LESSON 2: DYNAMICS I – FORCES, THE CAUSE OF MOTION

1. What is a force?

Watch the following video and try to figure out what the heck is a force.

A force is the **interaction** of a body with something external to it and is capable of
● modifying its state of motion or resting or (we will focus on it).
● causing deformation (we will ignore it).

A force is **vector magnitude**.
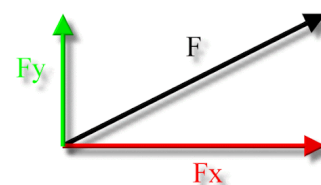
Source: http://zonalandeducation.com/mstm/physics/mechanics/forces/forceComponents/forceComponents.html [Requested on October the 3th of 2021]

There are two general kind of forces:
● contact forces: normal, friction, thrust, ...
● non-contact forces: weight, gravity, electric force, magnetic force, weak and strong nuclear force…
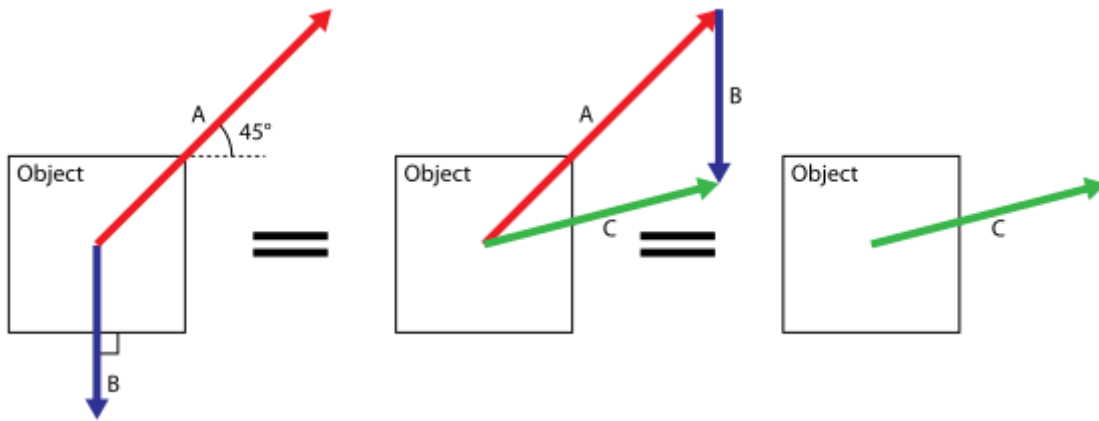
The **units** of force in the international system of units are **Newtons (N)**.

You can review the vector behaviour of forces **in valencian** from this educational blog link: https://fisquimcomval.wordpress.com/2020/10/16/caracter/.
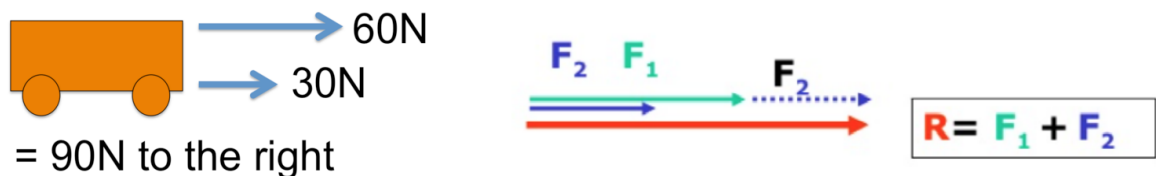
2. How to add forces.

As far as forces are vector magnitudes they have to be handled as such; it means, they have to be added as vectors, and so on…

2.1. How to add parallel forces.

Parallel forces can be vectorially added just by adding their modules as far as they have the same direction and orientation.

2.2. How to add antiparallel forces.

Antiparallel forces can be vectorially added just by subtracting their modules as far as they have the same direction but opposite orientation.
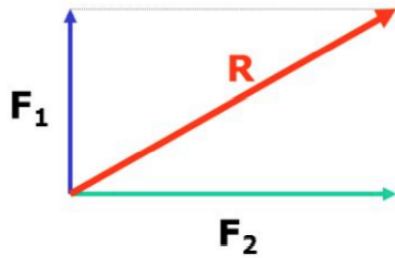
2.3. How to add perpendicular forces.

Antiparallel forces can be vectorially added just by applying the Pythagorean Theorem.

$$R = \sqrt{F_1^2 + F_2^2}$$

2.4. How to add forces in general.

From the graphical point of view vectors can be added by applying the parallelogram rule.

But from the analytical point of view, in order to add to general vectors, you need first to obtain their components.

2.4.1. How to calculate the components of a vector.

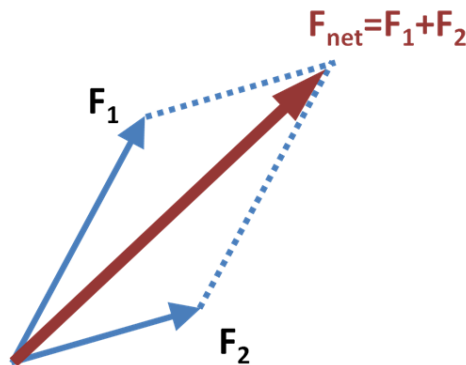To do that we will need to learn a couple of concepts of trigonometry that you will get introduced during this course in maths as well.
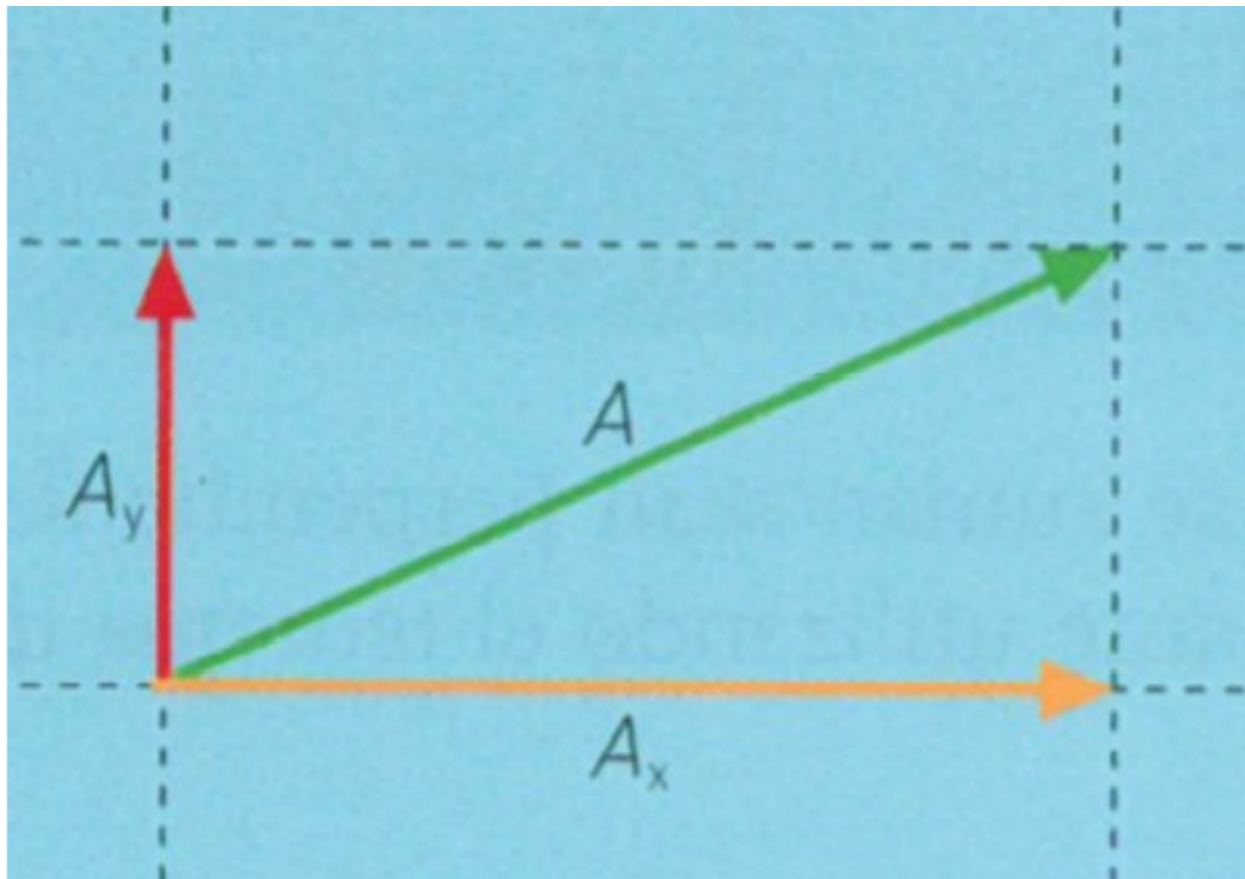
Author: Marisa Cumba, Source: https://mestreacasa.gva.es/c/document_library/get_file?folderId=500019510253&name=DLFE-1512887.pdf
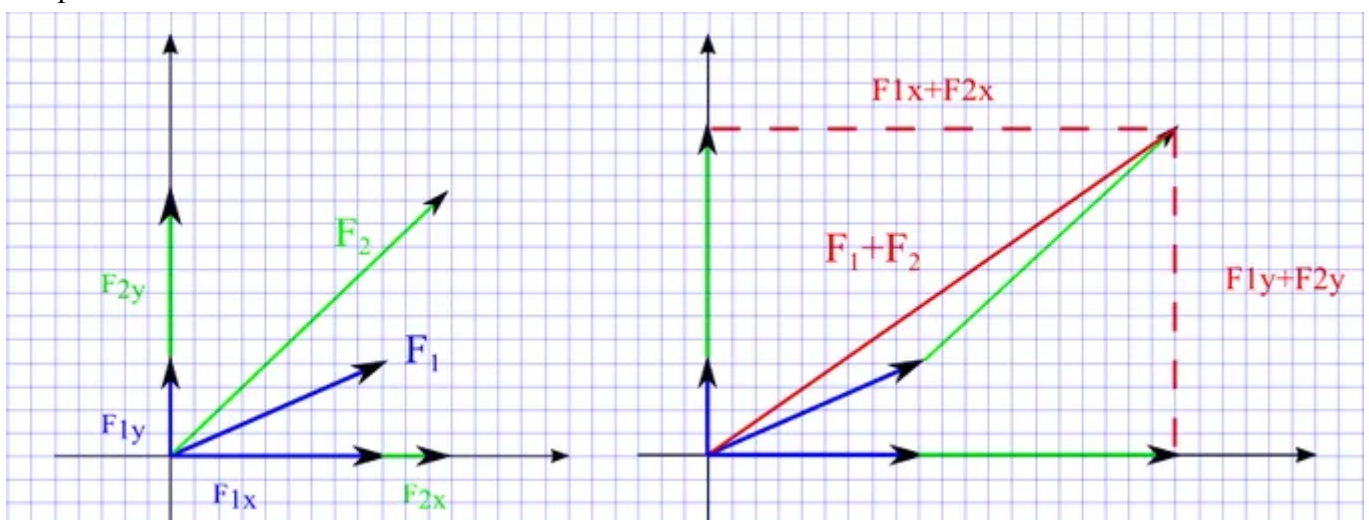
[Requested on October the 16th of 2021]

$$\vec{A} = \vec{A}_x + \vec{A}_y$$

$$sen\,\alpha = \frac{A_y}{A} \rightarrow A_y = A \cdot sen\,\alpha \qquad \cos\alpha = \frac{A_x}{A} \rightarrow A_x = A \cdot sen\,\alpha$$

You can review how to add forces from their components **in valencian** from this educational blog link: https://fisquimcomval.wordpress.com/2020/10/17/composicio-de-forces/.

2.5. Newton 's laws.

Newton summarized the laws of dynamics, this means, the laws describing the cause of motion, in 3 very generic and famous laws.

2.5.1. First law: the law of inertia.
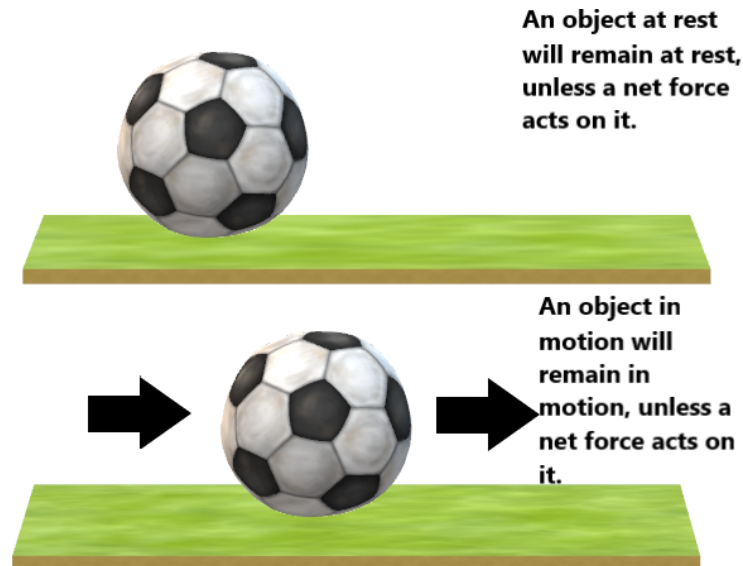

An object at rest will remain at rest, unless a net force acts on it.

An object in motion will remain in motion, unless a net force acts on it.

Author:Sally Jaktas (from an article written by the contribution of manandeep1610), Source: https://www.geeksforgeeks.org/newtons-first-law-of-motion/
[Requested on October the 16th of 2021]

In other words, an object following an URM will continue with this unless a net force acts on it. In the particular case of the object resting, this will remain resting if any net force acts on it.
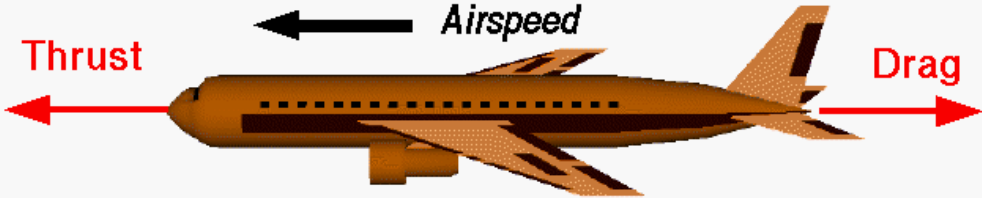
This page is intended for college, high school, or middle school students. For younger students, a simpler explanation of the information on this page is available on the Kids Page.

Newton's First Law
Applied to Airplanes

Glenn Research Center

Airspeed

Thrust

Drag

"Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."

When flying at a constant altitude :
If Thrust and Drag are equal, aircraft holds constant airspeed.

Author:NASA, Source: https://www.grc.nasa.gov/www/k-12/airplane/newton1.html [Requested on October the 16th of 2021]

2.5.2. Second law: the law of acceleration.

F = ma

In other words, when a net force acts on an object, this is accelerated in such a way, that the force is proportional to the mass of the object and the acceleration of it.
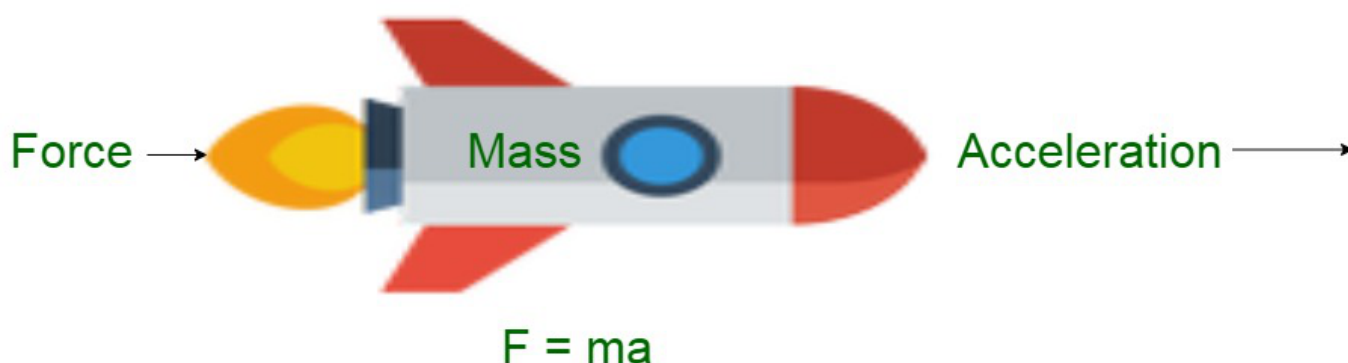
$$\sum_{i=1}^{N} \vec{F_i} = m \cdot \vec{a}$$
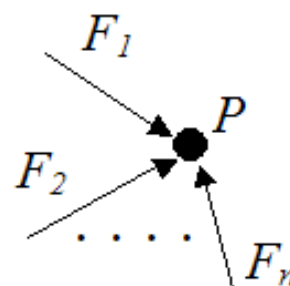
$$\sum \vec{F} = (\vec{F_1} + \vec{F_2} + ... + \vec{F_n}) = m\vec{a}$$

$$\sum F_X = F_{1X} + F_{2X} + .. + F_{nX}$$

$$\sum F_Y = F_{1Y} + F_{2Y} + .. + F_{nY}$$

$$\xrightarrow{+} \sum F_x = F_{1x} + F_{2x} + F_{3x} + ...$$

$$\uparrow^{+} \sum F_y = F_{1y} + F_{2y} + F_{3y} + ...$$

2.5.3. Third law: the law of action and reaction.

If a body acts on another with a force (<mark>action</mark>), the former reacts against the latter with a force equal in its value, but oriented in the opposite direction (<mark>reaction</mark>).
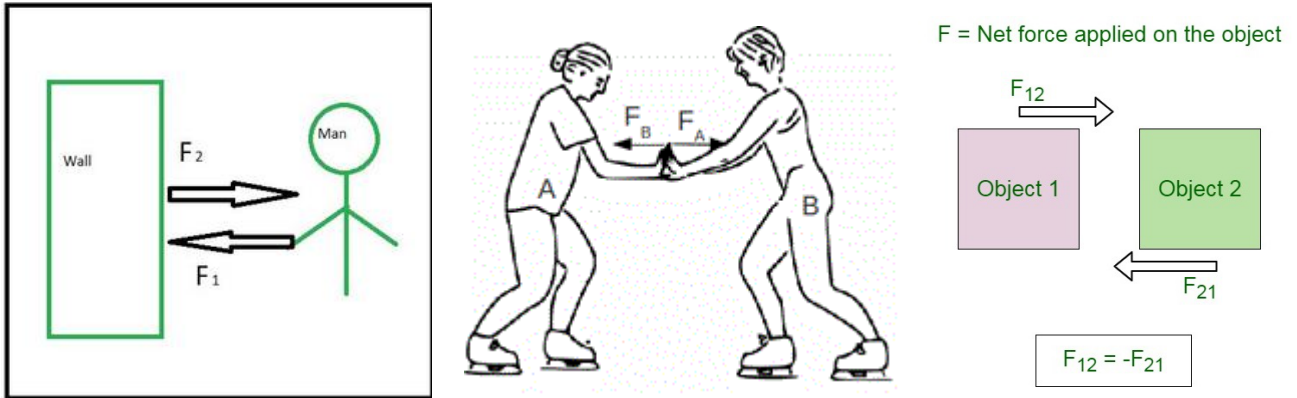
$$\vec{F}_{B \text{ on } A} = -\vec{F}_{A \text{ on } B}$$

On the left: Author: Sally Jaktas (from an article written by the contribution of saikatmohanta43434),
Source: https://www.geeksforgeeks.org/newtons-first-law-of-motion/
In the middle: Author: Benjamin Crowell (Wikipedia user bcrowell), Source =
https://commons.wikimedia.org/wiki/File:Skaters_showing_newtons_third_law.svg
On the right and below: Author: Sally Jaktas (from an article written by the contribution ofcodersgram9),
Source: https://www.geeksforgeeks.org/newtons-first-law-of-motion/
[All of them requested on October the 16ᵗʰ of 2021]
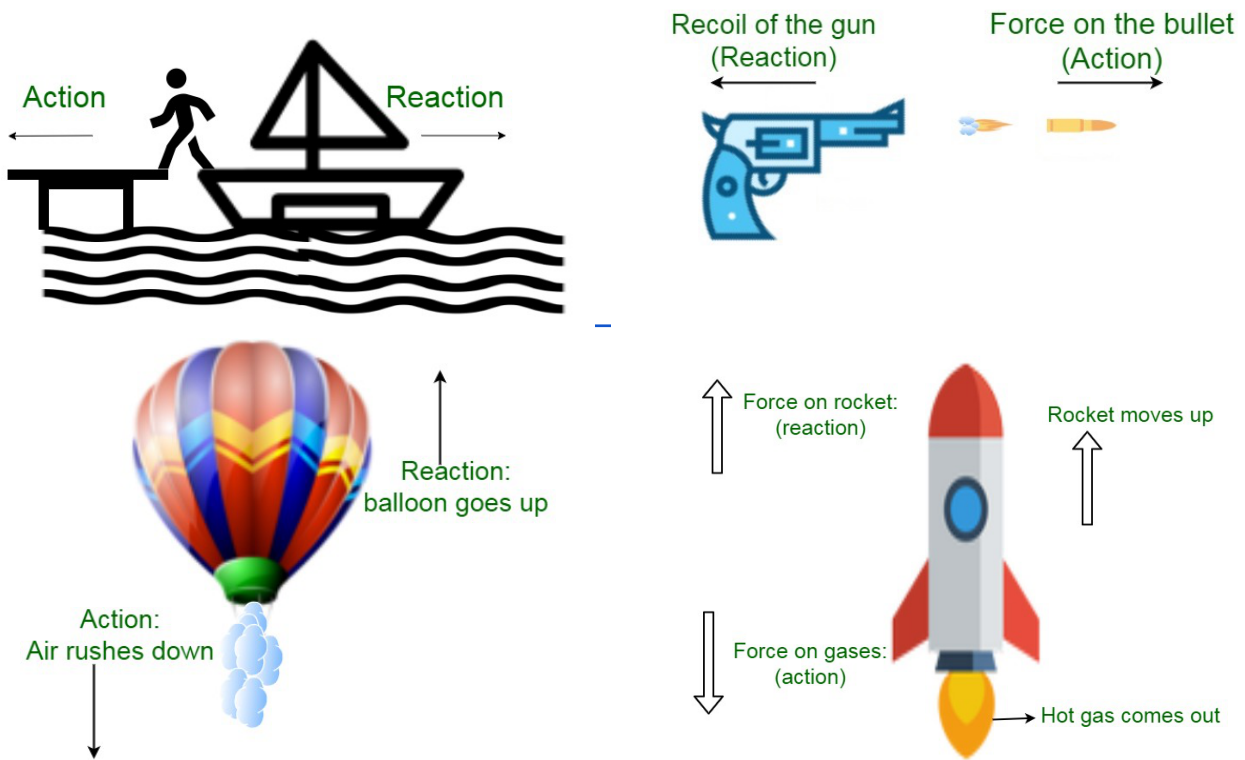
<mark>You can review the 3 Newton's laws **in valencian** from this educational blog link:</mark>
https://fisquimcomval.wordpress.com/les-lleis-de-newton/.

3. Main kind of forces.
3.1. The weight.

The weight is a force always pointing out to the center of the Earth in such a way that it transfers to all the bodies the acceleration of the gravity discovered by Galileo when they lie on or near the surface of the Earth. That's why the weight can be calculated as just:

Weight is another word

for the force of gravity

P = m·g, whereas g = 9,8 m/s².

$$F_g = mg = W$$

3.2. The Normal force.

The normal force (N) is a reaction force, it means, a force resulting from the application of the third Newton's law, which has to have just the value required for the net force along its axis to be null. This force is always perpendicular to the surface of contact.
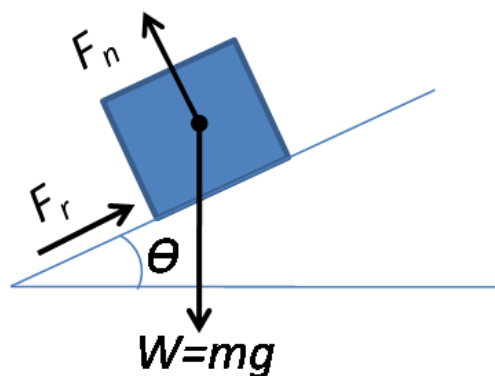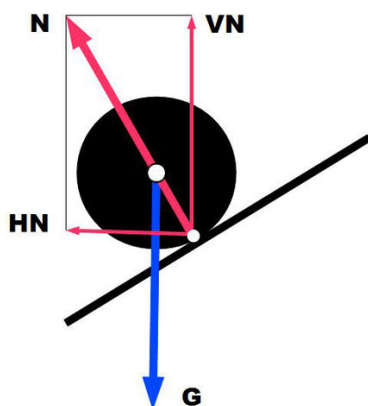
3.3. The friction force.

The friction force acts when a body moves on another in such a way that due to the contact of both surfaces the movement is braked. This means that the friction force is always oriented against the directions in which a body is moving. This force depends on the coefficient of friction which always takes a value between 0 and 1 ($0 \leq \mu \leq 1$) and the normal force.

$$\begin{cases} P = N \\ F - Fr = Fi \end{cases}$$

$P = mg$

$F_f \leq \mu N$
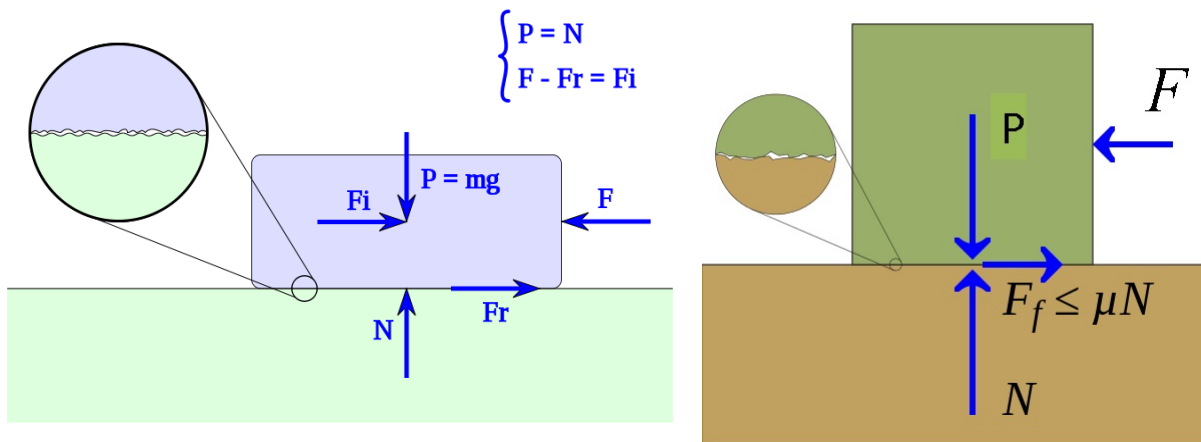
On the left: Author:HiTe, Source: https://commons.wikimedia.org/wiki/File:Fricci%C3%B3n_02.svg
On the right: Author:By Keta, Pieter Kuiper, Source: https://commons.wikimedia.org/wiki/File:Friction.svg
[Both requested on October the 16th of 2021]

So, $F_f = \mu \cdot N$.

3.4. The tension force.

The tension force is a reaction force that is transmitted through a string when this is in tension with the same value in both directions.
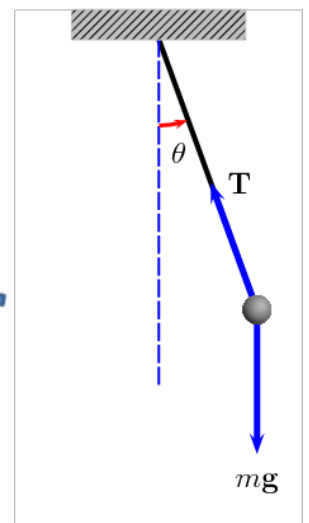
On the left: Author:John Moore, Source: https://commons.wikimedia.org/wiki/File:Tug_Of_War_Tension.png
On the right: Author: Ruryk, Source: https://commons.wikimedia.org/wiki/File:PenduloTmg.gif [Both requested on October the 17th of 2021]

In the pendulum the tension force just guarantees that the net force along the axis that is moving with the string is always null. We will see in the proper section how the tension affects when it is combined with an inclined plane.

3.5. The gravitational force.

The gravitational force is a force related to the attraction of two bodies due to their own mass. In fact, the weight is a particular case of this force. <mark>Since our plan is to dedicate a full lesson to it, we are not going to specify more details here. In order to mathematically define this force we will need to learn a bit of uniform circular motion (UCM) before</mark>.
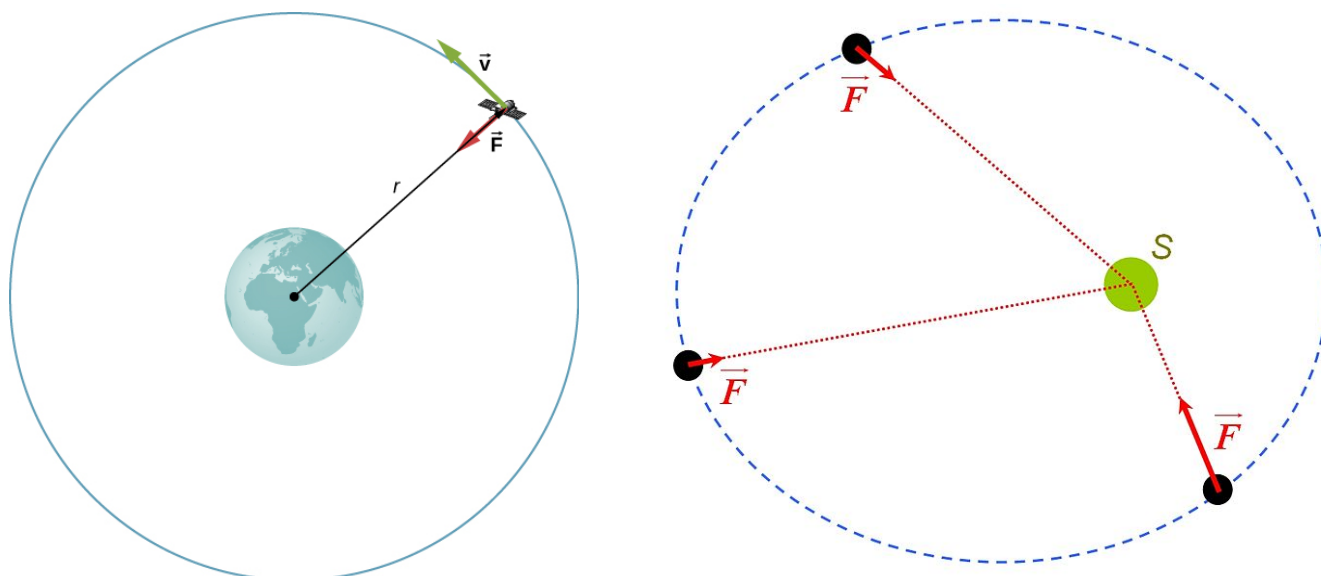
On the left: Author:OpenStax University Physics, Source: https://commons.wikimedia.org/wiki/File:CNX_UPhysics_13_04_orbit.png
On the right: Author: Tomasz59, Source: https://commons.wikimedia.org/wiki/File:GravitationalForces.jpg [Both requested on October the 17th of 2021]

3.6. Other important forces.

There are other important forces that we are not going to study yet. But anyway is nice, at least, to mention a few words about them:

- **Electrical force:** this is the force that is acting between two bodies or particles depending on their electrical charges, which values can be positive or negative.

  The force between bodies having charges with the same sign are repulsive, while the force between changes of the opposite sign are attractives.

  We start studying this force in the matter of Physics and Chemistry at the end of bachelors first going deeper in it in Physics of bachelors second.
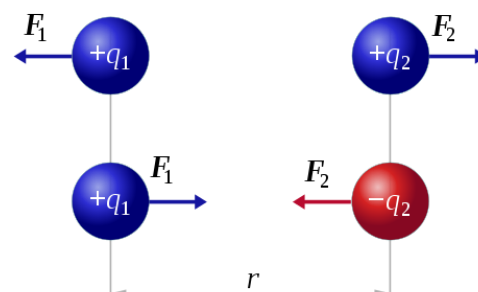
$$|F_1| = |F_2| = k_e \frac{|q_1 \times q_2|}{r^2}$$

Author: Dna-Dennis, Source: https://commons.wikimedia.org/wiki/File:CoulombsLaw.svg [Both requested on October the 17th of 2021]

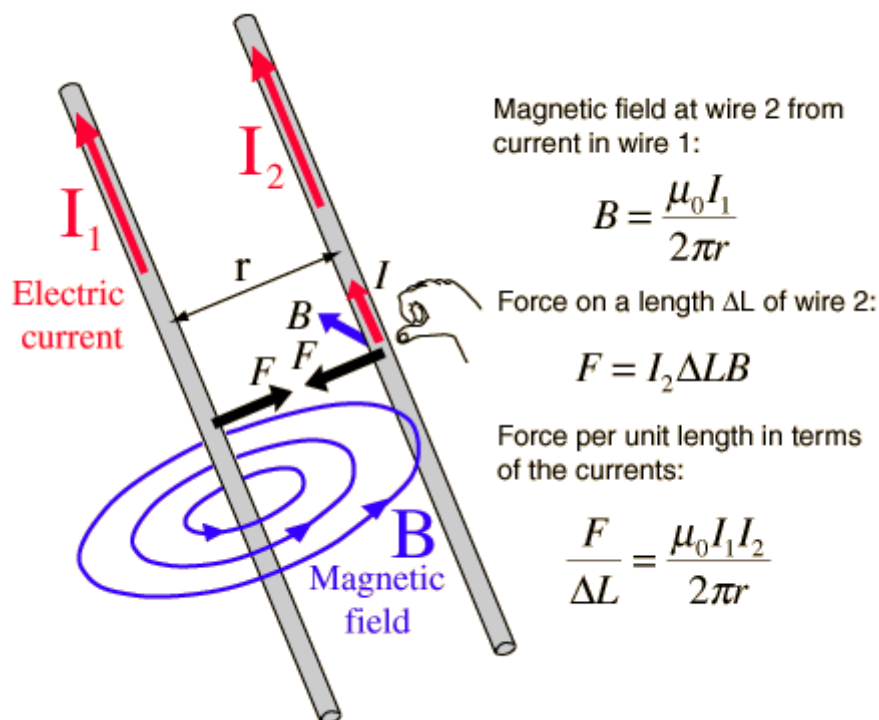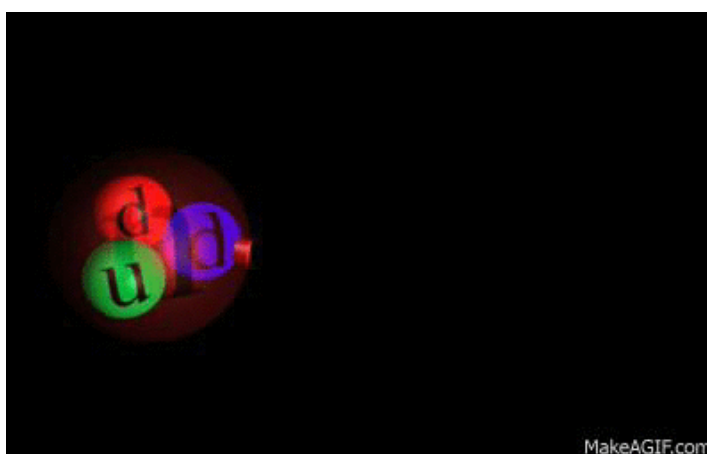- **Magnetic force:** this is a force acting between electrical charges in motion, this including electric currents. We all know of this force by its relation with magnets.

Magnetic field at wire 2 from current in wire 1:

$$B = \frac{\mu_0 I_1}{2\pi r}$$

Force on a length ΔL of wire 2:

$$F = I_2 \Delta L B$$

Force per unit length in terms of the currents:

$$\frac{F}{\Delta L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Author: P.Sumanth Naik, Source:https://commons.wikimedia.org/wiki/File:F_bw_wires.png [Both requested on October the 17th of 2021]

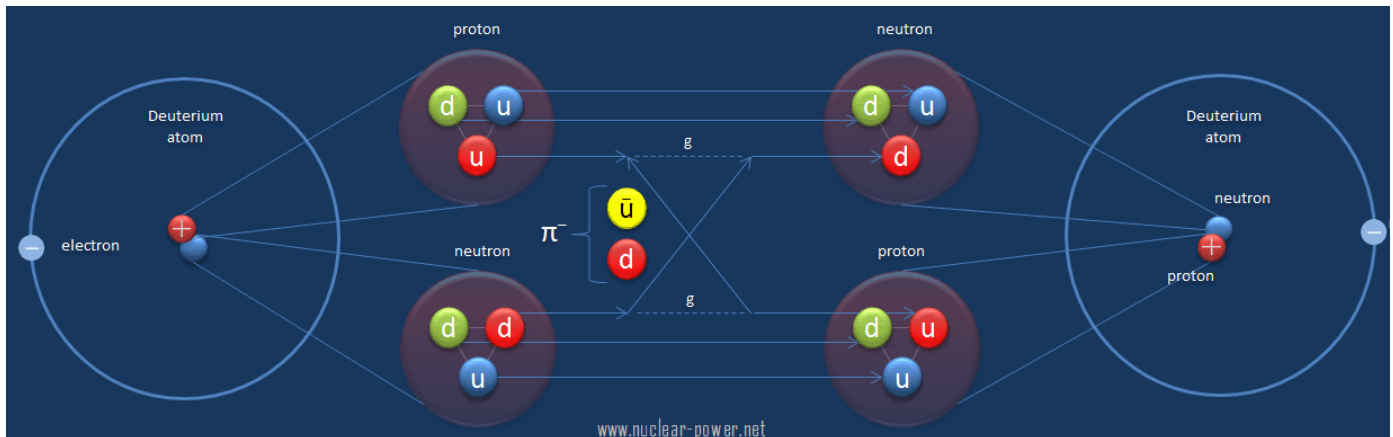We study this force and its introductory formulation in Physics of bachelor second.

- **Nuclear weak force:** this is the strangest force out of all forces. It acts only between elementary particles when they really passt very close to each other, provoking that they suddenly change to another type (or flavour) of elementary particle.

Author:https://i.stack.imgur.com/Dnyd1.gif, Source: https://physics.stackexchange.com/questions/562319/what-exactly-does-the-weak-force-do
[Requested on October the 17th of 2021]

This force is just mentioned in Physics of bachelor second and it is studied only in the Degree of Physics. This force cannot be handled as other forces that you have seen so far, but as an interaction.

- **Nuclear strong force:** the strong nuclear force acts between the particles protons and neutrons (among others) are made of: the quarks, keeping them together.

This force is just mentioned in Physics of bachelor second and it is studied only in the Degree of Physics. This force cannot be handled as other forces that you have seen so far, but as an interaction.

4. Main kind of problems.

In order to resolve any problem or exercise of dynamics it is highly recommended to always follow some steps:

1.   Draw a picture representing the context and add to it any variables related to it, such as distances or angles, …
2.   Draw as vectors all the forces that are acting and label them properly (usually with a letter and eventually another letter or abbreviation as a subindex and a narrow on it indicating its vector nature).
3.   Choose how to place and orient your system of coordinates. You could even draw the axes.
4.   Draw and label the components of these vectors not matching with any of the axes.
5.   Calculate these components from the angle they depend on, which you should properly add to the picture, sometimes deducing it from any other angle you know by applying trigonometry rules.
6.   In each axis, apply the second Newton's law, taking into account:
    6.1.   If it moves along this axis, the net force must be equal to the mass by the component of the acceleration along it (it will usually match with the module as far as it will move along a unique axis).
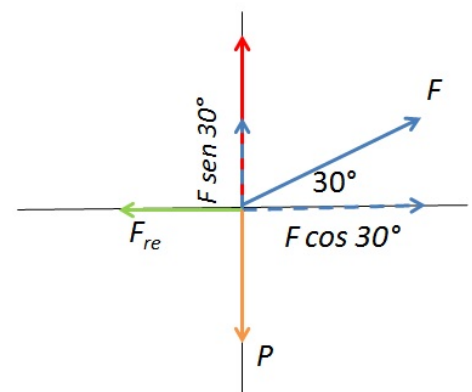
Alberto Cajal. (18 de junio de 2019). Fricción: tipos, coeficiente, cálculo, ejercicios. Lifeder. Recuperado de https://www.lifeder.com/friccion/

6.2.   If it doesn't move along this axis, the net force has to be equal to just zero (because, of course, the acceleration will have to be zero).

7.   Calculate all the forces from the expressions or ways you know (weight, normal, friction,...).
8.   Replace all the expressions and/or values of the variables involved in the equations written in step 6.
9.   Solve these equations by calculating the value/s of the variable/s you were asked to determine.

4.1. Horizontal plane.

The problems where the objects lie on a horizontal plane are usually simpler. Forces like the weight and the normal are always present. In some cases we also have to consider the force of friction, but not always. And this does not mean that other forces cannot be present. We will have to learn how to solve this kind of exercise regardless of the specific forces (more or less) that are acting by reading very carefully the text and "translating" all the information into the picture.

4.1.1. Without friction.

In this case the scheme or picture of the forces might look like this:
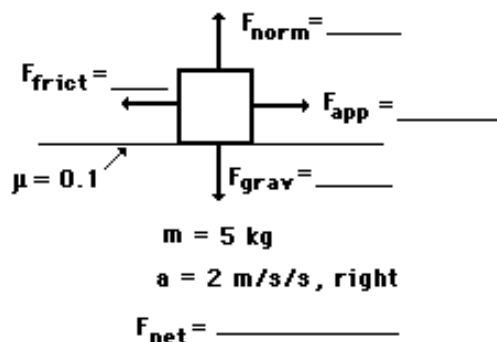

$$N = mg - F\sin(x)$$

$$N = mg + F\sin(x)$$
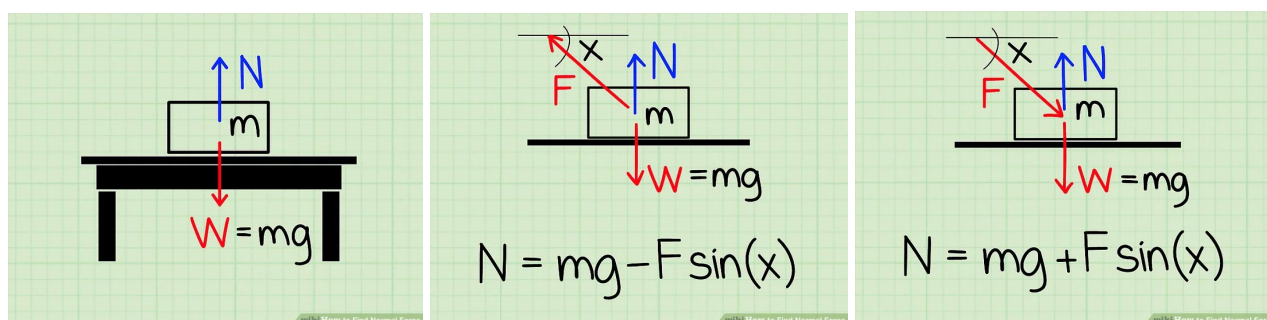
Author:16 co-authors, Source:https://www.wikihow.com/Find-Normal-Force [Requested on October the 17ᵗʰ of 2021]

Look at how the normal force should be calculated in these cases.

4.1.2. With friction.

In this case the scheme or picture of the forces might look like this. Let's fill the gaps...

Author:Tom Henderson, Source: https://www.physicsclassroom.com/class/newtlaws/Lesson-3/Finding-Individual-Forces
[Requested on October the 17ᵗʰ of 2021]

4.2. Inclined plane.

This is the more typical exercise at this level. The key for the inclined planes is the relationship between the angle of the plane and the one to decompose the forces acting on a body that lies on the plane. But, as in the previous section, ee will have to learn how to solve this kind of exercise regardless of the specific forces (more or less) that are acting by reading very carefully the text and "translating" all the information into the picture.

4.2.1. Without friction.

The picture of an inclined plane without friction might look like the image below, although eventually other forces could act in case the exercise specifies them. In the image on the right, you can see how the value of the normal force could be calculated in case no more forces are acting.
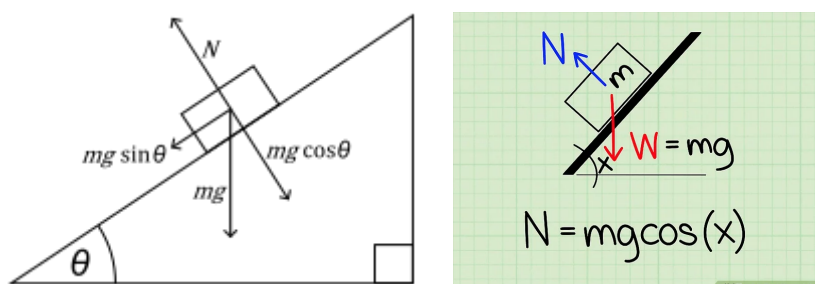

On the left: Author:Mets501, Source: https://en.wikipedia.org/wiki/File:Free_body_frictionless.svg [Requested on October the 17th of 2021]
On the right: Author:16 co-authors, Source: https://www.wikihow.com/Find-Normal-Force [Requested on October the 17th of 2021]

How could you calculate the angle of an inclined plane given the length and the height of a given track? Look at the answer by clicking on this link.

4.2.2. With friction.

The picture of an inclined plane without friction might look like the image below, although eventually other forces could act in case the exercise specifies them.
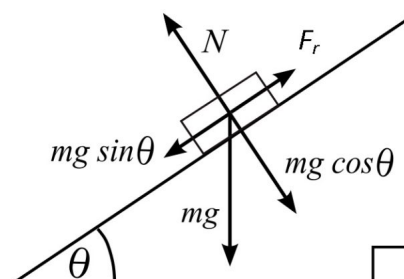
Friction in inclined plane [By Mets501(https://commons.wikimedia.org/wiki/File:Free_body.svg)] [Requested on October the 17th of 2021]

As we saw in the previous subsection, the normal force can be calculated like this.
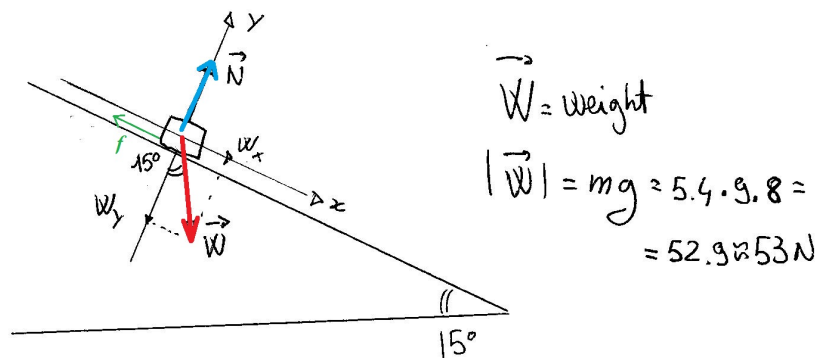
$$\vec{W} = \text{weight}$$

$$|\vec{W}| = mg = 5.4 \cdot 9.8 = $$
$$= 52.9 \approx 53 N$$

$$W_x = W \sin(15°) = 13.7 N$$
$$W_y = W \cos(15°) = 51.2 N$$

Newton's Second Law : $\boxed{\sum \vec{F} = m\vec{a}}$

along Y) $N - W_y = 0$

$$N = W_y = \underline{51.2 N}$$

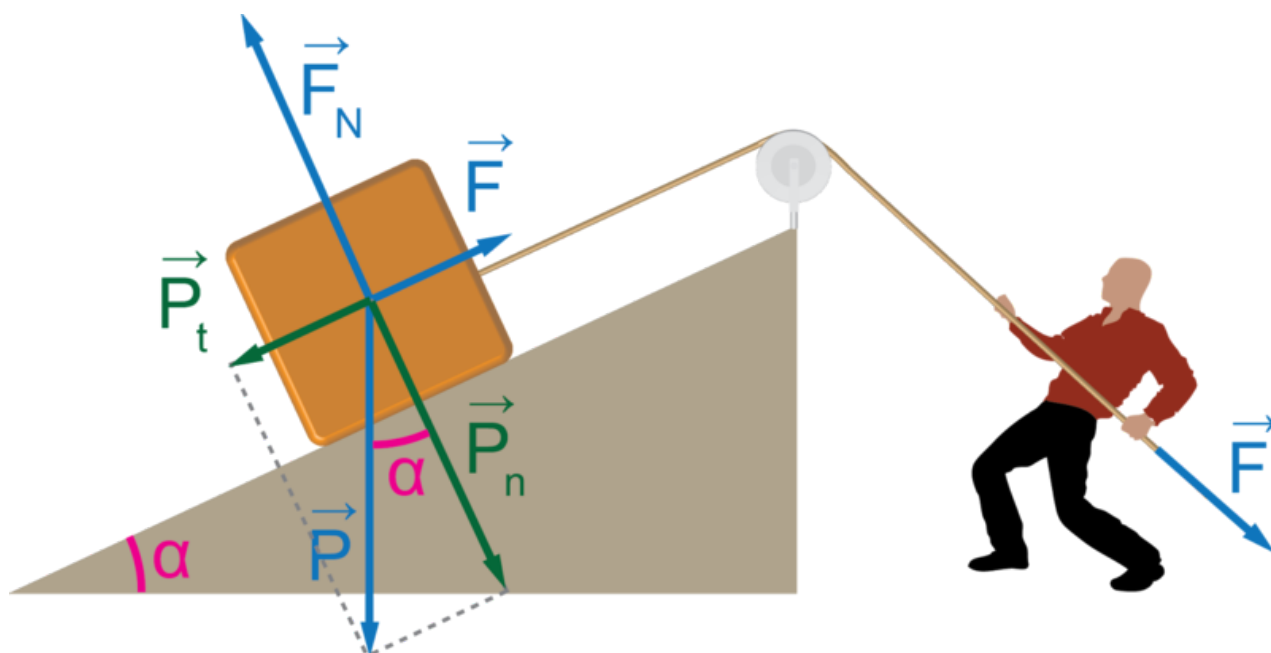This is a more generic schema of forces.
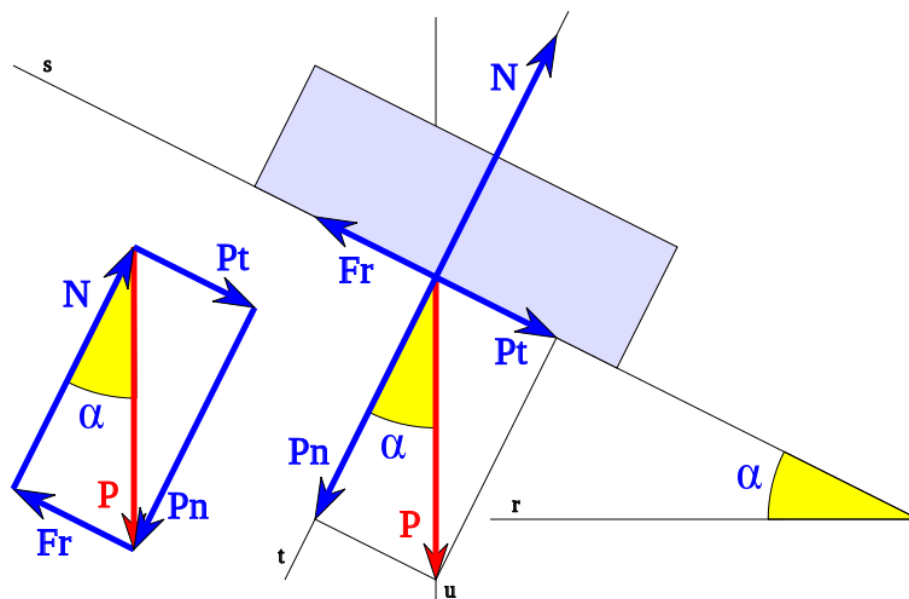
And this would be a still more generic case in which an inclined plane, a string and pulley is used.

In that case the tension force associated with the tension of the string will have to be taken into account. You can write the equations based on the laws of dynamics by separating them for each of the bodies involved in the exercise and using a proper system of coordinates for each of them.
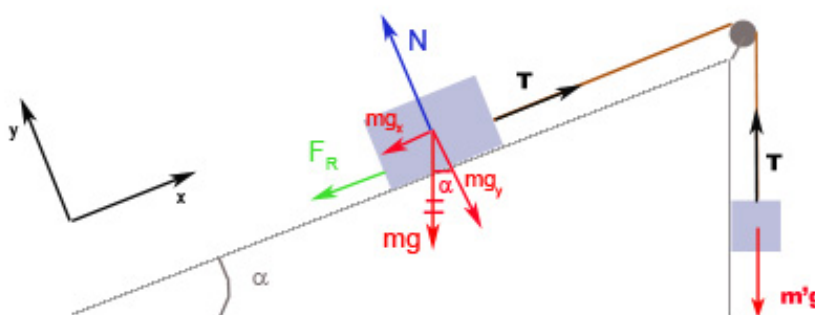
You can see an example on how to do that in http://hyperphysics.phy-astr.gsu.edu/hbase/incpl.html. You can see another example animated if you scroll down in this page until the applet available at the bottom: http://www.sc.ehu.es/sbweb/fisica3/dinamica/roza_inclinado/roza_inclinado.html.

You can review the most important kind of forces ant typical exercises associated to them **in valencian** from this educational blog link:
https://fisquimcomval.wordpress.com/forces-quotidianes-pes-normal-i-centripeta/