Physics 1 Mechanics - Dynamics (Newton's Laws of Motion)

With kinematics, we studied the motion of bodies, but we did not discuss how and why these objects move. In short, forces are what make bodies move and dynamics is the study of the connection between these forces and the motion they produce. One of the biggest contributors to our understanding of dynamics is Isaac Newton. Newton's most widely known contributions are often summarized as "Newton's Three Laws of Motion". The laws can be stated as follows.

Newton's First Law: If there is no net force on a body its ***velocity*** will not change, that is the acceleration will be zero.

Newton's Second Law: The magnitude of the acceleration of a body is directly proportional to the magnitude of the net force acting on it and inversely proportional to the mass of the body. The direction of the acceleration is in the same direction as the net force. Mathematically we can write this relationship as follows:

$$\boldsymbol{a} = \frac{\sum \boldsymbol{F}}{m}$$

The equation is more commonly written as by multiplying through by the mass:

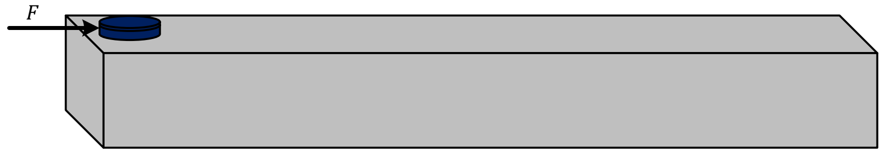
$$\sum \boldsymbol{F} = m\boldsymbol{a}$$

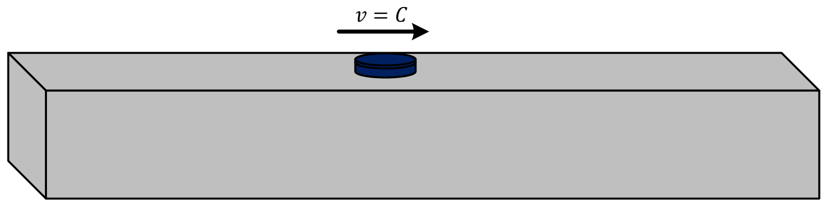
Newton's Third Law: When body 1 exerts a force on body 2 body 2 will exert an equal in magnitude but opposite in direction force on body 1.

Let's look more closely at each law get more familiar before we move onto example problems.

Newton's First Law Example:

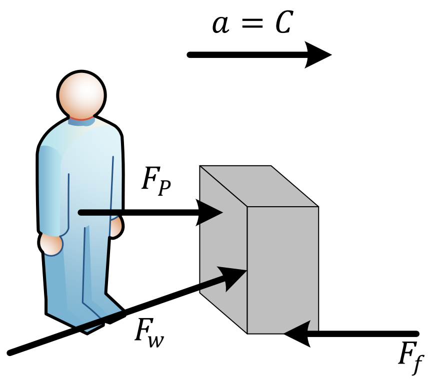
Assume we have a disk at rest on a completely frictionless surface that is infinitely long somewhere deep in space where there are no other forces to act on the disk. Newton's first law says that the disk will remain at rest forever unless a net force acts on it. Let's further assume that somehow you could provide a momentary small force to push the disk so that it begins to slides across the surface with a certain velocity. With no other forces acting on the disk Newtown's first law again says that the disk will continue to slide with the same velocity forever.





Newton's Second Law Example:

Assume a person is pushing a box with mass 10 kg across a non-smooth surface where the wind is blowing in the north east direction. We observe that the box is accelerating at 2 m/s^2 in the x-direction as a result of the forces acting on the box, i.e., pushing force, friction force, and wind force.



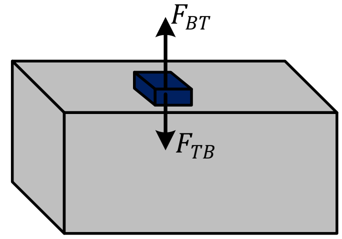
Regardless of the individual forces Newton's second law gives us a way to exactly compute the net force acting on the box in the direction of the movement, namely:

$$\sum F = ma$$
$$F_{net,x} = 10 * 2$$
$$F_{net,x} = 20\ N$$

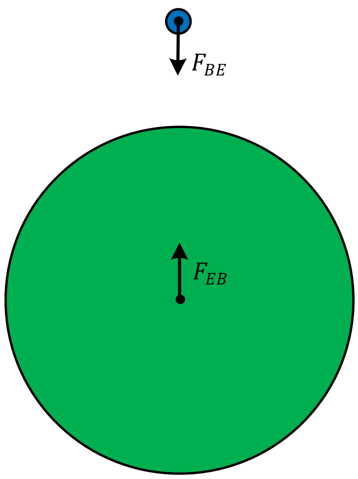
Newton's Third Law Example:

When discussing the third law we need to be careful that the two forces we consider are directly from the two interacting bodies. A simple example is that of a book sitting on a table. The two bodies are the book and the table. The book is applying a force on the table downwards, F_{TB}, (for the indices we say on the table ,T, by the book, B), and the table is applying an upward force on the book with the same magnitude, therefore we have:

$$F_{BT} = -F_{TB}$$



Another interesting example is that of a ball that is dropped from the rooftop of a building, which will be accelerating toward the ground. Recall from Newton's first law, since the ball is accelerating there must be a force acting on it. This is the force form the earth "pulling down" on the ball, which we call the gravitational force, F_{BE}.



To apply this to Newton's third law we need understand that gravity is a force that acts between any two bodies and therefore the ball is also "pulling up" on the earth, F_{EB}. These forces are again related through the third law as follows:

$$F_{BE} = -F_{EB}$$

It may seem strange that the ball applies the same magnitude force on the earth that the earth applies to the ball, however let's examine the acceleration of these two objects caused by these forces.

For sake of simplicity, lest say the mass of the ball is $1\ kg$. The mass of the earth is $5.98E^{24}\ kg$. The acceleration of the ball is then given by the net force acting on the ball, F_{BE}, divided by the mass of the ball.

$$a_B = \frac{F_{BE}}{1} = F_{BE}$$

Similarly, the acceleration of the earth is then given by the net force acting on it, $F_{EB} = -F_{BE}$, divided by the mass of the earth.

$$a_E = \frac{-F_{BE}}{5.98E^{24}} = -F_{BE} \cdot 1.67E^{-25}$$

Substituting F_{BE} from the first equation, $a_B = F_{BE}$, we can find the acceleration as compared to the acceleration of the ball.

$$a_E = -a_B \cdot 1.67E^{-25}$$
$$a_E = -0.00000000000000000000000016722408 a_B$$

As you can see the acceleration of the earth is MUCH smaller than the acceleration of the ball!

Final Summary for Dynamics – Newton's Three Laws of Motion

Newton's First Law
If there is no net force on a body its ***velocity*** will not change, that is the acceleration will be zero.
Newton's Second Law
The magnitude of the acceleration of a body is directly proportional to the magnitude of the net force acting on it and inversely proportional to the mass of the body. The direction of the acceleration is in the same direction as the net force. Mathematically we can write this relationship as follows: $$\boldsymbol{a} = \frac{\sum \boldsymbol{F}}{m}$$ The equation is more commonly written as by multiplying through by the mass: $$\sum \boldsymbol{F} = m\boldsymbol{a}$$
Newton's Third Law
When body 1 exerts a force on body 2 body 2 will exert an equal in magnitude but opposite in direction force on body 1.

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