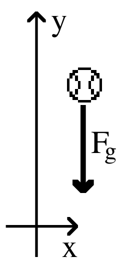
Section 11 – Four Common Forces

Section Outline
1. Weight - The Force of Gravity
2. Tension in Strings
3. The Normal Force from Surfaces
4. The Frictional Force from Surfaces

Why do objects do what they do? We now have an answer – because of the forces acting on them. In this section we'll delve deeper into Newton's Laws by looking at four forces that frequently appear in our everyday world.

1. Weight - The Force of Gravity



The weight of objects is due to the force exerted on them by the gravitational attraction due to Earth, We can get an expression for calculating this force by applying the Second Law to an object in freefall. By the Rule of Falling Bodies, we know the acceleration is g. The Second Law applied to the object in free fall gives,

$$\Sigma\vec{F} = m\vec{a} \Rightarrow -F_g = m(-g) \Rightarrow F_g = mg$$

Note the minus signs are consistent with the coordinates at the left.

The force of gravity is sometimes called "weight." In these notes, it will usually be called "the force of gravity." The term weight implies something possessed by an object. However, by the Third Law we know that forces are exchanged by objects not possessed by them.

Weight is distinct from mass, which is inertia. Mass is a property of an object while weight is a force that is exerted on an object by a large nearby mass like Earth. The relationship between mass and weight can be summarized by,

$$\boxed{\text{The Mass/weight Rule } F_g = mg}$$

The Second Law and the Mass/weight Rule explain the Rule of Falling Bodies (which was it was called it a rule, not a law). Objects that have more mass feel proportionally more force, which means that they wind up with the same acceleration according to the Second Law.

The units of force in the SI system will just be the product of the units for mass and the units for acceleration,

$$[F_g] = [m][g] = \text{kg}\,\tfrac{\text{m}}{\text{s}^2}.$$

We define $1\text{kg}\frac{\text{m}}{\text{s}^2} \equiv 1\text{Newton} = 1\text{N}$. In summary, mass comes in kilograms, while weight comes in Newton's.

Example 11.1: On the average, there are four apples per pound. Find the mass of an average apple.

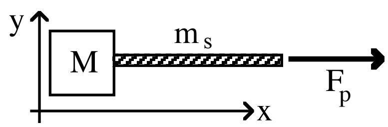
Given: $F_g = 0.250\text{lbs}$
Find: m = ?

You might be tempted to use the rule of thumb that 2.2lb = 1kg. However, this is technically incorrect because it equates a force to a mass. The correct method would be to convert the weight in pounds to a weight in Newtons.

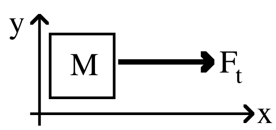
$$F_g = (0.250\,\text{lb})\left(4.45\,\tfrac{\text{N}}{\text{lb}}\right) = 1.11\text{N} \approx 1\text{N} \quad \text{(a coincidence? I think not!)}$$

Using the mass weight rule, $F_g = mg \Rightarrow m = \dfrac{F_g}{g} = \dfrac{1.11}{9.80} \Rightarrow \boxed{m = 0.113\text{kg}}$.

2. Tension in Strings



Imagine pulling on a string attached to a block. We can apply the Second Law to this system,
$\Sigma\vec{F} = m\vec{a} \Rightarrow F_p = (M + m_s)a$.



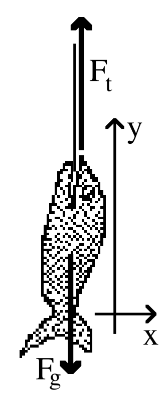
Looking at just the block, the only force on it is the force exerted by the string. This force is called the "tension."
$\Sigma\vec{F} = m\vec{a} \Rightarrow F_t = Ma$.

Solving for the resulting acceleration of the block, $F_t = Ma \Rightarrow a = \dfrac{F_t}{M}$.

Substituting this into the equation above gives, $F_p = (M + m_s)\dfrac{F_t}{M} \Rightarrow F_p = \left(1 + \dfrac{m_s}{M}\right)F_t$.

If the mass of the string is small compared to the mass of the block then $F_p \approx F_t$. In other words, the tension in a light string is transmitted undiminished throughout the entire string.

Example 11.2: A fisherman reels up a 1.20kg fish using 20.0N (4lb) test line. Find the maximum acceleration of the fish if the line is vertical.

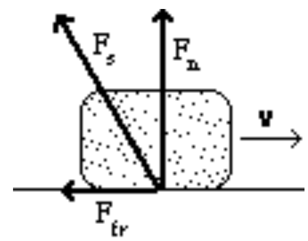


Given: m=1.20kg and F_t=20.0N
Find: a = ?

The forces that act on the fish are the force of gravity and the tension in the line. Applying the Second Law,
$\Sigma\vec{F} = m\vec{a} \Rightarrow F_t - F_g = ma \Rightarrow a = \dfrac{F_t - F_g}{m}$.
Using the mass/weight rule,
$a = \dfrac{F_t - mg}{m} = \dfrac{F_t}{m} - g = \dfrac{20.0}{1.20} - 9.80 \Rightarrow \boxed{a = 6.87\text{m/s}^2}$.
Note that the Second Law is used as a set of instructions to get an equation for this particular situation.

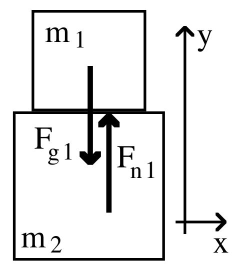
3. The Normal Force from Surfaces

In accordance with the Third Law, all surfaces will exert a force on an object that exerts a force on them. For example, consider a skidding block. The force from the surface has two components. The component along the surface is called “friction.” The component perpendicular to the surface is called the “normal force.” Remember, “normal” is used here to mean perpendicular, not usual or ordinary. We’ll discuss the frictional force in the next section. Let’s look at the properties of the normal force.



Example 11.3: A 20.0kg crate rests on top of a 30.0kg crate. Find (a)the normal force that the 30.0kg crate exerts on the 20.0kg crate and (b)the normal force that the ground exerts on the 30.0kg crate.

Given: m_1=20.0kg and m_2=30.0kg   Find: F_{n1}=? and F_{n2}=?



(a)Looking at only the 20.0kg crate, the only forces that act on it are the weight of the crate and the normal force exerted by the 30.0kg crate. Notice that the acceleration is zero because the crate is at rest. Applying the Second Law,

$$\Sigma\vec{F} = m\vec{a} \Rightarrow F_{n1} - F_{g1} = 0 \Rightarrow F_{n1} = F_{g1}$$

Using the mass/weight rule,

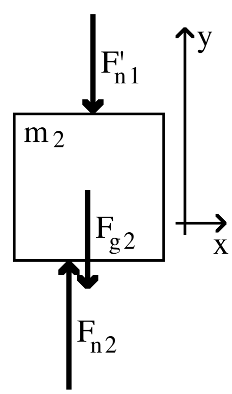
$$F_{n1} = m_1 g = (20.0)(9.80) \Rightarrow \boxed{F_{n1} = 196\text{N}}.$$

(b)Examining only the 30.0kg crate, there are three forces acting on it; gravity, the normal force from the floor and the reaction normal force from the 20.0kg crate. This force is, according to the Third Law, equal and opposite to the normal force found in part (a). Applying the Second Law and the mass/weight rule,

$$\Sigma\vec{F} = m\vec{a} \Rightarrow F_{n2} - F'_{n1} - F_{g2} = 0 \Rightarrow F_{n2} = F'_{n1} + F_{g2} \Rightarrow$$

$$F_{n2} = F'_{n1} + m_2 g \Rightarrow 196 + (30)(9.80) \Rightarrow \boxed{F_{n2} = 490N}$$

Note that the weight of the 20.0kg crate doesn’t act on the 30.0kg crate. It is a normal force that is exchanged between them.

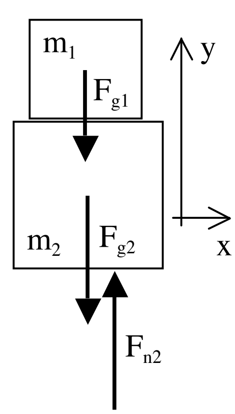


We could have looked at the system of both crates as a whole. In this case, the force that the upper crate exerts on the lower crate and the force that the lower crate exerts on the upper crate are both inside the system, so they don’t show up when we list the forces exerted on the system by objects outside the system. The only forces that appear are the forces of gravity exerted by Earth on each crate and the normal force exerted by the ground, so the Second Law gives,

$$\Sigma\vec{F} = m\vec{a} \Rightarrow F_{n2} - F'_{g1} - F_{g2} = 0 \Rightarrow F_{n2} = F_{g1} + F_{g2} \Rightarrow$$

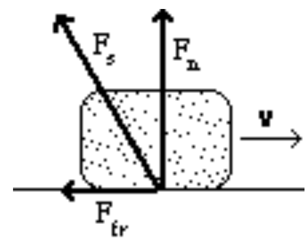
$$F_{n2} = m_1 g + m_2 g \Rightarrow (20)(9.80) + (30)(9.80) \Rightarrow \boxed{F_{n2} = 490N}$$

Notice that we get the same result as before. You can’t change the forces by choosing to look at a different system.



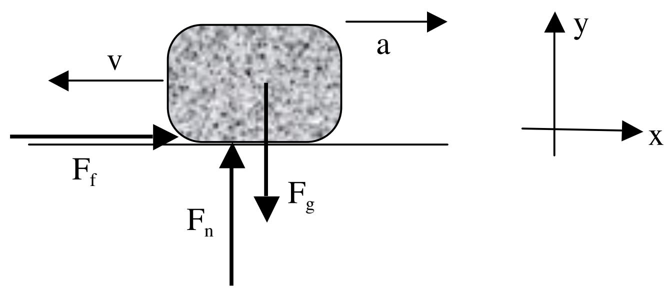
4. The Frictional Force from Surfaces

Returning back to the example of a skidding block. The force from the surface has two components. The component along the surface is called "friction." We'll look at the frictional force in detail in the next section, but get started thinking about it now.



Example 11.4: A 0.500kg block skidding to the left along a table decelerates at 0.300m/s^2. (a)Draw the forces acting on the block. (b)Find the size of each force.

Given: m = 0.500kg and
a = 0.300m/s^2
Find: F_g = ?, F_n =?, and F_f =?



(a)See the sketch at the right. The forces acting on the block are the gravitational, normal, and the frictional. Since the block is moving to the left and slowing, its acceleration must be toward the right. Therefore, the frictional force must be toward the right as well.

(b)The weight can be found using the mass/weight rule,
$F_g = mg = (0.500)(9.80) \Rightarrow \boxed{F_g = 4.90N}$.
Since Newton's Second Law is a vector equation, it can be broken down into two equations; one for the x-direction and one for the y-direction. Along x, only the frictional force is acting,
$\Sigma F_x = ma_x \Rightarrow F_f = ma = (0.500)(0.300) \Rightarrow \boxed{F_f = 0.150N}$.
Along y, the normal forces acts upward (positive) and the gravitational force acts downward (negative).
$\Sigma F_y = ma_x \Rightarrow F_n - F_g = ma_x$
The acceleration is only along the x-axis, so the y-acceleration is zero,
$F_n - F_g = 0 \Rightarrow F_n = F_g \Rightarrow \boxed{F_n = 4.90N}$.
One important idea to take away from this problem is the idea that the Second Law is a vector equation so each force must be broken down into its vector components before using the Second Law.

Section 11 - Summary

Having established Newton's Laws, we began to build an understanding of them by looking at four distinct fours that appear in our everyday world, the force of gravity often called weight, tension in strings, the normal force from surfaces, and the frictional force.

- The relationship between the mass of an object and the force of gravity it feels is summarized by the mass/weight rule $F_g = mg$
- The tension in strings, ropes, cables, and the like is transmitted undiminished throughout the string if the mass of the string is small compared to the other masses in the problem.
- The normal force is always perpendicular to the surface that is exerting it.
- The frictional force is always along the surface that exerts it. Friction will be discussed in more detail in the next section.

In addition we have begun building an appreciation of the fact that the 2^{nd} Law itself is not an equation. Instead, it is a set of instructions that allow us to build an equation to describe the acceleration of an object.