A BIG Deal Forces and Newton's Laws of Motion

Objectives – What You Should Know about Forces and Newton's Laws:

- Describe how forces affect the motion of objects.
- Interpret and construct free-body diagrams.
- Explain the relationship between the motion of an object and the net force acting on it.
- Determine the net external force on an object.
- Predict the direction and magnitude of the acceleration caused by a known net external force.
- Recognize the conditions required for equilibrium.
- Identify action-reaction pairs.

Forces

A force is a vector quantity that is typically described as a *push* or *pull.* Forces cause changes in velocities (accelerations)… more specifically, ***unbalanced forces*** cause changes in velocities The **newton** (**N**) is the SI unit for force… the pound is the English unit for force.

$$1\text{ N} = 1\text{ kg}\cdot\text{m/s}^2$$

Free-Body Diagrams

Free-body diagrams (FBDs) are graphical representations of objects where all forces acting ON the object are represented. ***Forces exerted BY the object ON other objects are not included in the diagram.*** FBDs are important tools we use to analyze the motion of an object based on the forces acting on the object. When you isolate an object, and identify all of the forces acting on it, you can predict how the object will move. But first, we need to understand the rules:

Newton's First Law of Motion *(Law of Inertia)* (BIG IDEA ALERT)

A body in motion will remain in motion *at a constant velocity*, and a body at rest will remain at rest unless acted upon by an unbalanced force.

Inertia is the resistance an object has to changes in its motion. ***Mass*** is a measure of inertia.

Implications of Newton's First Law

A body in motion at constant velocity *does not necessarily require a force to keep it in motion* at constant velocity. If there were no friction, objects moving along a horizontal surface would not slow down. Also, if an object is at rest, or moving with constant velocity, the forces acting on the object MUST BE BALANCED... that is, the sum of the forces is zero.

Okay, but what if there *were* an unbalanced force acting on the object?

Newton's Second Law of Motion (INSANELY BIG IDEA ALERT)

This Greek letter is called "sigma" and, in math, it means summation. ⟶ $\sum \vec{F} = m\vec{a}$

$\sum F$ is the ***summation of forces*** acting on the object under consideration, meaning you add the forces together always remembering that forces are vectors. $\sum F$ may also be called the ***net force***, or the ***unbalanced force***. If there is an unbalanced force acting on an object, the acceleration of the object is directly proportional to the unbalanced force and inversely proportional to the mass of the object.

Implications of Newton's Second

Bigger forces yield bigger accelerations on the same mass. The same net force accelerates a smaller mass more than larger mass.

Newton's Third Law of Motion (PRETTY DARN BIG IDEA ALERT)

For every action, there is an equal and opposite reaction. This statement of Newton's third law sounds so simple, but it is so often misunderstood. It means that for every instance where an object A exerts a force on an object B, object B exerts a force back on object A that is EQUAL in magnitude and OPPOSITE the direction of the force A on B. All interactions of force between two objects always occur in pairs. We call these pairs **action-reaction pairs**.

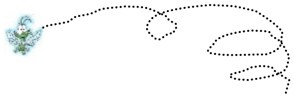
Implications of Newton's Third

On a free-body diagram, these action-reaction force pairs do NOT cancel each other out because the forces are exerted on *different objects*.

If a bug strikes the windshield of a car traveling 70 mph, the force the bug exerts on the car, and the force the car exerts on the car are EQUAL. This may sound preposterous, at first… people tend to think that the force the car exerts on the bug must be greater, because such a collision usually means game over for a bug. However, while the forces the car and the bug exert on each other are EQUAL in magnitude (and opposite in direction), the acceleration of the bug is significantly greater than that of the car, because the bug's mass is so tiny!

$$F_{bug} = F_{car}$$

$$m_{bug}\,\mathbf{a}_{bug} = \mathbf{m}_{car}\,a_{car}$$



Objectives for Forces We Encounter Every Day:

- Explain the difference between mass and weight.
- Determine what forces are acting on an object.
- Determine the direction and magnitude of normal forces.
- Determine the direction and magnitude of frictional forces.
- Determine the direction and magnitude and direction of tension forces

Mass vs. Weight

The ***mass*** of an object is the amount of matter contained by the object… that mass doesn't change, regardless of the position of the object within the universe. The ***weight*** of an object is the magnitude of the force of gravity acting on an object. Weight changes based on an object's position in the earth's gravitational field. The weight of an object near the surface of the earth may be calculated using:

$$F_g = \text{Weight} = mg$$ where g is the ___________________________.

On a free-body diagram, the ***weight*** of an object is always represented with a force vector pointing straight down from the center of mass, towards the center of the earth.

The Normal Force

A ***normal force*** (F_N) is a force exerted by one object on another in a direction perpendicular to the surfaces of contact. The normal force is NOT necessarily opposite the weight of an object (for example: think about an object on an incline).

Friction

Friction is a force that opposes the relative motion of two surfaces in contact. Friction is really a macroscopic effect caused by a complex combination of forces at a microscopic level, when two surfaces are in contact.

Static vs. Kinetic Friction

Static friction is the resistive force that opposes the relative motion of two contacting surfaces that are at rest with respect to each other. ***Kinetic friction*** is the resistive force that opposes the motion of two contacting surfaces that are moving across one another. Kinetic friction (F_k) is less than static friction (F_s). This means that it will take a greater force to overcome static friction when trying to move a stationary object than it would to overcome kinetic friction when moving the same object once it's in motion.

The Normal Force and Friction

The force of friction is proportional to the normal force. The proportionality constant is called the ***coefficient of friction*** ***(μ)***, and its value depends on the surfaces in contact. There are separate coefficients of friction for static ***(μ_s)*** and kinetic friction ***(μ_k)*** and these values may be found experimentally

$$\mu_s = \frac{F_{s\,max}}{F_N} \qquad \mu_k = \frac{F_k}{F_N}$$

Tension

Tension, as it applies to forces, is typically the force that is transmitted through a rope that is pulled tight, and has no slack. Tension forces are always represented as forces parallel to the rope(s), and always pull away from objects (think of a dog pulling on a leash).

Drawing Free-Body Diagrams

- ☑ Isolate the object(s) under consideration, and draw a simple shape representing each object.
- ☑ Draw and label all external forces acting on the object(s).
- ☑ Gravitational forces are always straight down, toward the center of the earth.
- ☑ Normal forces are always perpendicular to the surfaces in contact. If one object is pushing on another, the force is a normal force.
- ☑ Frictional forces are always drawn in the direction opposing motion, parallel to the surfaces in contact.
- ☑ Tensile forces are always drawn away from the objects.

How to Solve Problems

- ☑ Draw an appropriate free-body diagram, correctly labeling all forces acting on the object.
- ☑ Establish a convenient coordinate system. *The direction of the object's motion should be aligned with an axis.*
- ☑ Resolve all forces into components parallel and perpendicular to the object's motion.
- ☑ Write equations using Newton's Second Law ($\sum F=ma$) for each dimension.
    - The sum of the forces perpendicular to the object's motion should = 0 because there is NO acceleration in that dimension
    - The sum of the forces parallel to the object's motion should = ma, because there could be acceleration in that dimension
- ☑ Solve for unknown variables.