Force and Motion

Up to this point, we have simply described the motion of objects. Now, we will try to determine what made (or is making) the objects move the way they do. To do this, we need to introduce the ideas of force and mass.

Force: A force is a push or a pull. The push of pull could be a "contact" force (e.g. a bat hitting a ball) or it could be a non-contact force (e.g. the force of gravity).

Mass: Mass is a quantitative measure of inertia. Inertia is the natural tendency of an object to remain at rest or in motion at constant speed in a straight line.

Newton's Laws

Newton's 1st Law:

When an object is "left alone", it maintains constant velocity.

or

An object continues in a state of rest or in a state of motion at constant speed in a straight line, unless compelled to change that state by a net force.

The net force is the vector sum of all forces acting on an object:

- If there are no forces acting on an object, the net force is zero.
- If there are two forces which are equal in magnitude, but opposite in direction acting on an object, the net force is zero.
- If there is only one force acting on an object, or if the vector sum of all forces acting on an object is not zero, then there is a net force acting on the object.

Do we really believe Newton’s 1st Law?

In your common experience, if you give an object an initial push or a pull - let’s say on a level street, what happens?

• We will assume that after we give the initial push or pull, we stop exerting the force on the object.

• If the object is light (for example, a hockey puck) it will initially move fast.

• If the object is heavy (for example, your car) it will initially move slow (perhaps extremely slow).

• Newton’s 1st Law says that if there is no net force on an object, it should continue to move at constant speed in a straight line.

• However, in both cases, both objects eventually come to a stop. Why?

Do we really believe Newton’s 1st Law?

If you took the hockey puck, and gave it the same push on an ice covered surface, it would move much further, although again, it would eventually stop.

If we think about this for a moment, hopefully we can see that what is happening is that there is another force on each object - this is the force of friction between the ground and the puck or the car.

When the puck is pushed on the ice, the force of friction is much smaller.

If we can imagine a situation in which the force of friction is reduced to zero, then the object will in fact move at constant speed in a straight line (forever).

Newton’s Laws

Newton’s 2nd Law:

When a net force is applied to an object, it accelerates. The acceleration is directly proportional to the net force, and inversely proportional to the mass of the object. The direction of the acceleration is in the same direction as the net force.

$$\sum \vec{F} = m\vec{a}$$

In words, this equation states that the **vector sum** (this is what Σ means) of all forces on an object is equal to the mass of the object times its vector acceleration.

Newton's Laws

Newton's 2nd Law is a vector relationship! In practice, this means the above vector relationship is written as 3 equations:

$\sum F_x = ma_x$ $\Rightarrow$ The sum of the force components along the x direction is equal to the mass times the acceleration along the x-direction.

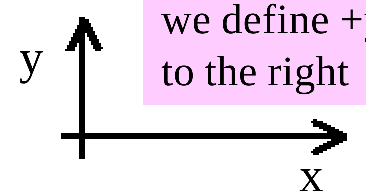
$\sum F_y = ma_y$ $\Rightarrow$ The sum of the force components along the y direction is equal to the mass times the acceleration along the y-direction.

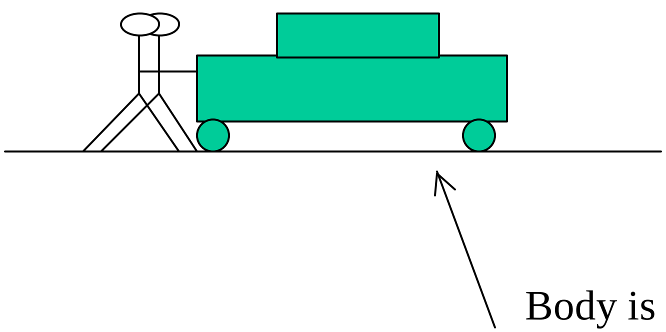
$\sum F_z = ma_z$ $\Rightarrow$ The sum of the force components along the z direction is equal to the mass times the acceleration along the z-direction.

Example: Two people are pushing a car. The mass of the car is 1850kg. One person applies a forces of 275N, while the other applies a force of 395N, both in the same direction. A third force of 560N, due to friction between the car tires and the street, acts on the car, in the opposite direction of the other two forces. What is the acceleration of the car?

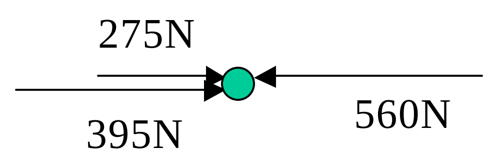
I) First draw a picture of the problem - a free-body diagram:

By drawing the axes like this we define +y as up and +x as to the right





Body is the car



Body is now represented as a dot. Forces are arrows that end or start on this dot.

Example: Continued

II) Now apply Newton's second law:

$$\sum \vec{F} = m\vec{a}$$

$$\sum F_x = ma_x$$

$$+275 + 395 - 560 = (1850)a_x$$

$$a_x = \frac{110\text{N}}{1850\text{kg}} = +0.059\text{m/s}^2$$

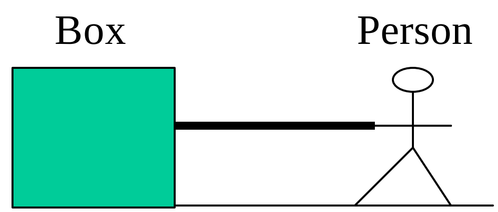
At this point, can we tell:

- the velocity of the car? (Answer is no, but why?)
- the change in velocity of the car? (Answer is yes, but why?)

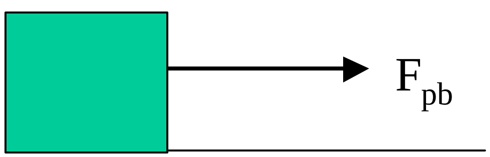
Newton's Laws

Newton's 3rd Law:

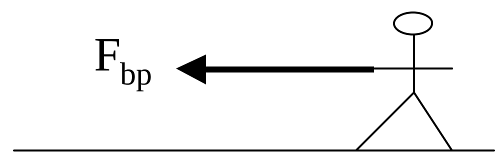
Whenever one body exerts a force on a second body, the second body exerts a force of equal magnitude and opposite direction on the first body.



Force on box:



Force on person:



$$F_{pb} = \text{Force of person on the box}$$

$$F_{bp} = \text{Force of the box on the person}$$

$$F_{pb} = -F_{bp}$$