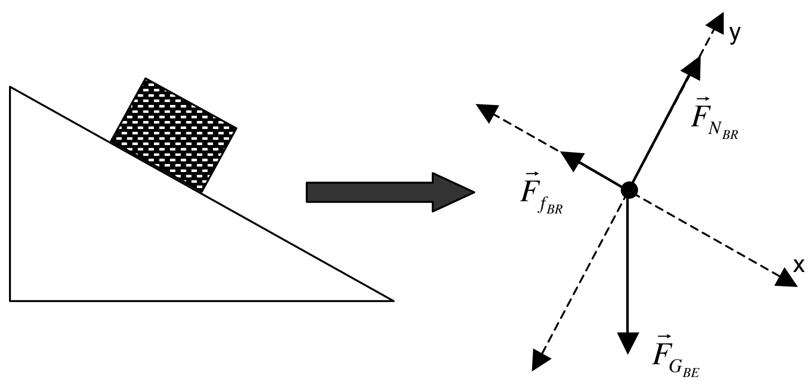
Step 4

Proceed around the system boundary line and identify all points at which there is contact between the system (log) and its surroundings. Construct qualitative vectors (indicating directions and relative magnitudes) to represent these forces. The contact forces would be friction, $\vec{F}_{f_{LG}}$, on the log by the ground, the normal force, $\vec{F}_{N_{LG}}$, (the force that is perpendicular to the ground) on the log by the ground, and the tension force, $\vec{F}_{T_{LC}}$, on the log by the chain. The long range force in this case would be only the force of gravity, $\vec{F}_{G_{LE}}$, on the log by the earth.

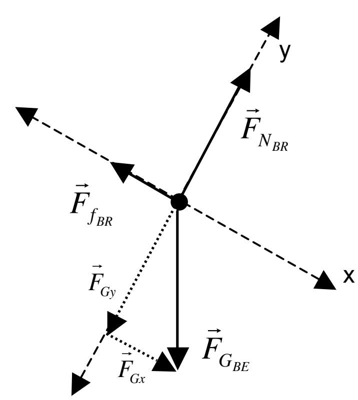


Since the log is moving at a constant velocity, the net force on it must be zero. Since the object is not accelerating horizontally, the forces in the x-direction must be balanced. The friction force vector is drawn to the same length as the tension force vector. These forces add vectorially to zero. This can be stated mathematically as $\sum \vec{F}_x = 0$. Similarly, since the log is not accelerating vertically, the forces in the y-direction must be balanced. The normal force vector is drawn to the same length as the gravitational force vector. These forces add vectorially to zero. This can be stated mathematically as $\sum \vec{F}_y = 0$. Since the forces add up to zero along each axis, the net force is zero. Mathematically, this is stated as $\sum \vec{F} = 0$.

Now consider the block at rest on a ramp as shown to the right. As before, we use a point to represent the object. Note that we have rotated the coordinate axes so that the *x*-axis is parallel to the surface of the ramp (the likely direction of motion), and the *y*-axis is perpendicular to the ramp.



Next, break any force vector that is not parallel to the coordinate axes (in this case, the force of gravity, F_G) into its *x*- and *y*-components. See the diagram at right. Note that the *x*-component and *y*-component form the sides of a right triangle with the original force vector, F_G as the hypotenuse.



In this case, the *y*-component of F_G balances the normal force, so the object does not accelerate perpendicular to the ramp.

The *x*-component of F_G is balanced by the force of static friction. If these forces have the same magnitude, the object will not accelerate parallel to the ramp.

What would happen if the frictional force were smaller than the *x*-component of gravity?