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Explanation of Newton's laws with simple and accessible experiments to anyone

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Abstract— In this paper one proposes the accomplishment of different demonstrative experiments and of classroom, by means of which we achieve the base to explain the essence of Newton's laws, achieving a major attention and motivation of the pupil. These experiments are simple and that anyone can accede to them, that is to say, experiments of low economic cost but with enormous value from a pedagogic point of view.

Index Terms—Demonstrative experiments, Newton's laws, pedagogical value.

I. INTRODUCTION

Carrying out experiments plays an important role in learning, since it gives the students first hand information about the elements which are the object of their study.

The students observe, manipulate, measure, take down notes, organize; their attention is strongly attracted and they are therefore motivated. They develop abilities and skills in the preparation, execution, development, modeling and evaluation of results.

Experiments, the explanatory sessions as well as the laboratory tests, can and should be presented more than once. In this way, the students can go from the Phenomenon to the Essence of the object under study through the completion of successive trials. Therefore, the experiments can be carried out at the beginning of a topic to create motivation and to situate themselves during the laboratory sessions; they can also be used in solving problems, in seminars and even in exams [1].

The experiments must be carried out by the students as part of their curricular studies within the time and space established for this purpose, and not as a formal additional activity. Otherwise, they will have no pedagogical value.

In the following pages, we shall see ways of explaining "The Laws of Newton" through simple experiments easily accessible to anybody; that is to say, experiments that have low economic cost but are of great value in the teaching field.

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II. THE NEWTON'S FIRST LAW

The first law about mechanical movement to be studied is the *law of inertia*: "The state of repose or of uniform rectilinear movement of a body is maintained while no bodies act upon them or when the influence of these is compensated" [2]-[4].

In this definition, two situations are considered. In the first place, there is no interaction with another body, and Secondly, when interaction occurs, the actions taken upon the same body are compensated. The analysis of both situations is of great value to understand that the natural state of the bodies is when in movement, and this is an intrinsic property of the same. For a body to move with constant speed, it does not need any internal moving force. Therefore, the natural state of the bodies is the condition of being in motion. This means that the cause of the variation in the state of repose or of uniform rectilinear movement of a body cannot be found in the body itself, but in an external agent. The experience that the students have in their daily life apparently constitutes a contradiction in relation to the essence of the first law. The fact that the bodies keep their state of repose if no other bodies act upon them or if their actions are compensated, does not create any doubt in the students. What is most difficult for them to understand is the fact that the bodies keep their constant speed under these conditions.

It is necessary for the students to understand that no experiment can confirm the law of inertia with absolute accuracy [5]. The experiments only confirm that the smaller the interaction is, the less change there will be in the speed of the body. If we maintain this way of reasoning (on the basis of abstraction or idealization), we come to the conclusion that if a body is not acted upon by other bodies, it will conserve its state of movement.

Galileo proved that the speed reached by a body tied to a pendulum is the same as that which it would have if it fell freely from a similar height or altitude (see Figure 1). This means that the speed reached by the body does not depend on the way taken, but simply on the height from which the body moves. This was proved by the following experiment [6]:

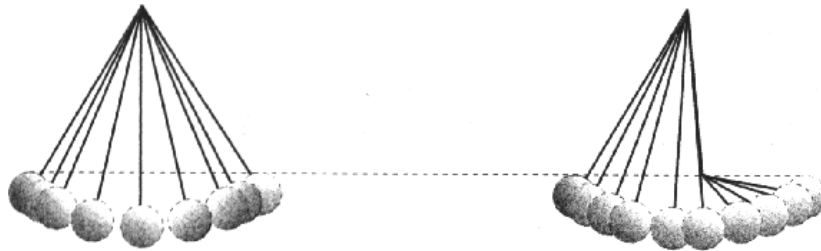


Fig. 1. Galileo's pendulum. It appears that the sphere always comes to the same height in the symmetrical side, independently wherefrom we place the obstacle

If the pendulum is released from height AB, it will oscillate until C and will continue until D, practically up to the same height as A. The ideal speed acquired in the fall from D to C is sufficient to take it to A again. If we put an obstacle on the way of the string, in M, the body will swing through a different way in E; it will take sufficient speed in C only to swing and reach A once more: "The way through which a body falls does not vary its speed; the speed depends only on the height or the distance from where the body has fallen". Another experiment conducted by Galileo is that we can observe in Figure 2:

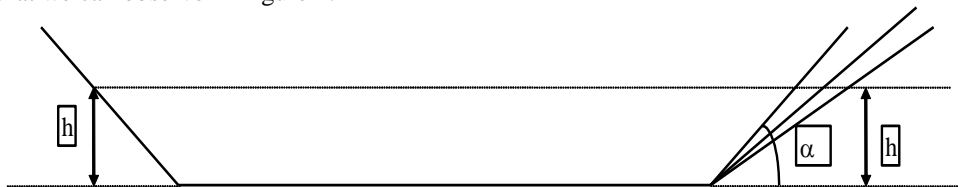


Fig.2. Inclined plane of Galileo

The body that goes down from height h acquires a speed that on passing C, allows it to reach the same height on the other side of the inclined surface. As h is decreased, it continues its way upwards until it reaches the same height, but it travels a larger space in a longer time. If the plane is situated in a totally horizontal position and there is almost no friction, the body moves indefinitely at the speed of C. That is to say: any body that is put into movement on a horizontal plane without friction continues moving indefinitely with constant speed ". (Law of Inertia). Other experiments related to this idea can be the following:



Fig.3. Cart going down for a sloping plane and being less and less rubbing in his way for the horizontal plane

In the Figure 3, we drop the cart and remove some sand. At first, the cart will stop; then it will go over the sand but with difficulty, and when all the sand is removed, it will move with the speed it takes on a horizontal plane. In the experiment of Figure 4, if we give the cart an impulse, it will move from its position while the smaller cart will maintain its position in relation to the floor; that is to say, it will maintain its state of repose.



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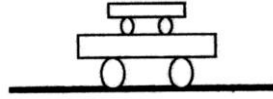


Fig.4. Experiments with a cart on a larger

If we first make both carts move with a uniform rectilinear movement and then stop the bigger cart, it maintains its state of movement in relation to the table, without accelerating until it is affected by the action of the other bodies (it may be because of friction or because of an object that stops it). These experiments are evidence of the phenomenon called *inertia*:

It refers to the fact that bodies conserve their state of movement. This phenomenon is more clearly seen as we reduce to the maximum, the actions that other bodies can exert upon them.

From the point of view of methodology, the difficulty that exists in the study of the law of inertia is related to the impossibility to create the ideal conditions in which this law is fulfilled “exactly” or with “accuracy”. The experiments shown can be considered only as approximate views, from which we can obtain certain theoretical ideas.

It is important that the teacher establish the difference between inertia as a physical phenomenon and the state of having inertia as a property of bodies. Inertia is present in the same way in all bodies: in a molecule as well as in a huge stone. The law of inertia is fulfilled with equal accuracy: speed is maintained in a constant way if the action of other bodies upon them is compensated. In relation to the fact that bodies in general have the property of inertia, we have to make another consideration: if during interaction, two bodies acquire different accelerations, this means that during the same interval of time the interaction lasts, and the bodies vary their speed in a different way. Therefore, bodies can be differentiated because of their inertness and we shall consider this state of inertia as an intrinsic property of bodies. The essence of this property lies in the fact that there is no such body that can vary its speed instantaneously. This always requires a certain time [7]. Hang up a heavy rope of a wire that can withstand a weight slightly higher than the load, as shown in the Figure 5:

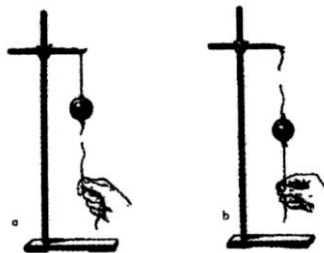


Fig.5. In the first figure there is demonstrated that if it throws itself sharply of the thread the low thread breaks. In the second figure there is demonstrated that if it throws itself softly the top thread breaks

If we pull the lower part of the thread brusquely, this will break; but if we slowly pull the same thread, gradually increasing the force, the upper part of the thread (in relation to the load) will break. For the upper part of the thread to break, it must go through complementary stretching. This means that the load must start to move. If we make a brusque pull, the hand acts upon the load for a very brief moment and the load does not have enough time to start any movement. This is why the lower part of the thread breaks.

III. THE NEWTON'S SECOND LAW

The second law of Newton or the Fundamental Equation of Dynamics can be expressed in these terms: “When a force or a set of forces act upon a body, an acceleration is produced in that body, and this is proportional in magnitude, in direction and sense of force to the resulting force or net force”.

This is mathematically expressed with the following equation:

$$\vec{F} = m \cdot \vec{a} \rightarrow \vec{a} = \frac{\sum \vec{F}^{est}}{m} \quad (1)$$

We can consider the following experiments [7]: We can see in Figure 5, a dynamometer connected to a cart that can be moved along. At the other end of the dynamometer, we fix a string that goes through a pulley which sustains a load (M).

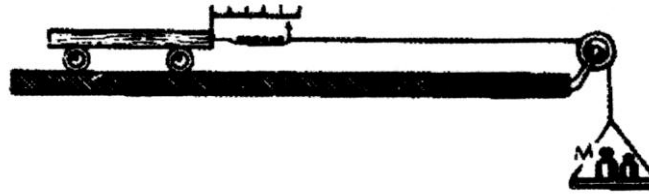


Fig.6. Cart accelerated by a load

From the readings in the dynamometer, we can determine the force that acts upon the cart. If we place a dropping glass in the cart, as seen in Figure 7, we can easily calculate the acceleration produced. If we place a drip cup in the carriage, we can easily calculate the acceleration produced, by tracing the paths traveled by the cart in its accelerated motion in different time intervals.

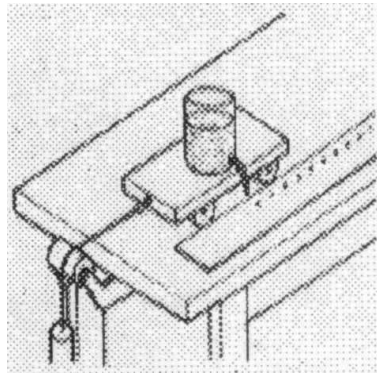


Fig.7. Shopping with dropper

The gauging indicates that the space travelled is proportional to the square of the time employed. Since the force is constant, we have a uniformly accelerated movement.

$$s = \frac{1}{2} a t^2 \Rightarrow a \quad (2)$$

Relationship between force and acceleration:

We hang different loads, gauge the forces with the dynamometer and calculate the acceleration, resulting in that the force is directly proportional to acceleration.

$$\frac{a_1}{a_2} = \frac{F_1}{F_2} \quad (3)$$

Relationship between the acceleration and mass:

The cart is acted upon with a constant force. If we load the cart with weights, we vary the mass of the system in movement. We shall now calculate the acceleration obtained by the cart.

The acceleration of the cart with weights is inversely proportional to its total mass.

$$\frac{a_1}{a_2} = \frac{m_2}{m_1} \quad (4)$$

Therefore, the results of the experiments show that: “The acceleration with which a body moves is directly proportional to the force that acts upon this body and is inversely proportional to the mass of the same”. Newton's second law. When various forces act upon a body, we can say that the acceleration of the body is provoked by the resulting force of these forces.

- It is convenient to indicate the characteristics of the concept force and of the second law of Newton that the students should assimilate.



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- The term Force in Mechanics is used to fix the action of a body on another body
- Force is a physical magnitude that characterizes the interaction of bodies.
- It is the gauge of the interaction.
- Force is a vector magnitude.
- Force creates a relationship between the magnitudes mass and acceleration.
- In the International System, Newton is used as a term of measurement.
- There are two ways of measuring force: The static method (by means of the dynamometer) and the dynamic method.
- In Mechanics, there are various types of force (force of gravity, force of elasticity, friction force).
- Forces are added vectorially.
- The Newton's second law is applicable to the vectorial sum of the forces that act on the body.
- The Second Law of Newton can be expressed as the relationship between two vectors: the resulting force and the acceleration.

IV. NEWTON'S THIRD LAW

If the second law of Newton is related to only one body, the third one analyzes the interaction between both bodies. It can be expressed in this way: "Whenever two bodies interact, the force that the first one exerts on the second body is the same and opposed to that which the second body exerts upon the first one."

- These two forces have:
 - The same numerical value.
 - The same direction and contrary sense of force.
 - The capacity to act on different bodies.
 - The same nature.

Force characterizes the action of a body upon another body.

It is not a unilateral action; it is a reciprocal action between two bodies.

Experiment: We have two dynamometers joined together, as seen in Figure 8 [8].

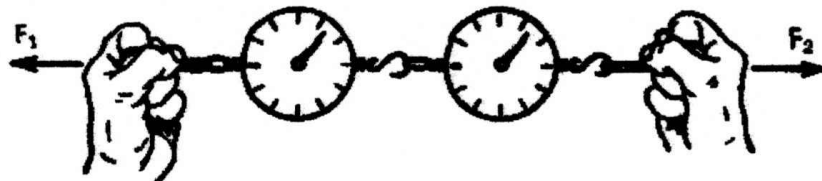


Fig.8. Two load cells connected together

We pull the ring of one of them towards one direction and we pull the ring of the other dynamometer towards the opposite direction. Both dynamometers give a force of equal intensity. Therefore, forces F_1 and F_2 have the same value and the same contrary sense of force.

Force F_1 acts upon one of the dynamometers and F_2 acts upon the other. The experiment shows that to pull the spring of the first dynamometer until a certain division is reached, we have to pull the spring of the second dynamometer until we reach the same division.

Experiment: Reciprocal action between two bodies situated at a certain distance, without any point of contact.

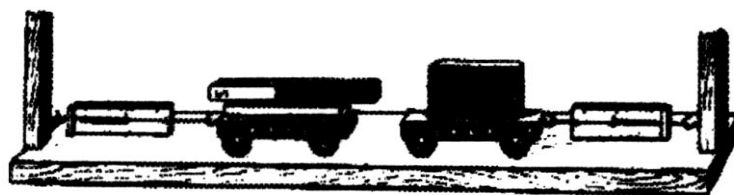


Fig.9. Interaction at a distance between a magnet and a piece of iron



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As seen in the Figure 9, as a result of the attraction between the magnet and the iron, the carts will move towards each other, thus pulling the springs of the dynamometers. When they stop, both dynamometers will indicate a force of equal intensity. On the basis of this experiment, we can say that magnet attracts iron with the same force (intensity) as that which iron attracts magnet.

Experiment: Let us consider the mutual action of two bodies in movement.

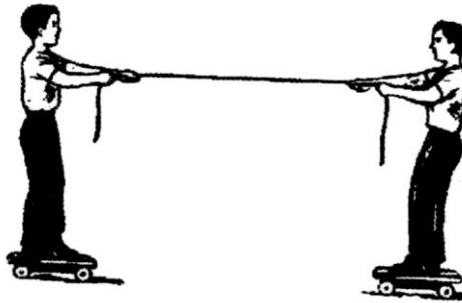


Fig.10. Let us consider the mutual action of two bodies in movement

In the Figure 10, we can see that when the boys pull the rope, they start moving towards each other together with the carts. So, the forces that act upon the boys are always the same and, in the opposite sense of force, regardless of the way the boys pull the rope.

When we measure the space travelled by the carts and the duration of its movement, we can see that accelerations a_1 and a_2 are inversely proportional to the masses in movement m_1 and m_2 . This means that:

$$\frac{a_1}{a_2} = \frac{m_2}{m_1} \Rightarrow m_1 \cdot a_1 = m_2 \cdot a_2 \quad (5)$$

But $m_1 \cdot a_1 = F_1$ y $m_2 \cdot a_2 = F_2 \rightarrow F_1 = F_2$. Since F_1 acts on one cart and F_2 on the other \rightarrow there is opposite sense of force.

$$\vec{F}_1 = -\vec{F}_2 \quad (6)$$

V. CONCLUSION

This methodology applied to the “Laws of Newton” has been used in different groups of students and it has helped in obtaining very good results not only in the understanding of the topic but also in the acquisition of knowledge. It has also been presented to different groups of teachers of Physics in different countries and they have considered the possibility of using the same method in their teaching of Physics.

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