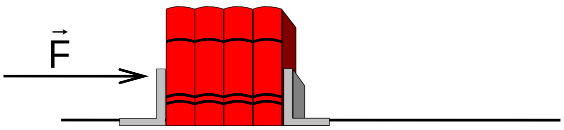
Physics 20 <u>Lesson 14</u>

Forces & Dynamics – Conceptual Change

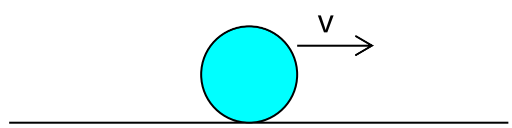
At this point in the course you have learned about Kinematics (the description of motion) and you have learned about vectors (addition, components). Kinematics and vectors provide us with the tools to learn why objects move as they do and how changes in motion occur.

I. Natural motion

Our everyday experience tells us that the natural motion of an object is to be at rest and if we wish to have an object maintain a uniform speed, we must continually apply a <u>force</u> on the object. **A <u>force</u> ($\vec{F}$) is a push or a pull in a given direction**. (Notice that **force is a vector** since it has a magnitude and a direction.) For example, if we wish to have some books move across a table at constant speed we must apply a constant force.

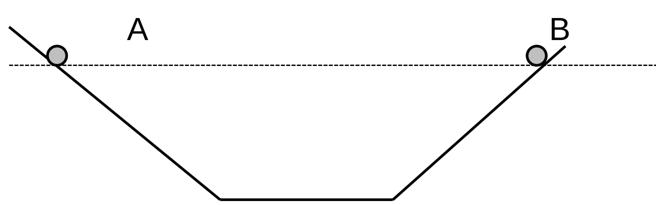


However, what if we push a heavy steel ball across a table? Unlike the books, we only have to give the ball a small push to get it going. Assuming a smooth level surface, once the ball is moving no force is required to keep it moving. There is something strange going on here, why does the same applied force result in such different motions?

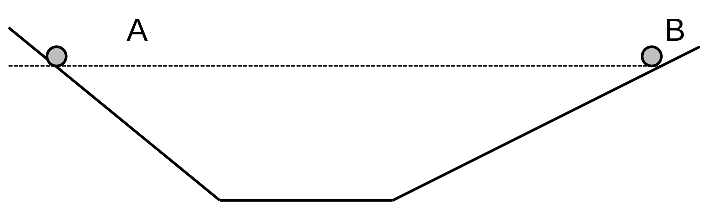


Many years ago Galileo Galilei (1564 - 1642 CE) thought about these things as well. He realised that our everyday experience with objects always involved friction in one way or another. He wondered what the resulting motion would be if friction were minimised or eliminated. With the materials at his disposal Galileo was only moderately successful at minimising friction so he devised the following **thought experiment**:

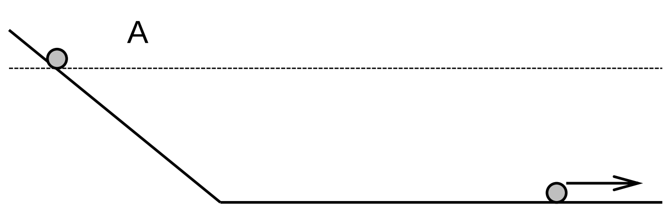
Suppose we release a heavy, smooth ball from point A on a smooth ramp. The ball rolls down the ramp, along a horizontal section, and then up another ramp on the other side. The ball is observed to come to a stop at the same height on the second ramp at point B.



Next we make the second ramp less steep. What happens? The ball still rolls up the ramp and once again stops at B which is at the same height as A.



Now suppose we lay the second ramp down so it is horizontal. What happens? Galileo argued that, in the absence of friction or an incline, the ball would continue to go at a constant speed forever.



Our usual common sense view is that the natural motion of an object is to be rest. However, based on his experimentation and reasoning, Galileo proposed that the **natural motion of an object is to maintain a constant velocity**, whether at rest or already in motion. Galileo stated this as the **Law of Inertia**:

> Inertia is the tendency of an object to remain in its curent motion. If the object is at rest, it tends to remain at rest. If an object is in motion, it tends to remain in motion. Further, the inertia of an object is proportional to its mass.

(In case you missed it, this is a very important idea.)

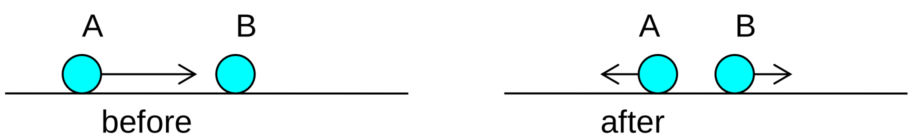
II. Newton's laws of motion

Isaac Newton (1642 - 1727 CE) was born on the day that Galileo died. He took the work of Galileo further. Newton agreed that the natural motion of an object is uniform motion, but he went on to ask: What causes a change in motion? He reasoned that if an object's velocity remains constant, then its acceleration is zero. In addition, when a change in velocity occurs, an acceleration is involved. Recall that

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$

Newton then asked: What causes an object to accelerate? Newton realised that acceleration is caused by forces or, to be more precise, **an unbalanced force causes an object to accelerate**. If the forces acting on an object are **balanced**, there is no acceleration and the motion remains uniform. However, if the forces acting on an object are **unbalanced**, the object will accelerate in the direction of the **net unbalanced force**. (In case you missed it, this paragraph contains probably the most important concept in Physics 20.)

But Newton did not stop there, he also noted that forces always occur in pairs. For example, if a ball (A) is moving with a given speed and it collides with another ball (B) initially at rest, the result is that the motions of both balls are changed.



The first ball slows down, stops, or rebounds, depending on the conditions involved, while the second ball moves away. From our discussion above, a change in motion involves an unbalanced force. The force of ball A on ball B caused ball B to move. Similarly, the force of ball B on ball A caused the change in ball A's motion. Newton reasoned that the **action force** of ball A on ball B automatically resulted in an equal and opposite **reaction force** – the force of ball B on ball A. Forces always occur in action-reaction pairs. (In case you missed it, this is an important idea as well.)

From considerations like these, Newton proposed three laws of motion:

Newton's First Law Of Motion (The Law of Inertia)

Every object continues in a state of rest or uniform motion, unless acted on by an unbalanced force. (see Pearson pages 137 to 141)

Newton's Second Law Of Motion

If an object is subjected to an unbalanced net force, it will accelerate in the direction of the net force:

- Acceleration is <u>directly</u> proportional to the magnitude of the net force. (i.e. the greater the force, the greater the acceleration)

  $$\vec{a} \propto \vec{F}$$

- Acceleration is <u>inversely</u> proportional to the mass (inertia). (i.e. the greater the mass, the smaller the acceleration)

  $$\vec{a} \propto \frac{1}{m}$$

When we combine the proportionality statements above we get:

$$\vec{a} = \frac{\vec{F}}{m}$$ acceleration (m/s^2)

Rearranging the equation we get Newton's 2nd law of motion:

$$\vec{F}_{NET} = m\vec{a}$$

acceleration (m/s^2)

$\vec{F}_{NET}$ (net force)

units: $\frac{kg\,m}{s^2}$ **= N** (Newton)

mass (kg)

(see Pearson pages 143 to 148)

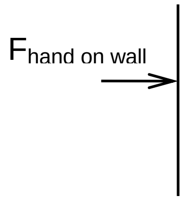
Newton's Third Law Of Motion

Whenever one object exerts a force on a second object, the second exerts an equal and opposite force on the first. (see Pearson pages 159 to 163)

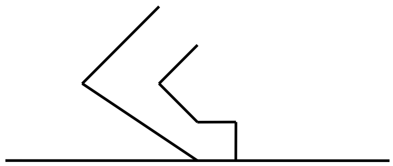
- *forces always occur in pairs*
- *each force of the pair acts on a <u>different</u> object*
- *each force of the pair is equal in magnitude but opposite in direction*

Example 1

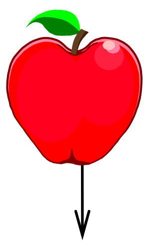
A. What is the reaction force to a person pushing her hand against a wall?



B. When walking across a floor, what is the direction of the force of your foot on the floor? What is the reaction force? Which force propels you forward? What would happen if the friction between your foot and the floor became zero?



C. An apple on a tree is pulled down toward the Earth. What is the reaction force?



Answers:

A. The reaction force is the wall pushing back on the hand.

B. The reaction force is the floor on the foot. It is the reaction force that propels the foot forward. If the friction became zero, no forces could be made and therefore no change in motion could occur.

C. The reaction force is the Earth being pulled up to the apple.

III. Mass and weight

In everyday usage the words **mass** and **weight** are used interchangeably, but in physics they have very precise and different meanings.

Mass (Inertia)

The mass of an object is the amount of matter within the object. The basic unit of mass is the kilogram (kg). The terms **mass** and **inertia** mean the same thing. Note that the mass of an object is completely independent of where the object is and the changes in motion of the object. A 10 kg mass on Earth is still a 10 kg mass on the Moon. Inertia/mass is a scalar.

Weight (Force due to gravity)

The **weight** of an object is the common name for the **force due to gravity** (F_g) on an object. The force due to gravity depends on two factors: (1) The strength of the acceleration of gravity (g) and (2) on the mass of an object. The equation for the force due to gravity is:

$$\vec{F}_g = m\vec{g}$$

Since weight is a force, its basic unit is the Newton (N). In addition, since weight is a force, it also has a definite direction – downward. Weight is a vector.

Unlike the mass of an object, the force due to gravity does depend on where the object is. The acceleration due to gravity on the surface of the Earth is 9.81 m/s^2, on the Moon it is 1.61 m/s^2, and on Mars it is 3.72 m/s^2. Therefore a 10 kg mass will weigh 98.1 N on Earth, 16.1 N on the Moon, and 37.2 N on Mars. (If you want to lose weight fast, go to the moon.)

Example 2

What is the mass and weight of a 30 kg object located on the surface of the Earth and on the Moon ($g = 1.61\ m/s^2$)?

The mass on the Earth and on the Moon is 30 kg.

(Earth) $F_g = m\,g = 30\text{ kg}(-9.81\ m/s^2) =$ **– 294.3 N** or = **294.3 N down**

(Moon) $F_g = m\,g = 30\text{ kg}(-1.61\ m/s^2) =$ **– 48.3 N** or = **48.3 N down**

IV. Hand-in Assignment

1. Why does a child in a wagon fall backward when another child suddenly pulls the wagon forward?
2. Explain what the term *inertia* means.
3. A rear-end collision between a soft-drink truck and a car occurs. A lawsuit develops over who is at fault. The truck driver claims the car backed into him, while the auto driver claims that the truck hit him from behind. The only evidence is that quite a number of soft-drink bottles fell forward in the truck. From the evidence, can you tell who was at fault? Explain.
4. What is the principle behind a magician's ability to pull a tablecloth from beneath china and glassware without breaking them? Explain.
5. Whiplash is a common result of an auto accident when the victim's car is struck from the rear. Why does the victim's head get thrown backward in this kind of an accident?
6. Explain why automobiles use more gasoline for city driving than for highway driving.
7. Why do you exert more force on the pedals of a bicycle when you first start out than when you reach constant speed?
8. When you lift a bag of groceries, you exert an upward force on the bag. Newton's third law says that there is a "reaction" force to your upward force on the bag. What object exerts this reaction force and in what direction does this force act?
9. Explain why when you walk on a log floating in water, the log moves backward as you move forward.
10. Why does it hurt your toe when you kick a rock?
11. State the reaction force for each of the following forces.
    a. the southward force of a field goal kicker's toe on a football
    b. the backward force of a jogger's shoe on the ground
    c. the downward force of a book on a desk
    d. the backward force of a jet's engines on its exhaust gases
    e. the backward pull of a swimmer's hands on the water in the butterfly stroke.
12. A beginning physics student, confused by a seeming contradiction in Newton's laws, asks her teacher the following question: "If, for every force there is an equal and opposite reaction force, then all forces in nature come in equal and opposite pairs, and are therefore balanced. Thus, since there can never be such a thing as an unbalanced force, how can any object ever accelerate?" Explain the fault in this common misconception.
13. A fireman at the scene of a fire is holding a heavy hose out of which water is gushing. To keep his balance, he often has to lean. Which way does he lean, forward toward the water or backward away from the water, and why?
14. A squirrel with an armful of nuts is sliding helplessly across a flat, icy roof, getting dangerously close to the edge. He understands Newton's Third Law, and is able to save himself. Explain how he does it.