Intellectual Output 1 – A1

Leader: Emphasys Centre

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1. Introduction to PhysicsKIT4STEM

PhysicsKIT4STEM was created in order to address the gender inequality in STEM education which was the result of female students systematically dropping out of STEM-related tracks at various levels of their education. Furthermore, there has been noticeable decrease in the number of students who pursue science and other STEM-related subjects in general. At an era where education in sciences is more accessible than ever, and where there is an increasing need for more skilled scientists in our society, it is important to understand why so many young students have lost an interest in STEM-related subjects. The issue was identified in our current teaching methods and it was suggested that actions must be taken to increase stimulation, engagement and gender-balance in this area. It was pointed out that the issue must be addressed in secondary education, where young students are more likely to become fond of STEM related subjects and may wish to pursue it in further education or even as a career choice.

In order for these goals to be attained, PhysicsKIT4STEM aims to improve the teaching skills of STEM educators through an alternative hands-on approach to physics. This will be done by capturing the interest of both educators and students through the use DIY kits to learn electronics and programming by using a Raspberry Pi computer. In addition, the project aims to indirectly pique the interest of young girls to pursue science and engineering to increase the gender-balance in STEM classrooms and the STEM industry in general.

The curriculum modules of this project will cover aspects of physics such as:

1. Forces and motion

2. Conservation of energy and momentum

3. Electricity and magnetism

4. Waves

5. Gravity

The main objective of this project will be achieved by putting together the developed curriculum, glossary, as well as instructions to assemble the PhysicsKIT consisting of sensors and a Raspberry Pi. In addition, lesson plans for each module developed will support and guide educators through the process of delivering the material. The curriculum will be delivered through a Learning Motivation Environment for skill retention purposes. Finally, the PhysicsKIT Club virtual space will provide access to all project results and infrastructure for supporting the growth of a community of adopters/practitioners/enthusiasts.

2. Forces and Motion

2.1 Glossary

Term	Definition
Acceleration	The rate of velocity change of an object with respect to time.
Applied force	A force applied to an object or being.
Force	A push or pull action.
Friction	A force produced when two objects are rubbing against each other.
Frictional force	The force caused by friction.
Gravity	The force that pulls objects towards the Earth's core.
Inertia	Inertia is a property of all objects that have mass. If an object is moving, then inertia helps it to stay moving and if an object is motionless, then inertia helps it to stay motionless.
Isaac Newton	An English mathematician who originated the theory of forces.
Magnetic force	The force created by a magnet.
Mass	The amount of matter in an object.
Momentum	Any object that has mass, and is moving then it has momentum.
Motion	The changing of location or position of an object.
Normal force	The force applied to an object that supports other objects, such as a glass on a kitchen counter.
Opposing forces	These are forces which work against each other.
Python	Python is an interpreted, object-oriented, high-level programming language. Python has simple, easy to learn syntax that emphasizes readability and therefore reduces the overall time needed to learn it and to develop and maintain a program. Python supports modules and packages, which encourages program modularity and code reuse. The Python interpreter and the extensive standard library are available in source or binary form without charge for all major platforms and can be freely distributed.

Raspberry Pi	Raspberry Pi is a credit card sized, fully functional computer which operates on Raspberry Pi OS.
Raspberry Pi GPIO	Raspberry Pi GPIO is the row of pins along the top edge of the board. A 40-pin header is found on all current Raspberry Pi boards. Most of the functionality of the Raspberry Pi comes from these pins which can be configured and controlled using a programming language. Any of the GPIO pins can be designated in software as an input or output pin and used for a wide range of purposes such as to control LEDs, buzzers, motors, servos, to interact with sensors, to communicate with other devices, etc.
Raspberry Pi OS	The operating system for Raspberry Pi.
Resisting force	A force that changes the state of motion of an object, by either making it moving slower or by stopping it completety.
Sensor	A sensor is a hardware device that measures physical input from its environment and converts it into electronic or visual data which are then interpreted by a human or a machine.
Speed of light	The speed of light in vacuum, commonly denoted ***c***, is a universal physical constant and its exact value is defined as 299 792 458 m/s.
Spring force	Elastic force, created by a spring
Tension force	Tension force is the force applied to cables or wires that are anchored on opposite ends to opposing walls or other objects.
Velocity	Velocity is the speed an object has at a certain direction. If an object changes direction, then its velocity changes as well since it is not moving in its original direction.

2.2 Introduction to Forces and Motion

Module 1 offers an introduction to two fundamental principles of physics. These principles have defined the subject of physics which, without them, we would not be able to understand life itself. Motion and forces are everywhere in our world. From a chair we pull to sit down, to a bridge that stands still and from a ball we kick and flies into the air, to Earth itself as a planet.

In fact, everything in our world is in motion. These concepts were first tried to be explained by Greek philosophers, Aristotle and Archimedes. However, it was not until the 17th century when these concepts were fully defined. Understanding motion and forces was one of the greatest achievements in science, thanks to Isaac Newton. The Newtonian Laws are still used in our days to explain how motion works and how forces affect motion.

However, not all forces cause motion. For example, a desk stands on a floor without moving but there are forces still applied to it. In this module, we will try to explain what forces are and what types of different motion they produce.

2.3 Learning Outcomes

In this module, your will learn about forces and motion and their different types and characteristics, as well as Newton's Laws and the theory behind them. The learning material will cover:

1. Net force
2. Motion
3. Friction
4. Acceleration

You will also learn about force values, sum of forces, resistance and velocity.

Along with the teaching material, you will find some experiments that you can perform using the Raspberry Pi and various other sensors. In addition, resources, references and other useful material have been included at the end of the chapter to improve your learning and understanding of the topic. By the end of this module, you should have a good understanding of the field of forces and motion, the theory around them and be able to use the PhysicsKIT to perform experiments related to the topic.

2.4 Theory

2.4.1 What is force?

A force is defined as a push or pull move which can make things move, change direction, or change shape. A force has both magnitude and direction. It is measured in newtons and represented by the symbol F.

Forces can be identified everywhere in our world. For example, there is an object in our house, let us say a box. When the box stands still there are two forces applied to it, a force which pulls the object to the ground ensuring the box does not float in the air and an equal and opposite force pushing the box from the ground. When we try to change the box's position, we apply another force to it, which causes the box to move and change position. At the same instance, another force resists us pushing the box. There are also other forces applied to the box or us which are equally important to learn.

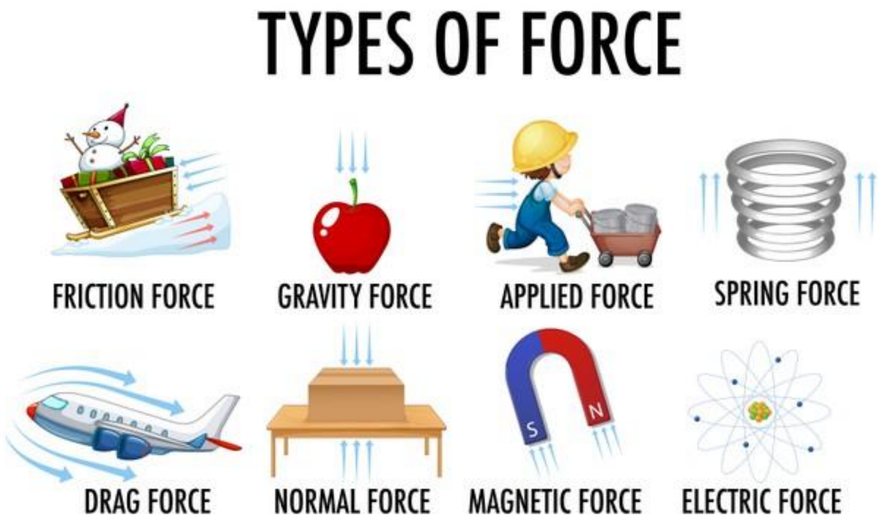

FIGURE 1: TYPES OF FORCES. RETRIEVED FROM HTTPS://WWW.FREEPIK.COM/

Two natural forces that we experience in every day life are the force of gravity and magnetic forces. These two forces do not need direct contact between objects to function.

Gravity pulls objects towards each other, and it is the force that keeps the Earth revolving around the sun and what pulls objects and beings towards the ground.

On the other hand, magnetism pulls opposite ends of two magnets together or pushes the matching ends apart. It also attracts objects of metal, but that is a different topic.

2.4.2 Types of force

There are six types of forces which acts on objects or beings. These forces apply when contact is made between two or more objects. These forces are:

- Normal force
- Applied force
- Frictional force
- Tension force
- Spring force
- Resisting force

Normal force

An object is placed on a table, having the force of gravity pulling it towards the Earth. But the object is not moving because there is an opposing force acting on the object by the table. This force is called "*normal force"*.

Applied force

An *applied force* refers to a force applied to an object, for example when we move a piece of furniture across a room, or we push a button on the remote control for our TV.

Frictional force

A *frictional force* refers to a force caused by two surfaces that come into contact with each other. Friction can be helpful, for example friction allows us to walk across the ground and not slide. Friction can also be destructive, for example friction wear out the tires of a car which need change after a period of time.

Tension force

Tension force is the force applied to cables or wires that are anchored on opposite ends to opposing walls or other objects. This creates a force that equally pulls in the opposite directions.

Spring force (elastic force)

Spring force is the force created by a compressed or stretched spring. A spring can pull or push the objects that are attached, creating a force.

Resisting force

Similar to friction, a *resisting force* changes the state of motion of an object (either slow or stop and object). Air resistance makes leaves travel in the wind. Friction is applied on a pen in our hand and let us write on a piece of paper.

2.4.3 What is inertia?

Inertia is a property that all objects and beings have because they have mass. Inertia is not considered a force. The more mass an object has, the more inertia this object is subjected to. It can be described as a property that makes something hard to push around. In other words, inertia is nature's tendency to resist any change in movement.

A real-life example is the cargo of a truck that drives on the highway. The truck has brakes to stop, but the cargo does not. Therefore, when the truck brakes hard, the cargo moves in the cargo bay.

FIGURE 2: A TRUCK IS TRANSPORTING A HUGE STONE. WHILE THE TRUCK IS IN MOTION, THE STONE IS ALSO IN MOTION. A DEER SUDDENLY JUMPS INTO THE ROAD AND THE DRIVER SLAMS THE BREAKS. THE TRUCK STOPS BUT THE STONE MOVES FORWARD BECAUSE THE STONE, THAT IS IN MOTION, FIGHTS TO STAY IN MOTION. RETRIEVED FROM HTTPS://WWW.EXPII.COM/T/MASS-AND-INERTIA-632

2.4.4 What is friction?

Friction is a force that applies when two objects are in contact. Moving the objects causes the appearance of friction. As a general rule, the heavier the object, the stronger the force of friction. For example, we can push a car because the force we apply is greater than the force of friction between the wheels and the ground. But we would not be able to push a train because the friction between the train wheels and the ground is more intense. Again, we can see that mass plays an important role in defining the forces around objects.

2.4.5 Understanding forces

Understanding how objects work or move means that we try to identify the force that is responsible. However, it is rare to find only one force acting on an object. There are always many different forces working at the same time, pulling and pushing with different magnitude and different directions. Adding or subtracting these forces from one another, produces an overall force, which sometimes can be zero.

When all forces acting on an object are in balance, their effects cancel one another out. An interesting example is a suspension bridge. There is the weight of the vehicles passing the bridge that which pulls downward and there is the bridge's own weight. Thinking about the force of gravity, we expect the bridge to fall into the canyon. This does not happen because the force of gravity is exactly balanced by tension (pulling force) in the suspension cables. All forces on the bridge are equal, hence the bridge does not go anywhere so it is safe for vehicles to drive across.

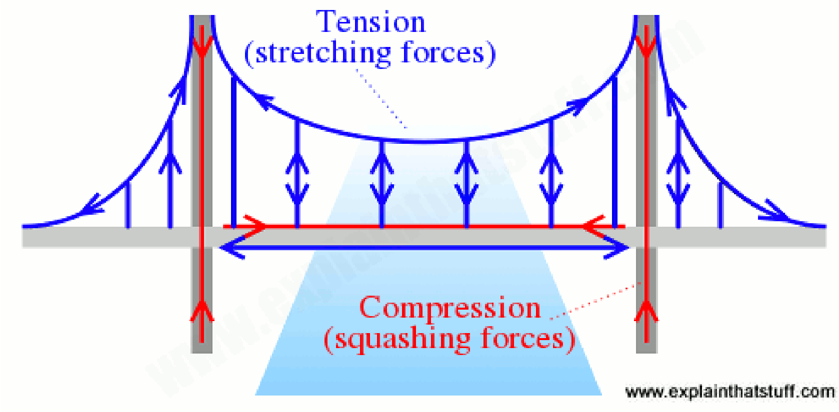

FIGURE 3: BRIDGES ARE GIANT STATIC STRUCTURES, BUT THAT DOESN'T MEAN THEY'RE FORCE FREE. BRIDGES CARRY LOADS BY BALANCING THEM WITH STRETCHING FORCES (TENSION, SHOWN IN BLUE), SQUASHING FORCES (COMPRESSION, SHOWN IN RED), OR BOTH. DIFFERENT TYPES OF BRIDGES DO THIS IN DIFFERENT WAYS. IN A SUSPENSION BRIDGE, THE TOWERS ARE IN COMPRESSION (SQUASHED DOWN) WHILE THE HUGE CABLES THAT SUPPORT THEM ARE IN TENSION (PULLING TIGHT). RETRIEVED FROM HTTPS://WWW.EXPLAINTHATSTUFF.COM/MOTION.HTML

In principle, when different forces act on an object from different directions, and that object moves in a certain direction, one of those forces is "winning". This is called the resultant force since it is the overall force that results when several forces act on the same object at the same time.

2.4.6 Forces and movement

When a force acts on an object, it usually makes it move faster, slower or in a different direction. Once an object is moving, it will carry on moving all by itself unless another force alternates that movement. Every time we want to make an object speed up (accelerate) or slow down (decelerate) we need to use a force. English scientist Isaac Newton was the first person to figure out properly how forces act on objects and change the way they move.

2.4.7 Motion

We mentioned several times that forces make objects move. Forces and motion are linked together and can be measured and calculated following certain principles. Newton's work helps us tie forces and motion together and also let us calculate how objects will move when we apply forces to them.

According to a story, Newton saw an apple fall from a tree to the ground and figures out that the same force which caused the apple to fall, also governed the motion of the moon and the other planets in our solar system. In 1687, Newton published his three laws of motion in the *"Principia Mathematica Philosophiae Naturalis"*. These laws explained how the concepts of force and motion work.

Newton's three laws of motion apply to almost everything (except to the subatomic world and to objects moving close to the speed of light).

2.4.8 1st Law of Motion – Law of Inertia

Objects that are still remain still and objects that are moving keep moving with a constant velocity unless acted on by an external net force (resultant force).

In other words, if a body is moving, its inertia will tend to keep it in motion, and if something is at rest, its inertia will tend to keep it at rest. In principle, inertia applies equally well to constant velocity motion as it does to rest.

Mathematically, we can say that if the net force on an object is zero, then the velocity of that object is constant.

$$\sum F = 0 \Leftrightarrow \frac{dv}{dt} = 0$$

2.4.9 2nd Law of Motion – Law of Momentum

When a force acts (pushed/pulls) on an object, it changes the object's velocity by either changing its speed or its direction or both. In other words, a force will make an object accelerate towards a certain direction. The bigger the force, the more the object accelerates.

The original form of Newton's second law states that the net force acting upon an object is equal to the rate at which its momentum changes with time. If the mass of the object is constant, this law implies that the acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object.

Mathematically, we can say that the rate of change of momentum of a body over time is directly proportional to the force applied, occurring in the same direction as the applied force.

$$F = \frac{dp}{dt}$$

Where ***F*** is the net (sum) force, ***p*** is the momentum of the system and ***t*** is the time.

For objects and systems with constant mass, the second law can be re-stated in terms of an object's acceleration.

$$a = \frac{dv}{dt}$$

Where ***a*** is the acceleration, ***v*** is the velocity and ***t*** is the time.

Then, by substituting the definition of acceleration, Newton's second law for constant mass bodies is derived:

$$F = m \cdot a$$

Where ***F*** is the applied net force, ***m*** is the body mass, and ***a*** is the acceleration of the body.

The equation of motion for bodies whose mass *m* vary with time by either removing or adding mass is obtained by applying the second law to the entire constant-mass system consisting of the body and its lost or gained mass.

$$F + u\frac{dm}{dt} = m\frac{dv}{dt}$$

Where ***u*** is the exhaust velocity of the escaping or incoming mass relative to the body.

Finally, velocity is how much speed an object has at a certain direction. If an object changes direction, then its velocity changes as well since it is not moving in its original direction.

$$v = \frac{d}{dt}$$

Where **v** is the velocity, **d** is the distance and **t** is the time.

2.4.10 3rd Law of Motion – Action-Reaction Law

When a force acts on an object there is an equal force (reaction) acting in the opposite direction. In other words, for every force and action, there is an equal and opposite reaction. Newton's third law is a result of applying symmetry to situations where forces can be attributed to different objects. It also means that all forces are interactions between different bodies.

$$F_A = -F_B$$

The force exerted by Body A on Body B is the "action". The force exerted from Body B on Body A is the "reaction". This is why the 3rd law is also referred as the action-reaction law.

2.4.11 Experiments

In this section, we will learn how to connect and control two sensors using the Raspberry Pi GPIO and some simple Python programming. No tools are necessary as none of the electronic circuits we create are permanent. We just need the sensors, some jumper wires and a breadboard.

Before we start with the experiments, some overall theory regarding the electronics we use is necessary. First of all, a Raspberry Pi is an open-source, fully functional, credit card sized computer made by the Raspberry Pi Foundation.

The Raspberry Pi has 40 open GPIO pins which will be used for connecting and controlling electronics and sensors. GPIO stands for “General Purpose Input/Output” which means that these pins send and receive electrical signals to control hardware or read sensor data.

Secondly, we use Python to program these sensors. Python is an object-oriented programming language. No prior knowledge in programming is required as the programs we will create are very simple and use the simplest of Python commands.

Now let us dive into the experiments.

Experiment #1 – Controlling the SG90 Servo Motor

For this experiment we will need:

- Raspberry Pi 3 (RPi)
- Jumper wires (male-to-male)
- SG90 Servo Motor
- Breadboard

The SG90 Servo is a type of DC motor which upon receiving a signal of a certain frequency, can rotate itself to any angle from 0 to 180 degrees. The 90 degrees position is generally referred to as the "neutral" position.

The SG90 reads information that is sent to it by using an electrical signal called PWM (Pulse Width Modulation). This means sending ON electrical signals for certain amounts of time, followed by an OFF period, and repeated hundreds of times a second. The amount of time the signal is ON sets the angle the servo motor will rotate to. In most servos the expected frequency is 50Hz or 3000 cycles per minute. When given a signal of 0.5 ms the servo will set to 0 degrees, when given 1.5 ms the servo will rotate to 90 degrees and when given 2.5 ms the servo will rotate to 180 degrees.

Three wires will run from the servo to the Raspberry Pi. We'll be sending PWM signals from one GPIO pin and powering the servo using another GPIO pin. The third wire is the ground (GND)

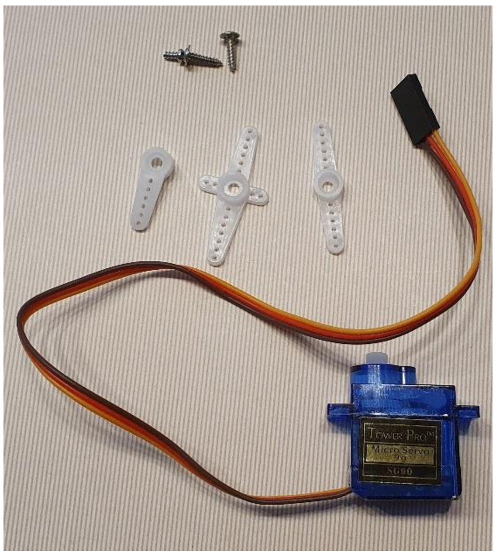

FIGURE 4 SG90 SERVO MOTOR

The SG90 Servo comes with three different headers which can be attached on top of its body and can be used to assemble various DIY structures. For this experiment, we will not attach any other object on top. We will just use the cross-like header.

In the context of physics, the SG90 Servo can be used to experiment with forces, such as tension and friction by simply attaching the servo to a string or another structure and program it to turn in various positions to pull or push objects.

Back to our experiment, we need to connect the sensor with the GPIO pins of our Raspberry Pi. To do that, we need to plug the three wires from the servo into the GPIO board using three jumper wires. The PhysicsKIT, makes our lives easier since our breadboard is already connected to the GPIO using a T-Cobbler and a ribbon cable, which means that we can run jumper cables directly from the attached breadboard to the servo motor without losing GPIO functionality.

We need to plug a male-to-male jumper wire into each of the holes on the end of the servo cord, then plug the other side on the attached to the PhysicsKIT breadboard.

	Pin No.		
3.3V	1	2	5V
GPIO2	3	4	5V
GPIO3	5	6	GND
GPIO4	7	8	GPIO14
GND	9	10	GPIO15
GPIO17	11	12	GPIO18
GPIO27	13	14	GND
GPIO22	15	16	GPIO23
3.3V	17	18	GPIO24
GPIO10	19	20	GND
GPIO9	21	22	GPIO25
GPIO11	23	24	GPIO8
GND	25	26	GPIO7
DNC	27	28	DNC
GPIO5	29	30	GND
GPIO6	31	32	GPIO12
GPIO13	33	34	GND
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
GND	39	40	GPIO21

FIGURE 5 GPIO PIN NUMBERS

- The red wire goes into pin #2 (5V)
- The brown wire goes into pin #6 (GND)
- The yellow wire goes into pin #3 (GPIO2)

Figure 6 shows in detail how to connect the servo on your breadboard and Raspberry Pi.

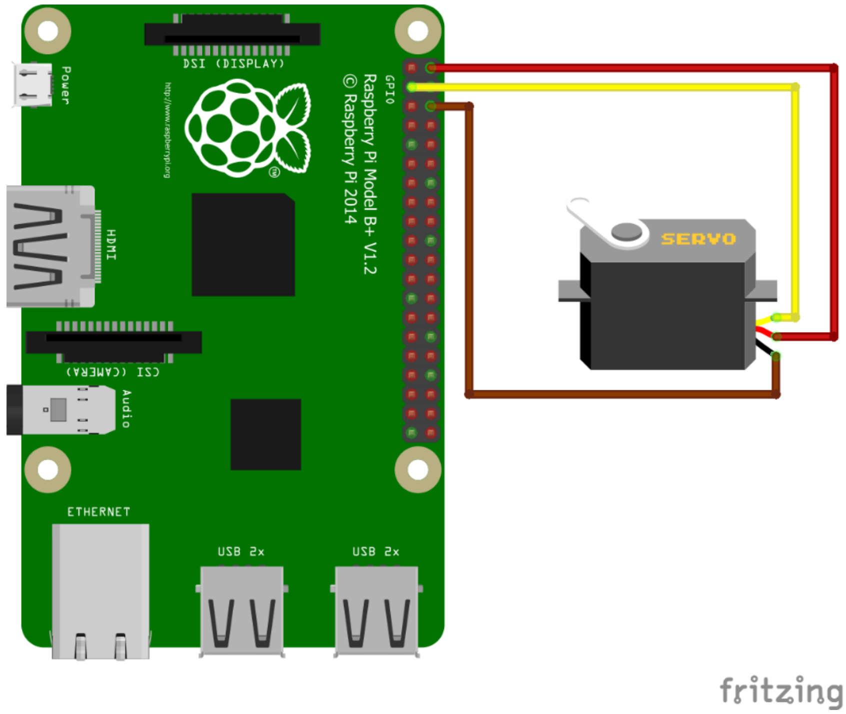

Figure 6 Schematic for connecting the SG90 Servo Motor

When our circuit is ready, we can start writing our program in Thonny Python (IDLE) which will control the SG90 Servo.

We open Thonny Python, and we save our file as *servo.py*

We need to write the following program:

```
#################################################################
#imports GPIO module
import RPi.GPIO as GPIO
#from module time we import a command called sleep
from time import sleep

#we set the pin names to board mode, which names the pins in numbers
GPIO.setmode(GPIO.BOARD)
#we need an output to send the PWM signal
GPIO.setup(03, GPIO.OUT)
#we disable any warnings the Python compiler might give us
GPIO.setwarnings(False)
#we setup PWM on pin #3 at 50Hz
pwm = GPIO.PWM(03, 50)
#we start the servo with 0 duty cycle to start on neutral position
pwm.start(0)

#we create a function which sets the servo according to the angle
def SetAngle(angle):
      duty = angle / 18 +2
      GPIO.output(03, True)
      pwm.ChangeDutyCycle(duty)
      sleep(1)
      GPIO.output(03, False)
      pwm.ChangeDutyCycle(0)

#we set the desired angle for our servo
SetAngle(90)

#we stop sending PWM signals
pwm.stop()
#we clean the GPIO, so it doesn't store our settings
GPIO.cleanup()
#################################################################
```

We needed to define a function that handles the calculation for setting the servo in an angle, so we don't need to write all these lines of code every time we want to set an angle. Explaining the function even further, we should note the following:

- At the first line we set up a function called 'SetAngle' which we can use in our code to give the angle degrees as input.
- At the second line we set a variable equal to our angle and divided by 18 plus 2 .
- At the third line we turn on the GPIO pin for output.
- At the fourth line we change the duty cycle to match what was calculated at line two.
- At the fifth line we set the program to wait 1 second so the servo has the required time to make a turn. Depending on the speed of our servo we might need to set this times longer or shorter.
- At the sixth line we turn off the GPIO pin.
- At the seventh line we change the duty back to 0 so we stop sending inputs to the servo.

When we finish with our code, we need to save the file, and we are ready to test it. The program will communicate with the servo and will tell it to go to 90 degrees angle. We can change the number in the `SetAngle(90)` line to whatever degree we want and the servo will turn to that position. We can also call the function several times in our program and see the servo changing angles accordingly.

Experiment #2 – Controlling a small 3V DC Motor with an L293D control chip

For this experiment we will need:

- Raspberry Pi 3 (RPi)
- L293D control chip
- Jumper wires (male-to-male and female-to-male)
- 3V DC motor
- Breadboard

A DC motor receives small voltages from the GPIO through the PWM (Pulse Width Modulation) module which controls the amount of time a voltage is on by flipping between high and low for a set amount of time. This time is called “duty cycle” and its percentage defines the percentage of power the motor runs on.

The L293D is a simple chip which is used to control DC motors in terms of direction and speed. The L293D chip uses two pins referred to as inputs to sense the desired direction and another pin called “Enable” to sense On/Off. So if we want the motor to spin forward we need to set “Enable” to On, Input 1 to “True” or “HIGH” and Input 2 to “False or “LOW”. If we want the motor to spin backwards, then we need to set Input 1 to “False” or “LOW” and Input 2 to “True” or “HIGH”. If both inputs or True or both are False, the motor will not run.

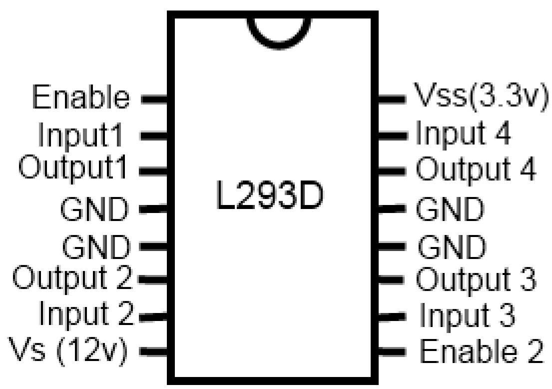

FIGURE 7 L293D CONTROL IC

To control the speed the motor runs, we will use the PWM module to control the power according to the duty cycle we set in the “Enable” pin.

On the Raspberry Pi, we need 3 GPIO output pins (2 for the inputs on the chip and one for the “Enable”), one 3.3V power supply and one grounding (GND) pin.

	Pin No.		
3.3V	1	2	5V
GPIO2	3	4	5V
GPIO3	5	6	GND
GPIO4	7	8	GPIO14
GND	9	10	GPIO15
GPIO17	11	12	GPIO18
GPIO27	13	14	GND
GPIO22	15	16	GPIO23
3.3V	17	18	GPIO24
GPIO10	19	20	GND
GPIO9	21	22	GPIO25
GPIO11	23	24	GPIO8
GND	25	26	GPIO7
DNC	27	28	DNC
GPIO5	29	30	GND
GPIO6	31	32	GPIO12
GPIO13	33	34	GND
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
GND	39	40	GPIO21

FIGURE 8 GPIO PIN NUMBERS

Once again, the PhysicsKIT makes our lives easier since our breadboard is already connected to the GPIO using a T-Cobbler and a ribbon cable, which means that we can run jumper cables directly from the attached breadboard to the secondary breadboard without losing GPIO functionality.

On the secondary breadboard, we place the L293D chip with half its pins on either side, so it runs parallel with the board. To make sure you route the voltages to the correct pins, use the diagram in Figure 5. To know which end of the IC Chip is which, look for a little semi-circle notch on one end that corresponds to the diagram in Figure 5.

Now, let us create the circuit according to Figure 9.

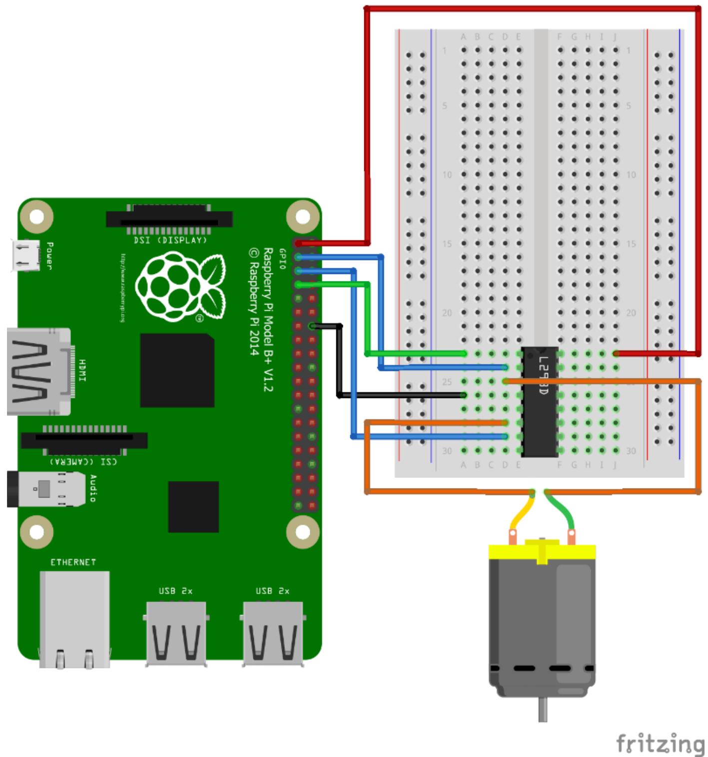

FIGURE 9 SCHEMATIC FOR CONNECTING THE 3V DC MOTOR

When our circuit is ready, we can start writing our program in Thonny Python (IDLE) which will control the DC Motor.

We open Thonny Python, and we save our file as *dcmotor.py*

We need to write the following program:

```
#################################################################
#imports GPIO module
import RPi.GPIO as GPIO
#from module time we import a command called sleep
from time import sleep

#we set the pin names to board mode, which names the pins in numbers
GPIO.setmode(GPIO.BOARD)
#we need an output to send the PWM signal
GPIO.setup(03, GPIO.OUT)
GPIO.setup(05, GPIO.OUT)
GPIO.setup(07, GPIO.OUT)
#we disable any warnings the Python compiler might give us
GPIO.setwarnings(False)
#we setup PWM on pin #7 at 100Hz
pwm = GPIO.PWM(07, 100)
#we start the servo with 0 duty cycle to start on neutral position
pwm.start(0)

#the rest of the code changes depending on how we want to run the
#motor. In this example, the motor will run forward at 50% power
#for 3 seconds, then will run backwards at 75% power for 3 seconds
GPIO.output(03, True)
GPIO.output(05, False)
pwm.ChangeDutyCycle(50)
GPIO.output(07, True)
sleep(3)

GPIO.output(07, False)

GPIO.output(03, False)
GPIO.output(05, True)
pwm.ChangeDutyCycle(75)
GPIO.output(07, True)
sleep(3)

GPIO.output(07, False)

#we stop sending PWM signals
pwm.stop()
#we clean the GPIO, so it doesn't store our settings
GPIO.cleanup()
#################################################################
```

When we finish with our code, we need to save the file, and we are ready to test it. The program will communicate with the motor through the L293D chip and will tell it to spin forward using 50% power for 3 seconds, then to spin backwards using 75% power for another 3 seconds. By slightly changing our program we can set the DC motor to run in the pattern we want. For example, if we want to add attachments on top of the motor, we can program it to spin accordingly. A DC motor could prove to be very useful in the physics context as the concepts of velocity, acceleration and also forces can be simulated using simple DIY structures and several DC motors.

2.5 Assessment

1. Why is a force acting on an object not working?
    a. The object is moving with the help of a machine.
    b. The acting force is in different direction than the object's motion.
    c. Friction is lower than the acting force.
    d. The object accelerates.
2. A car traveled 100km in 20 minutes. What is its speed?
    a. 40 km/h
    b. 100 km/h
    c. 60 km/h
    d. 200 km/h
3. What is the SI unit of force?
    a. A newton
    b. A pascal
    c. m/s^2
    d. g/cm^3
4. How can we call the amount of matter in an object?
    a. Balance
    b. Mass
    c. Inertia
    d. Force
5. The force that one surface exerts on another when the two rub against each other is called:
    a. Gravity
    b. Friction
    c. Inertia
    d. Acceleration
6. If the speed and direction of a moving object are known, then what else is known?
    a. Average speed of the object
    b. Acceleration of the object
    c. Distance the object has traveled
    d. Velocity of the object
7. One way to increase acceleration is by:
    a. Decreasing force.
    b. Increasing mass.
    c. Decreasing mass.
    d. Increasing both force and mass proportionally.
8. According to Newton's third law of motion, when a hammer strikes and exerts force on a nail, the nail:
    a. Disappears into the wood.
    b. Exerts an equal force back on the hammer.
    c. Moves at a constant speed.
    d. Creates a friction with the hammer.
9. When a pair of balanced forces acts on an object, the net force that results is:

a. Greater in size than one of the forces.
b. Equal to zero.
c. Equal in size to one of the forces.
d. Greater in size than both forces combined.

10. According to Newton's second law of motion, the acceleration of an object equals the net force acting on the object divided by the object's:
    a. Mass.
    b. Momentum.
    c. Velocity.
    d. Weight.

2.6 Conclusion

Module 1 explored the fundamental concepts of Force and Motion. We learnt the different types of forces, how to calculate them and how they affect objects and beings. We also navigated through Newton's Laws of Motion and learnt several of the formulas to calculate velocity, inertia, acceleration, etc. On a more practical side, we also learnt how the PhysicsKIT can be used to perform experiments related to the topic of Force and Motion. As a final note, we strongly advise educators as well as students to further explore these concepts of physics and discover new ways of using the PhysicsKIT and the Raspberry Pi to perform experiments and understand physics through hands-on educational play.

2.7 Additional Resources

- useful links, images, tools, graphs, maybe an appendix with data where relevant, link to videos with instructions on how perform an experiment

- What is force? – Part 1: https://www.youtube.com/watch?v=B6mi1-YoRT4&t=24s
- What is force? – Part 2: https://www.youtube.com/watch?v=iGwBZTWySWk
- Distance and Displacement: https://www.youtube.com/watch?v=21BwUNDOQno&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=1
- What is Friction? https://www.youtube.com/watch?v=n2gQs1mcZHA&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=33
- What is Velocity? https://www.youtube.com/watch?v=apewLkLAR-U&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=4
- What is Acceleration? https://www.youtube.com/watch?v=vxFYfumAAlY&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=5
- Equations of Motion: https://www.youtube.com/watch?v=xViRvJxTu6k&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=6
- Newton's First Law of Motion:

https://www.youtube.com/watch?v=5oi5j11FkQg&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=11

- Inertia and Mass: https://www.youtube.com/watch?v=YbWjx3LUc0U&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=12
- Newton's Second Law of Motion: https://www.youtube.com/watch?v=8YhYqN9BwB4&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=13
- Newton's Third Law of Motion: https://www.youtube.com/watch?v=TVAxASr0iUY&list=PLmdFyQYShrjcoTLhPodQGjtZKPKIWc3Vp&index=14
- Low cost Sensors in the Physics Classroom: https://www.instructables.com/Low-cost-Sensors-in-the-Physics-Classroom/

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2. Conservation of Energy and Momentum

2.1. Glossary

Chemical energy	Energy stored in the bonds of chemical compounds like atoms and molecules
Conservative forces	If the force required to move an object between 2 points, whatever the path chosen, remains the same, it is said to be a conservative force
Elastic potential energy	Energy produced by the deformation of an elastic object which restores its initial shape after the energy has been released
Electrical potential energy	Energy produced by the arrangement and the motion of charges in electrical and magnetic fields
Energy	Capacity for doing work or to change the state of a system
Fission	If a massive nucleus becomes unstable, the nucleus will split into pieces to gain stability
Force	A push or pull action
Friction	Force produced when two objects rub against each other.
Fusion	If a light nucleus is unstable, nuclei will be gathered to gain stability
Gravitational potential energy	Capacity to produce work depending on the position of the object into the gravitational fields
Joule	Unit of energy in the international system, named after the English physicist James Prescott Joule. A Joule equals the energy needed to use a Newton of force to move to one meter an object.

Kinetic energy	Macroscopic and organized energy based on a mass in movement
Mass	Amount of matter in an object
Mechanical energy	Energy based on motion involving an object with or without a mass
Momentum	Property acquired by an object moving. All objects have mass. Which means that whenever an object moves it gains momentum. This is called mass in motion.
Motion	When an object changes of location or position.
Non-conservative forces	Forces that turn work into heat, sound or light. Then at a macroscopic level, mechanical energy seems lost or non-conservative
Nuclear energy	Energy stored inside the nuclei of atoms.
Potential energy	When stored energy which has a potential to do work is suspended (until the energy is released)
Radiant energy	Microscopic and organised energy based on wave movement without involving mass
Sound	Microscopic and organised energy based on wave movement involving mass
Thermal energy (heat)	Microscopic and disorganised energy based on a mass in movement
Transfer (of energy)	When the same type of energy goes through multiple systems (like a chain reaction)
Transformation (of energy)	When the energy changes its form to go through multiple systems (like a chain reaction)
Velocity	Speed of an object in one direction

2.2. Introduction to Conservation of Energy and Momentum

This module proposes an introduction to the concepts of conservation of energy and momentum. Energy is, like the principles and concepts presented in this curriculum, very important when it comes to the knowledge of our universe.

Universe is indeed composed of matter and energy. In one hand, matter is concrete and visible, formed by atoms and has a mass. We observe it with our own eye or with a microscope when it is too small. In the other hand, even if we feel what the energy is, we never observe it, only its effect on our environment. Like the wind: we can't see it, but we feel it when it blows against our cheek, we see it when it blows in the trees and their leaves move. Energy is defined by the capacity to change the state of a system. This can be about the system's velocity, temperature, stretching, wave emission... the modification will alter any physic properties of the system. Again, if we feel the wind, it is because it changes the state of our cheek by applying a pressure; if we see it, it is because the leaves gain in motion.

People know a lot of transformation of energy examples without really understanding them: the photosynthesis by the plants, when you turn on a light bulb, when you use a dynamo, when you watch television, when you use your computer or your optical fiber internet connection. This module will propose simple but essential activities to understand these concepts that are essential in this field of study, to allow young students to improve their knowledge and to encourage them to continue to discover their own pathway within science.

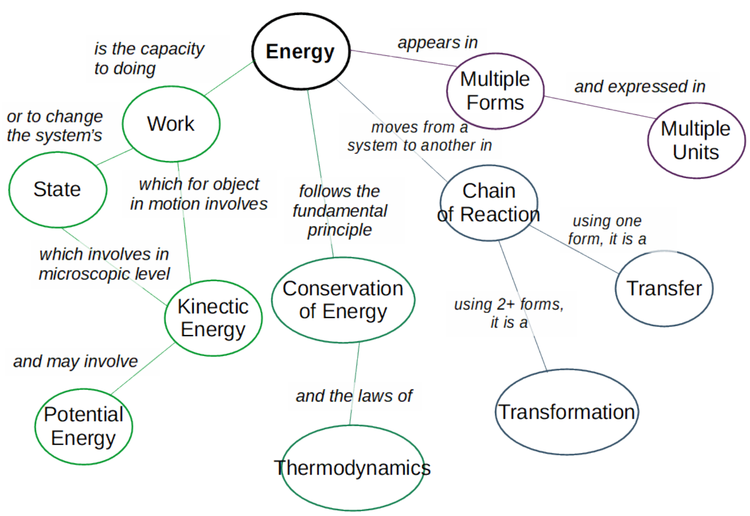


IMAGE 1: **MINDMAP OF ENERGY AND THE CONCEPTS AROUND IT**

The unit of energy in the international system is the Joule. A Joule equals the energy needed to use a Newton of force to move to one meter an object, based on the basic definition of energy which is the capacity to doing work. However, the Joule is a very small unit. For example, in 2020 for a European medium-sized household, the energy consumption (electricity) is about 10 kWh per day, which equals to 36 000 000 J!

2.3. Learning Outcomes

In this module, you will learn about the conservation of energy. But before this topic, you need to understand what energy is and its different aspects/forms. The learning material will cover:

1/ the definition of energy

2/ forms of energy

3/ transfer and transformation of energy

4/ conservation of energy and its laws

You will also learn about momentum conservation; the concept of momentum has already been explained in chapter 2.4.9.

Along with the teaching material, you will find some experiments that you can perform using the Raspberry Pi and various other sensors. In addition, resources, references and other useful material have been included at the end of the chapter to improve your learning and understanding of the topic. By the end of this module, you should have a basic understanding of the concept of energy and the conservative laws of energy.

2.4. Theory

2.4.1. Forms of energy

There are two big categories of energy: energy based on motion and energy based on potential energy, that is, energy that is stored and is waiting to be released. Within those two, we find different forms of energy that we will look at in more detail:

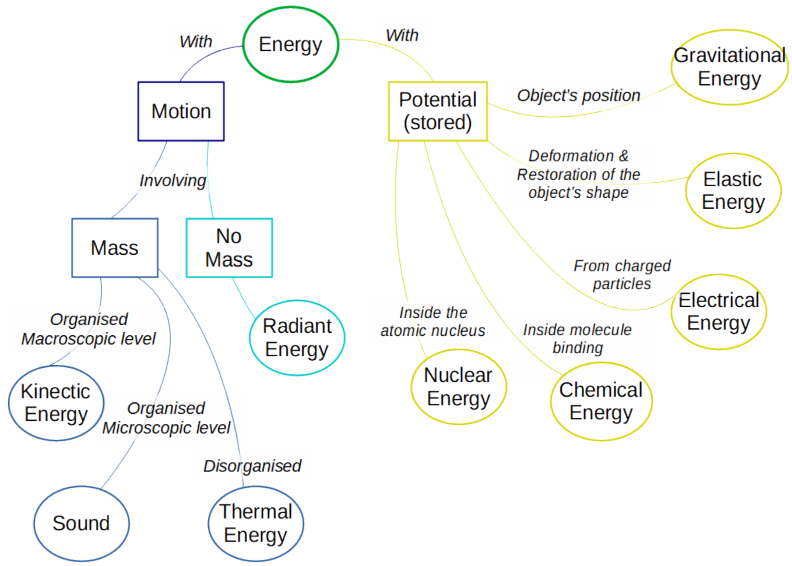


*IMAGE 2: **MINDMAP** OF THE DIFFERENT FORMS OF ENERGY*

MECHANICAL ENERGY/MOTION ENERGY

An object in movement, be it macroscopic or microscopic, has energy. If the movement involves mass, is macroscopic and is organised, then this type of energy is called kinetic energy. If it is microscopic, then we're talking about sound; if it is microscopic and disorganised, it's thermal energy. And finally, a movement without a mass involved is radiant energy.

- The macroscopic **kinetic energy** is the easiest energy to observe. It depends on the mass and the speed of the object, following this equation:

  $KE = 1/2\ m.v^2$

where KE is kinetic energy measured in J, m is mass measured in Kg and v is velocity of the object measured in m/s.

So, the heavier and the faster the object is, the more the object gains in KE. But this energy is only obtained when the object or the system is in movement. Otherwise, the KE is null. So a car parked has no KE. Looking at the equation, it is obvious that the speed, due to the term squared, has a larger effect on KE than mass. A 500 Kg car driving at 50 Km/h (~14 m/s) is given ~49 000 J. A 1T car driving at 50 Km/h is given ~98 000 J. And yet, the same 500 Kg car driving this time at 75 Km/h (~21 m/s, so 1.5 faster) is given ~110 250 J, more than twice the KE at 50 km/h. Therefore, the faster a car moves, the more dangerous it is: all this KE gained has to be transferred or transformed to another object like another car, tree, body... (**cf Transfer and transformation of energy**)

KE can be further divided into rotational KE which is the energy given to an object spinning around an axis. It follows this equation: $KEr = 1/2\ I.w^2$ where KEr is the rotational KE (in J); w is the angular speed in rad/s; I is the rotational mass of inertia also called the angular mass (in Kg/m^2) for which the calculation depends on the form of the object.

- **Thermal Energy is** also informally called heat. It is another form of KE but we are looking at it on a different level: thermal energy is the result of the total microscopic KE of the rotation, vibration and/or motion of particles inside an object, a liquid or a gas. Because the molecules of solid objects cannot go around, the only way to move and create heat is to vibrate. Therefore, when you rub your hands, the molecules on the surface of the skin start vibrating, creating some energy that will be dissipated by heat. The heat can even reach a high enough temperature to ignite a fire, like from rubbing of two sticks of wood. In a gas or liquid, the molecules are freer, so their motion and rotation is also involved. When we agitate a glass of water with a spoon, the KE of the spoon is transmitted to the water molecules that move faster, and then dissipated the KE received by increasing the water temperature. So, the temperature of a system depends on all of the microscopic kinetic energy that makes up the system.

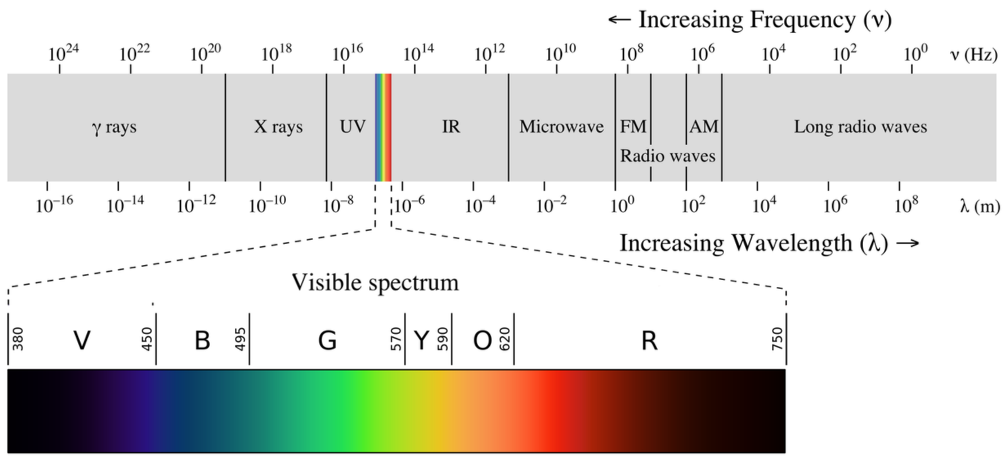
- **Sound** is also a microscopic movement of molecules but organised, in wave form. It is a variation of pressure transmitted through a medium, and which can be displaced in the same or opposite direction of the wave **(See longitudinal waves in chapter 5.3.1)**. So, a second of noise is composed of waves of greater and lesser pressure. The speed of sound is related to temperature: the hotter it is, the faster the sound will travel. It is also related to the density of the medium and its elasticity properties.

  When a collision occurs, one part of the energy is lost in sound. When an object flies, we can hear it. During flight, the object impacts air molecules and makes them vibrate faster. The vibration propagates and therefore, at a macroscopic level we heard a sound.

  If there two objects are rubbing, it causes vibrations (microscopic motion) of the molecules on the surface, then transmitted to the air, which slightly changes its pressure and sound is produced. We hear the friction.

- **Radiant Energy** is based on wave movement without a mass, like electromagnetic waves or radiation. The electromagnetic spectrum is composed of (from the shortest to the longest waves ~ wavelength) gamma rays, X rays, ultraviolet light, visible light, infra-red light, microwaves and radio waves. Light is the only visible electromagnetic wave to the human eye.

IMAGE 3: ELECTROMAGNETIC SPECTRUM WITH VISIBLE LIGHT HIGHLIGHTED. FROM LEFT TO RIGHT: GAMMA RAYS, X RAYS, ULTRA-VIOLET LIGHT, VISIBLE LIGHT, INFRA-RED LIGHT, MICROWAVES AND RADIO



WAVES (IMAGE FROM: HTTPS://EN.WIKIPEDIA.ORG/WIKI/ELECTROMAGNETIC_RADIATION#/MEDIA/FILE:EM_SPECTRUMREVISED.PNG)

Radiant energy is found in the warmth of sunlight or fire; by heating food in the microwave. This energy transmission occurs without involving mass. However electromagnetic radiation is also made of individual particles called photons. When the light travels, it has no mass and reaches the speed of light; when the light collides with the matter, it loses its velocity and then an electron is ejected out of the matter. This is light's duality: a wave without mass and, at the same time, particles with mass.

Each photon carries a small "unbreakable" pack of energy, also known as quantum energy. The unit used is electron Volt (eV) due to the small quantity of energy involved. 1 eV = $1{,}6 \times 10^{-19}$ J. 1 eV corresponds to the energy given to an electron from an acceleration through 1 volt of electric potential difference. For example, the energy given by a photon of blue light of wavelength 450 nm is equal to 2,76 eV. And you cannot obtain half of it as you cannot have halve a photon.

Radiant energy (or quantum energy) depends on photon frequency or wavelength which are proportional:

E = h.v where E is quantum energy in eV; h is Plank's constant about 6.626×10^{-34} J/s; v is radiation frequency in Hz

In addition, c = v.λ where v is radiation frequency in Hz; c is light velocity in m/s; λ is the wavelength in m

To sum up, energy of electromagnetic radiation, its frequency and its wavelength are linked. If radiant energy decreases, then the wavelength increases and the frequency decreases.

POTENTIAL ENERGIES

Each object of the Universe is a tank of energy waiting to be used. A ‘potential to do work’ is locked until the energy is released.

- **The gravitational potential energy** is the capacity to produce work depending on the position of the object in the gravitational field.

  PE = m.g.h where PE is gravitational potential energy in J; m is mass in Kg; h is height is m; g is the gravitational acceleration in m/s^2. The last one is a constant representing the potential of motion near the surface (~9.8 m/s^2 on Earth).

  If PE=0 when the object is on the surface of the system (the zero point) which can be any coordinate point (on the top of the mountain, or the surface of a table or the 2nd floor, or even on the crater of the moon). Then, the object gains energy when it is lifted at a height h above the zero point.

  The higher and the larger an object is, the more PE it possesses. Moreover, the gravity of the system modulates this energy. For example, the acceleration given to an object on the moon (~1.6 m/s^2) is smaller/weaker and on Jupiter (~24.8 m/s^2) is greater than on Earth.

- **Chemical energy** is the potential energy inside molecules whose atoms can be combined differently. A chemical reaction is the destruction of chemical bonds or the creation of new ones. When chemical bonds are created, energy is dissipated; when they are broken energy is needed.

- **Nuclear energy** is the energy stored inside the nuclei of atoms. A nucleus is composed of protons and neutrons which are bound to each other by strong forces while high repulsion occurs between the protons (due to their positive charges). The energy contained inside a nucleus can be estimated with the following equation:

  $E = \Delta m.c^2$ where E is the nuclear binding energy in eV; Δm is the difference between the sum of all the individual part constituting the nucleus (protons and neutrons) and the mass of the nucleus; c is the speed of the light in m/s

  To appreciate the huge amount of energy stored in the nucleus, let's compare the ionization and the fission of an hydrogen atom: it takes 13,6 eV to pull apart its electron (ionization) but you need $28,3 \times 10^6$ eV to break its nucleus and separate the protons from the neutrons.

  So, inside the nucleus, two of the strongest forces in nature enter in conflict: the Coulomb force which is the cause of the repulsion of the same charged elements and the "strong force" which holds together the nucleus. Therefore, it is not surprising to observe unstable nuclei. According to their mass, unstable isotopes release nuclear energy through 2 processes: fission and fusion. If a massive nucleus becomes unstable, a great amount of energy is released by fission. And the sum of masses of all new individual nuclei will be lighter than the mass of the combination. The difference has been transformed into energy. Fission is used in nuclear power plants where uranium is the dominant choice for fuel. On the other hand, if a nucleus lighter than iron is unstable, a great amount of energy is also produced by fusion. And the mass of the combination will be less than the sum of mass of the individual nuclei. The difference has been transformed into energy. This phenomenon occurs in the Sun to create a huge amount of energy.

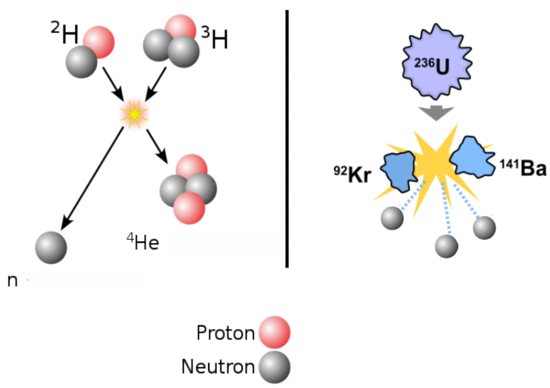


IMAGE 4: AT THE LEFT, FUSION OF DEUTERIUM WITH TRITIUM CREATES HELIUM-4, FREEING A NEUTRON. AT THE RIGHT, THE FISSION RESULTS IN THE EXCITATION AND INSTABILITY OF THE URANIUM-236 WHICH SPLITS INTO LIGHTER ELEMENTS (KRYPTON AND BARIUM) AND RELEASES A SMALL AMOUNT OF FREE NEUTRONS. (IMAGE FROM: HTTPS://EN.WIKIPEDIA.ORG/WIKI/NUCLEAR_FUSION#/MEDIA/FILE:DEUTERIUM-TRITIUM_FUSION.SVG AND HTTPS://EN.WIKIPEDIA.ORG/WIKI/NUCLEAR_FISSION#/MEDIA/FILE:NUCLEAR_FISSION.SVG)

- **Elastic potential energy** is the energy given by the deformation of an elastic object, springs are a good example of this. It depends on the objects deformation capacity and the distance stretched, following this equation:

  PE=1/2 k.x² where PE is potential energy in J; k is elastic or spring constant in N/m; x is the displacement of the spring, in other word the distance stretched, in m

  Elastic/spring constant is the force necessary to deform the elastic object by a certain length. It depends on the shape and the material. The higher the number is, the more resistant the spring will be and the more force should be applied to deform it.

  PE=0 when the spring is not stretched. It is given energy when it is stretched or compressed. A spring can maintain compression or stretching for extended periods in time without dissipating energy. When all the energy is dissipated, its initial shape or starting length is restored (if not, it is not an elastic object).

- **Electrical potential energy,** especially in a capacitor (electrical storage as batteries), is the energy given by the arrangement and the motion of charges (usually electrons) in electrical and magnetic fields (**See Chapter 4.4.1**). Usually, a charge is paired with its opposite sign and this association neutralizes them.

Matter is composed of atoms which possess positive charges inside its nucleus (protons) and negative charges moving around its nucleus (electrons); if there are the same amount of negative charges as positive charges the the matter is neutral. Some processes can separate and stock charges in batteries or storm clouds, for example, thud creating electrical potential energy. This energy uses the electromagnetic forces which leads to strong repulsion between identical charges and pulls together the opposite charges with just as much force. Electrical energy moves from one point to another, being held in the movement of electrical charges. However, it is difficult to store electricity in large quantities.

2.4.2. Transfer and transformation of energy

TRANSFER

Energy is in motion and it's essentially invisible. We can only see the effects of energy on our environment. We often observe its transfer from one system to another. Like we cannot see the wind, but air molecules are moving which will move leaves in trees via a chain reaction. Another example from daily life is cycling. To ride a bike, the cyclist applies forces on the pedals which turn and cause the chain to move and the wheel to rotate. All the energy used to trigger the wheel's rotation was based on kinetic energy.

TRANSFORMATION

Energy can also be stored, waiting to be released. Energy has many faces as we describe it in the preceding section. When it changes from one form of energy to another wa call it transformation. Let's focus and explore this idea in the following examples:

- **Photosynthesis** is a natural phenomenon for plants (with chlorophyll pigments) to obtain sugar in daylight. The chlorophyll captures the radiant energy of the Sun to transform it into chemical energy. Light tears electrons from the hydrogen of water molecules (H_2O) that becomes unstable. The stability will be reached by becoming oxygen (O_2). The freed hydrogens enter a chain reaction to produce carbohydrates which store long-term energy into their chemical bonds and short-term energy storage which is a kind of biological energy currency as ATP (adenosine triphosphate).

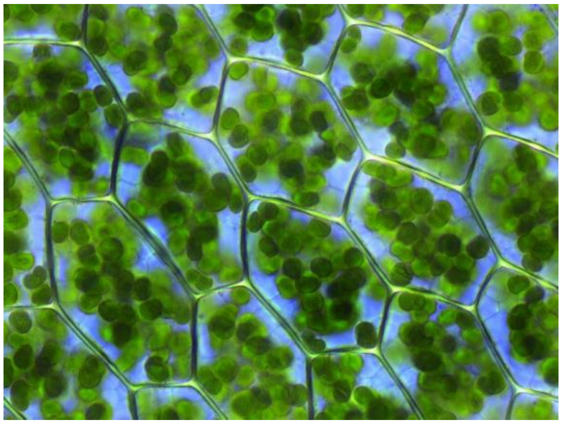


IMAGE 5: ***MOSS*** CELLS WITH VISIBLE CHLOROPLASTS (IMAGE FROM:HTTPS://EN.WIKIPEDIA.ORG/WIKI/PHOTOSYNTHESIS#/MEDIA/FILE:PLAGIOMNIUM_AFFINE_LAMINAZELLEN.JPEG)

- To turn on a **light bulb**, you need electricity. Electricity goes through a filament with resistance. This resistance leads to the filament heating up. It then emits light by incandescence. A very hot object emits light (first red toward yellow and then blue). It transforms heat into light to lower the temperature. A hot object without light emission does not mean that it is not producing electromagnetic radiations, it is simply too weak for us to perceive. However, we lose a lot of energy through heat emissions instead of light. Nowadays, we use LED lamps which are more energy efficient. LED lamps are based on electroluminescence which use an electric current to excite electrons. Then, excited electrons release their energy into photons - in other words, light. More energy is transformed into light; less energy is lost into heat (but still exists).
- A **car engine,** also called an internal combustion engine, contains potential chemical energy in its fuel. When the fuel is ignited, the energy is transferred to the air molecules through thermal energy. Hot air molecules occupy more space and volume and push the engine piston. So, the thermal energy is transformed into linear KE. The piston is linked to a crankshaft by a connecting rod, which allows the conversion from linear motion to rotational motion. In terms of energy, the linear KE is converted into rotational KE which turns the wheels.
- A **mountain river** possesses potential gravitational energy until it reaches a waterfall. Then, the stored potential energy is transformed into KE and the water tumbles forcefully into another river. The force, and the quantity of energy

converted, depend on the sea level. The potential gravitational energy decreases until the river reaches the sea or the ocean. A dam uses this potential gravitational energy to turn pals of a turbine (linear KE to rotational KE) which create electrical potential energy.

- A **bike dynamo**: from muscles to the lamps. Potential chemical energy contained in the ATP molecules in the body allowed muscles to function and produce linear KE (the foot pulls the pedal). After a chain reaction of KE, the wheels turns, and the bike moves. On the wheels, we often find a bottle dynamo, an electrical generator that converts mechanical energy to electrical potential energy. Then electrical energy is transformed to radiant energy (light) and heat, and the lamp lights up.

IMAGE 6: BOTTLE DYNAMO MOUNTED ON A BICYCLE. (IMAGE FROM:HTTPS://EN.WIKIPEDIA.ORG/WIKI/BOTTLE_DYNAMO#/MEDIA/FILE:FAHRRAD-DETAIL-23.JPG)

2.4.3. Conservation of Energy: Law

Energy is ruled by a fundamental principle: "Energy can neither be created nor destroyed". In other words, in an isolated system, energy does not appear or disappear; it remains constant by changing its form.

CONSERVATIVE FORCES

When only conservative forces are applied in a system, mechanical energy is the sum of kinetic and potential energy following this equation:

E = KE + PE where E is the mechanical energy; KE is the kinetic energy and PE is the potential gravitational energy (all in J)

This equation could also be written as:

$E \sim 1/2mv^2 + m.c^2$ where E is the rest mass energy in J; m the mass of the object in kg; c is the speed of light in m/s; v is the speed of the object in m/s

You may notice that the first term that is the equation of KE and the second term is Einstein's famous equation also known as the relativistic energy or the rest-mass energy. The equation of energy is often shortened into $E \sim m.c^2$ since the value of v is in general quite ridiculous compared to the speed of light. Einstein thought that anything with mass, even the smallest amount, contains energy. If you look carefully, his nuclear binding energy equation is close to his one of relativistic energy. While the nuclear binding energy is about the energy contained inside the binding between protons and neutrons, the rest mass energy is about the capacity of the entire object to contain energy.

NON-CONSERVATIVE FORCES

If non-conservative forces, like air resistance, enter into the system, it could be seen as not applying the conservative energy law. However, at the level of particles, air friction results in the heating of particles. The application of the energy conservation is translated by the 1st law of thermodynamics that follow this equation:

$Et=Ei+W+Q$ *where Et* is the total of mechanical energy of a system; *Ei* is the initial energy of a system; *W* is the work done by or on the system; *Q* is the heat added to, or removed from, the system (all in J)

In summary, mechanical energy is converted in work or/and heat. But be aware that all work can be turned into heat but not all heat can be turned into work. This is the 2nd law of thermodynamics principle.

A WORD ABOUT MOMENTUM

Momentum is a mass in motion (**See Chapter 2.4.9 for details**). So, the mass has potential energy and because of its motion it possesses mechanical energy too. With all this energy, momentum is also subjected to the conservative law. The conservation of momentum means that in an isolated system, momentum is a constant. Like the 2.4.10 part explained it, for every force and action, there is an equal and opposite reaction. Therefore, the vector sum of all forces should remain constant in an isolated system, and this constant cannot be changed by interactions within the system. As Dr C. R. Nave tells us "as far as we can tell, conservation of momentum is an absolute symmetry of nature. That is, we do not know of anything in nature that violates it" (Quote from his website called hyperphysics).

2.4.4. Experiments

EXPERIMENT 1

The objective of this experiment is to understand what energy is and observe some types of it.

For this experiment we will need:

- different beads like marbles, steel beads, paper beads (could be other objects like different coins or dice...)
- Semolina (or modeling clay)
- Tray

Preparation

First, put semolina into the tray. Then, drop the objects from a given height.

Observation

Observe how the marbles or beads have different sounds when dropping. Notice how big the crater they form is. Try to change the height. Does it change something?

Which type of energy do you see? (Answer: potential gravitational energy, sound, kinetic energy, probably heat) Can you calculate one of them? (PE=mgh)

Conclusion

The heavier the bead is, the louder the sound and bigger the crater will be.

The higher the dropping is, the louder the sound and bigger the crater will be.

EXPERIMENT 2

This experiment is a representation of energy conservation. By playing with the elements, students will understand how the energy is distributed.

Part #1 – Setting the SG90 Servo Motor

For this part we will need:

- Raspberry Pi 3 (RPi)
- Jumper wires (male-to-male and female-to-male)
- SG90 Servo Motor
- Breadboard + T-Cobbler

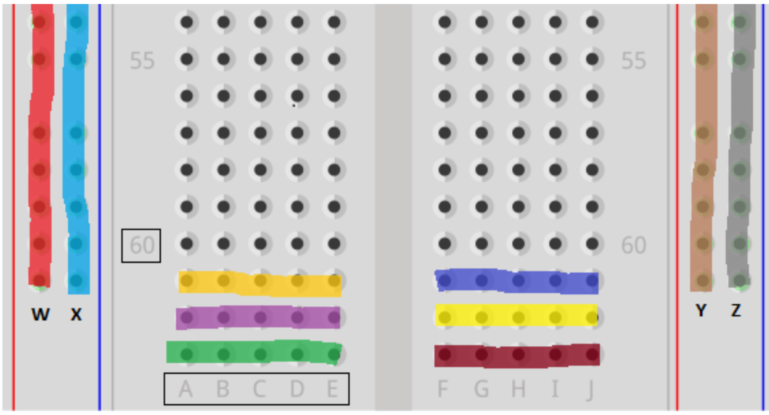


IMAGE 7: HOW THE BREADBOARD IS ORGANISED (IMAGE OBTAINED WITH FRITZING SOFTWARE): THE DIFFERENT UNDERLINED ROWS OR COLUMNS SHOW HOW THE HOLES ARE CONNECTED. THE CONNECTED HOLES OF A ROW HAVE A LETTER (A, B, C, D, E IN ONE SIDE; F, G, H, I, J IN THE OTHER). THERE IS A SEPARATION BETWEEN THE 2 SIDES AND ALSO BETWEEN THE EXTREME COLUMN AND THE INSIDE ROWS. ROWS HAVE ALSO NUMBERS

The breadboard is an extension of the RPi, which allowed us to link more components to it. On the breadboard, you see letters (A, B, C, D, E in one side; F, G, H, I, J in the other) which are all connected in the same row by side. So let's look at the first row: if you put a wire in 1A, 1B or 1C it will be the same as plugging into the GPIO itself. The 2 columns of holes on the outside, without any letter, are connected along the column; on the schematic they are called W, X, Y and Z. The RPi possesses some current entries (3.3V, 5V) and exits (GND). After clipping the RPi we want the entries and exits available along the breadboard so we need to link, using jumper wires, the 3.3V entry (like the first row) to one of the outside column (W) and then the GND exit (row 5) to the next column (X). Do the same with the 5V entry (from row 1 to column Y) and the GND (from row 3 to column Z) exit on the other side.

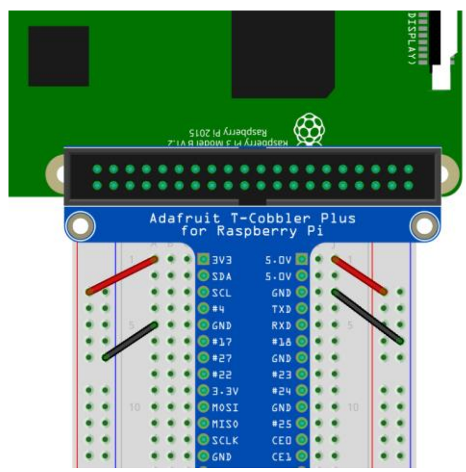


IMAGE 8: HOW TO POWER AND PLACE THE GROUND INTO THE BREADBOARD

The SG90 Servo comes with three different headers which can be attached on top of its body and can be used to assemble various DIY structures. For this experiment, we will not attach any other object on top. We will just use the one-side header as a gauge.

We need to plug a male-to-male jumper wire into each of the holes on the end of the servo cord, then plug the other side on the breadboard. We'll be sending signals from one GPIO pin (yellow wire) and powering the servo with 5V using another pin (red wire). The third wire is the ground (GND; black wire). So the red wire goes into the Y column, the black wire goes into the Z column and the yellow wire goes into the GPIO pin #18 in our example (J8).

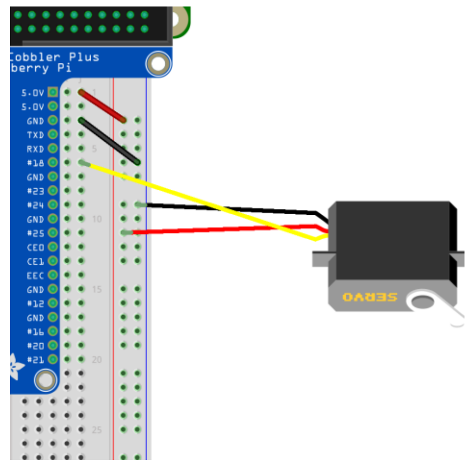


IMAGE 9: CIRCUIT DIAGRAM OF THE BREADBOARD PREPARATION *(IMAGE OBTAINED WITH FRITZING SOFTWARE)*

The servomotor will act as a sensor of the quantity of energy left into the circuit. Each time a component is turned on, the servomotor will decrease its gauge.

Part #2 – Adding LED and buttons

For this part we will need:

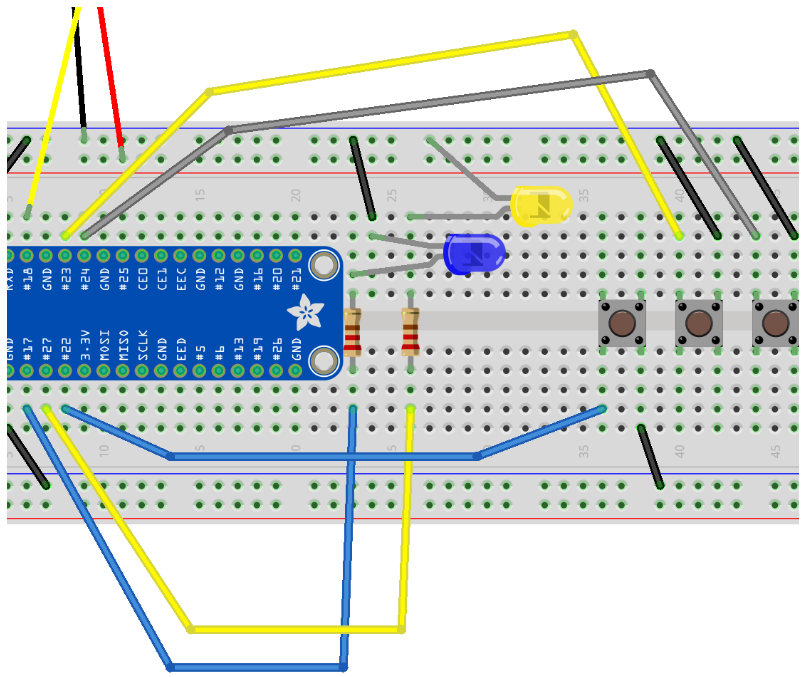
- LEDs
- Jumper wires (male-to-male)
- buttons
- resistances

Now, we want to add some components that will be turned on and off. When none of the components are turned on, the gauge (the servomotor) will be at its maximal angle. When they are in use, the angle will decrease. To control each of the components, we will also place some buttons which half its pins on either side, so it runs parallel with the board. One side of buttons needs to be linked to ground (column X or Z) and one GPIO pin (#22, #23 and #24 in our example).

We will also need resistances to avoid a strong current that will break the LED. In our example, we used resistances of 220Ω (red – red – brown marks).

First place the LEDs, the short leg (cathode) should be plugged in the GND column (Z) and the long leg in the column J26 (see the yellow LED example). If you have difficulties, you can plug the two legs in 2 different rows and link the short leg to the GND column with a jumper wire (see the blue LED example). Then, place one of the pins of the 220Ω resistance in the same row as the long leg of the LED (F26 for the yellow LED) and the other pin on the other side of the breadboard. Finally, we want them to be connected to the GPIO. In our example, we linked the resistance of the yellow LED to the GPIO pin #27 and the one of the blue LED to the GPIO pin #17.

IMAGE 10: CIRCUIT DIAGRAM OF THE PLUGGING OF LEDS AND BUTTONS *(IMAGE OBTAINED WITH*



FRITZING SOFTWARE)

Part #3 – Controlling a small 3V DC Motor with an L293D control chip

The motor is another component that we want to turn on and off by using the 3rd button. To control the motor, an L293D chip is necessary. Place the chip with half its pins on either side, so it runs parallel with the board. Each side can be used to control and run one motor. In our case, the motor speed will be controlled by the rotary encoder module (see next part).

Image 11: Pin details of the L293D control chip. Pin 1: sense On/Off motor #1; Pin 2: input for the direction of the motor #1 spinning; Pin 3: output of motor #1; Pin 4-5: ground; Pin 6: output of motor #1; Pin 7: input for the direction of the motor #1 spinning; Pin 8: voltage pin for the motors. It should be comprised between 4,5V and 36V; Pin 9: sense On/Off motor #2; Pin 10: input from the GPIO for the direction of the motor #2 spinning; Pin 11: output of motor #2; Pin 12-13: ground; Pin 14: output of motor #2; Pin 15: input from the GPIO for the direction of the motor #2 spinning; Pin 16: chip power. The tension should be comprised between 4,5V and 7V (image from: https://microcontrollerslab.com/l293d-motor-driver-ic-introduction-pinouts-example/)

First, we need to power the chip (Pin 1, 8, 9, 16 of the chip to the 5V/Y column) and place the ground (Pin 4-5 to the X column and Pin 12-13 to the Z column). Then, we plug the outputs of the motor to the pins 11 and 14 of the chip. Now we need to link the raspberry to the chip by using respectively the GPIO pins #16 and #20 with the pins 10 and 15 of the chip.

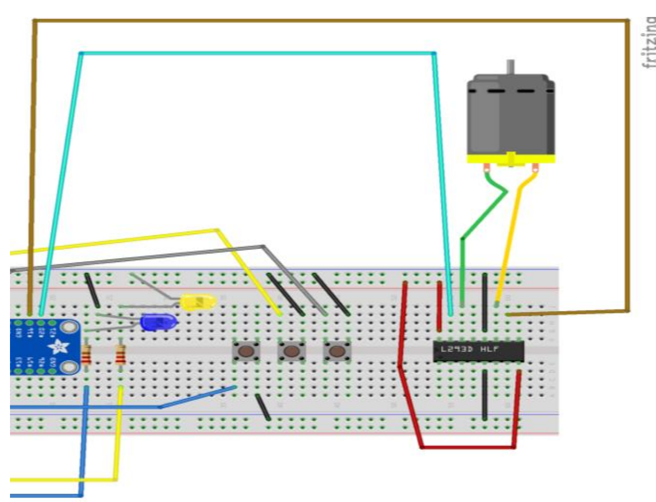


IMAGE 12: CIRCUIT DIAGRAM OF THE PLUGGING OF THE DC MOTOR AND ITS L293D CONTROL CHIP (IMAGE OBTAINED WITH FRITZING SOFTWARE)

Part # 4 – Adding the rotary encoder

For this part we will need:

- Rotary encoder
- Jumper wires (female-to-male)

Finally, we will add a rotary encoder which allows us to vary the power given to the components. More power will be given, brighter the LED will shine, faster the motor will run and more the angle of gauge (mimicking by the servomotor) will decrease.

The rotary encoder sends a digital signal for each degree of rotation applied to it, clockwise or counterclockwise. It has 5 pins: 2 for the rotary encoder (CLK and DT), one for powering the rotary encoder with 3.3V, the last one (GND) for the ground. In our example we plugged them using female-to-male jumper wires respectively to GPIO pin #6 (B16), GPIO pin #5 (B15), column W, column X.

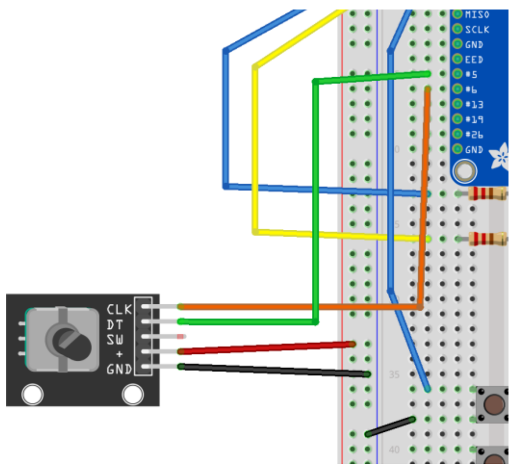


IMAGE 13: CIRCUIT DIAGRAM OF THE PLUGGING OF THE ROTARY ENCODER (IMAGE OBTAINED WITH FRITZING SOFTWARE)

The conservation of energy is illustrated by adding the energy left in the gauge (the servomotor) plus the transformative energy of the component (light and movement). Whatever the gauge level is, we always have the same amount of energy.

Part # 5 – The code

When our circuit is ready, we can start writing our program in Thonny Python (IDLE).

We open Thonny Python, and we save our file as *energy.py*

We need to write the following program:

```
##################################################################
 # little "hacking" to make the servomotor more precise
from gpiozero.pins.pigpio import PiGPIOFactory
import os
os.system("sudo pigpiod 2> /dev/null")

# Importation of libraries
from gpiozero import RotaryEncoder, PWMLED, Button, Servo, Motor
from time import sleep
NB_OF_COMPONENT = 3

# Initialisation of the rotary encoder, 2 LEDs, motor, servomotor
and 3 buttons
# All numbers in bold are corresponding to pins used by each
component (17 <=> 'GPIO17')
rotor = RotaryEncoder(6, 5, max_steps=5)
rotor.steps = -5
led1 = PWMLED(17)
# composant_state equals 0 when the component is turned off, and
it equals 1 when it is turned on
led1_state = 0
led2 = PWMLED(27)
led2_state = 0
motor = Motor(forward=20, backward=16)
motor_state = 0
servo = Servo(18, pin_factory=PiGPIOFactory())
button_led1 = Button(22)
button_led2 = Button(23)
button_motor = Button(24)

# Fonction which convert a value comprised between src_min and
src_max in a value comprised between dst_min and dst_max
# It defaults to a value comprised between -1 and 1 (for the rotary
encoder) and between 0 et 1 (for LEDs and motor)
def scale(val, src_min=-1, src_max=1, dst_min=0, dst_max=1):
    return ((val - src_min) / (src_max - src_min)) * (dst_max -
dst_min) + dst_min


# Give back a value comprised between 0 (all 3 components are
turned on to their maximum) and 1 (all 3 components are turned off)
```

```
def    compute_nrj_left(rotor_value,    led1_state,    led2_state,
motor_state):
    # According to the value of the rotary encoder, each component
uses between 0 and 1/3 of energy
    individual_nrj = scale(rotor_value, dst_max=1/NB_OF_COMPONENT)
    total_nrj  =  individual_nrj  *  (led1_state  +  led2_state  +
motor_state)
    return 1 - total_nrj

# Fonctions which will be executed if a button is pressed
def button_led1_pressed():
    global led1_state
    if led1_state == 1:
        led1.off()
    # If the state of the component is at 0, then it goes to 1 and
inversely
    led1_state = 1 - led1_state

def button_led2_pressed():
    global led2_state
    if led2_state == 1:
        led2.off()
    led2_state = 1 - led2_state

def button_motor_pressed():
    global motor_state
    if motor_state == 1:
        motor.stop()
    motor_state = 1 - motor_state

# The 3 preceding fonctions are associated with the 3 buttons
button_led1.when_pressed = button_led1_pressed
button_led2.when_pressed = button_led2_pressed
button_motor.when_pressed = button_motor_pressed

# "try except" allows to try the execution of a piece of code and
to execute another part if an error comes
# Here we try an infinite loop and if there is an error it will be
writen on the screen
try:
    # Infinite loop
```

```
    while True:
        if led1_state == 1:
            led1.value = scale(rotor.value)
        if led2_state == 1:
            led2.value = scale(rotor.value)
        if motor_state == 1:
            motor.value = scale(rotor.value)
        nrj_left = compute_nrj_left(rotor.value, led1_state, 
led2_state, motor_state)
        # For this experiment, the minimal value of the servomotor 
is 1, the maximal one is -1 (because the rotation is anticlockwise)
        servo.value = scale(nrj_left, src_min=0, src_max=1, 
dst_min=1, dst_max=-1)
        sleep(0.1)
except Exception as e:
    # The error on the screen ("Keyboard interruption" if we stop 
the program with Ctrl + C)
    print(e)

#################################################################
```

2.5. Assessments

I. What is the international measurement unit of energy?
a) Joule (correct answer)
b) Hertz
c) Watt
d) Calorie

II. Photosynthesis is a process of transformation of energy applied in photography.

a. True
b. False (correct answer)

III. Thermal energy is one form of kinetic energy.
a. True (correct answer)
b. False

IV. Which energy below is not a potential energy?
a. Chemical
b. Nuclear
c. Elastic
d. Thermal (correct answer)

V. In the equation E=KE+PE, what does PE mean?
a. Potential gravitational energy (correct answer)
b. Potential kinetic energy
c. Potential optimal energy
d. The speed of light

VI. Radiant energy is based on motion.
a. True (correct answer)
b. False

VII. Nuclear energy is a chemical energy.
a. True
b. False (correct answer)

VIII. The engine can be connected directly to the Raspberry Pi
  a. True
  b. False (Correct answer: You need the chip L293D)

IX. We do need a resistance to turn on a LED because a high voltage would deteriorate it.
  a. True (correct answer)
  b. False

X. What major transformation of energy do we see when we turn on the LED?
  a. Electric to radiant energy (correct answer)
  b. Chemical to electric energy
  c. Electric energy to nuclear energy
  d. Thermal energy to electric energy

2.6. Conclusion

Energy is the capacity to change the state of a system. It is invisible and has many faces. The final purpose of energy (mechanical or potential) is to produce a work or a motion, but it can also release heat, light or electricity (which are, at a certain level, the expression of particle movements).

To sum up the first law, energy is neither created nor destroyed. And in an isolated system, energy remains constant. But a strictly isolated system is hard to find because it does not exist as a shield against gravity or electromagnetic forces yet. However, we can picture all the Universe like an isolated system, so at the end energy seems conserved.

In the prism of the expansion of the Universe, the law of conservative energy is also questionable. From the Big Bang, the beginning of the Universe, galaxies grow and spread in space. Scientists studied stars and suns without conceiving that perhaps galaxies receded from each other. But one day of 1912, one of them, Vesto Slipher, an American astronomer, noticed that light from faraway galaxies became warmer, reddish. The redshift phenomenon is the result of the expansion of the Universe. More the galaxies are receding, the more the wavelength of the light is stretched out, meaning that the wavelength is increasing. And a larger wavelength carries less energy. So where does the missing energy go? Since the birth of the Universe, is the energy slightly disappearing? Well, at the end, we have more questions than at the beginning...

2.7. Additional Resources

Energy is the most powerful and useful concept in all of physics, but what exactly is it? https://www.pbs.org/video/what-is-energy-iehizp/https://www.pbs.org/video/what-is-energy-iehizp/

Is energy always conserved? https://www.pbs.org/video/physics-girl-energy-conserved/

Energy unit comparison: http://hyperphysics.phy-astr.gsu.edu/hbase/egex.html#eu

Energy Forms and Changes Simulation https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html

Gas Properties Simulation: https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_en.html

Energy Transformation Simulation: skate park example https://phet.colorado.edu/sims/html/energy-skate-park/latest/energy-skate-park_en.html

Mass and Spring Simulation: https://phet.colorado.edu/sims/html/masses-and-springs/latest/masses-and-springs_en.html

Simple demonstration of the transfer of momentum through collisions between the two objects: https://www.youtube.com/watch?v=yhTz_6NFmV0

First experiment in situation: https://www.wikidebrouillard.org/wiki/Des_crat%C3%A8res_d%27%C3%A9nergie

2.8. References

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HyperPhysics © C.R. Nave, 2017 hosted by the Department of Physics and Astronomy in Georgia State University

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Actisciences - Matière et Energie (cycle 2 et 3), Sequence 1: Qu’est-ce que l’énergie? David Wilgenbus, Hélène Gaillard, Gabrielle Zimmermann, Paris : Ed. Sed Mureaux, 2015. 978-2-8223-0206-7 [in French] available online: https://www.fondation-lamap.org/sites/default/files/upload/media/ressources/activites/65459/F4121%20-%20Extrait%20-%20Mati%C3%A8re%20et%20%C3%89nergie%20-%20FR%20-%20Seq1.pdf

Engineering of the circuit https://gpiozero.readthedocs.io/en/stable/recipes.html

Electricity and Magnetism

2.1 Glossary

Term	Definition
Actuator	An actuator is a device that transforms the energy provided to it into a physical phenomenon that provides work, alters the behavior or condition of a system.
Anion	An Anion is an ion that, having gained one or more electrons, carries one or more negative elemental electrical charge: for example, the Cl chloride ion⁻ is the chlorine atom that has gained an electron.
Atom	An atom is the smallest part of a single body that can chemically combine with another. Atoms are the elementary constituents of all solid, liquid or gaseous substances.
Bluetooth	Bluetooth is a communication standard that allows two-way data exchange at short distances using UHF radio waves on the 2.4 GHz frequency band. Its goal is to simplify connections between nearby electronic devices by removing wired links.
Cation	A cation is an ion that, having lost one or more electrons, carries one or more positive electrical charge: conversely, an anion contains more electrons than protons.
Electron hole	In physics, chemistry, and electronic engineering, an electron hole (often simply called a hole) is the lack of an electron at a position where one could exist in an atom or atomic lattice. Holes are not actually particles, but rather quasiparticles; they are different

	from the positron, which is the antiparticle of the electron
Force centrifugal	Centrifugal force, the common but "abusive" name for the centrifugal effect, is a particular case of fictitious force that appears in physics in the context of the study of the movement of objects in non-inertial repositories. The effect felt is due to the rotational movements of these repositories and results in a tendency to move the bodies away from the center of rotation. This is, for example, the ejection sensation of a traveler in a vehicle that makes a turn.
Incandescent Lamp	The incandescent lamp is an electric light fixture that illuminates by incandescently bearing a tungsten filament, the metal that has the highest melting point.
Linux	Linux or GNU/Linux is a family of Unix-type open source operating systems based on the Linux kernel, created in 1991 by Linus Torvalds. Many Linux distributions have since emerged and are an important vehicle for popularizing the free software movement.
Microprocessor	A microprocessor is a processor whose components have been miniaturized enough to be grouped into a single case. Functionally, the processor is the part of a computer that executes instructions and processes program data.
Proton	The proton is a subatomic particle with a positive elementary electrical charge. Protons are present in atomic nuclei, usually linked to neutrons by the strong interaction.
Sensor	A sensor is a device that transforms the state of an observed physical size into a usable size, such as an electrical voltage, a height of mercury, an intensity or the deviation of a needle.
Thermocouple	A thermocouple, or thermo-electric couple, is, in physics, a couple of materials whose Seebeck effect, discovered in 1821 by the German physicist Thomas Johann

	Seebeck, is used for measuring temperature

2.2 Introduction to Electricity and Magnetism

Electricity has existed since the beginning of the universe, which is composed, according to the physical principles of "matter". Its human-created history dates back to the beginnings of mankind. It is very discreet most of the time, but sometimes manifests itself in a very spectacular and brutal way: for example, in the form of lightning associated with thunder and the attraction of some substances by others (amber and magnet stones).

Discovered in the 18th century, electricity can be made from different sources of energy. The most common is thermal energy, that is, heat produced by burning coal, oil or gas. This heat can also come from groundwater hot water, this is called geothermal. It also comes from radioactive metals such as uranium or plutonium used in nuclear power plants. On the other hand, this heat can simply be that of the sun, it is the solar energy, or that from the wind, it and the wind.

The electricity we receive in homes, factories, schools, ... is produced in power plants. This electricity can be produced in a variety of ways, including:

- **By friction:** rubbing one object on another (Static electricity) . A plastic latte rubbed on fabric attracts small pieces of paper.
  The rubbing of a sweater on the skin...
  The movement of clouds in the atmosphere

- **By light:** (continuous current)
  Transforming solar energy into electricity.
  Photovolataic panel, Calculator, watch, ...

- **Chemical action:** by dipping two different materials into a Mixture Acid (continuous current) and batteries.

- **In heat:** by heating two welded materials together (continuous current) Thermocouple.

- **Wind:** Wind energy is the energy of the wind, whose driving force (kinetic energy) is used in the movement of sailboats.

Between 1831 and 1839 Michael FARADAY, British physicist and chemist, known for his fundamental work in the field of electromagnetism, multiplied the founding discoveries of modern electricity, including *electromagnetic induction*, whose applications serve as the basis for the entire electrical industry.

4.3 Learning Outcomes

At the end of this module, the student will be able to correctly use the vocabulary and terms used in electricity and understand the basic laws and properly apply the formulas to study an electrical system.

The learning tool will cover the production of electricity, the Constitution of matter, Electrical circuit, voltage, electrical current, resistance, Ohm's Law and magnetism.

In this chapter also some experiments that you can perform using the Raspberry Pi and various other sensors. In addition, resources, references and other useful materials were included at the end to improve your learning and understanding of the subject.

2.4 Theory
2.4.1. Constitution of matter

What is electricity?

To answer this question, let's examine the smallest element that constitutes matter. indeed the **atom**. This latter made up of:

- of a **nucleus** which is positive (+).

- one or more **electrons** which are negative (-).

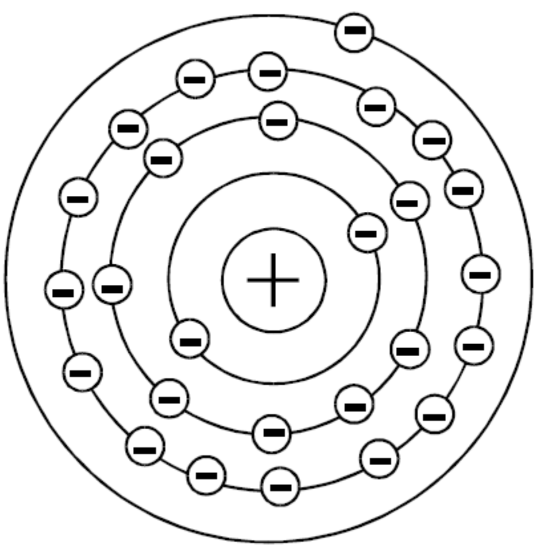
The electron rotates, in an orbit (layer), around the core.

The electrons (-) are attracted to the nucleus (+), but don't stick to it because there is a force centrifugal which moves it away from the nucleus.

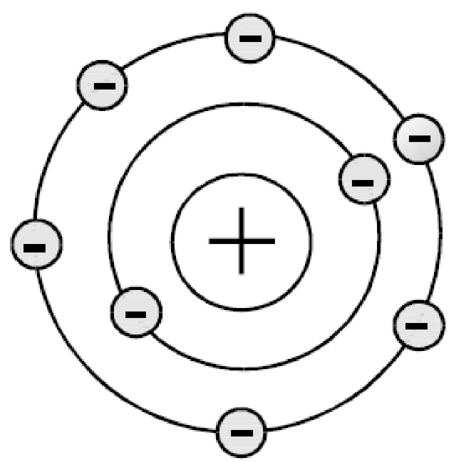
The atom has a precise number of electrons (-) distributed over successive layers.

Let us take two examples:

- **The copper atom**



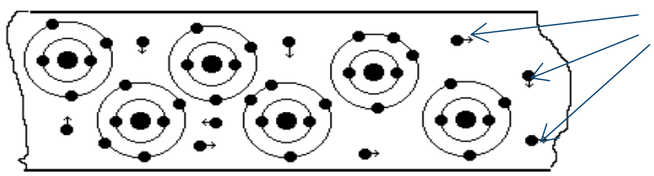
- **The carbon atom**



Atoms which have less than four electrons in their last shell easily lose one (this is the case with copper). We call this: electron-free.

The atom which has lost an electron is no longer complete. It will then try to attract another free electron in its vicinity or on another nearby atom. This happens in all subjects.

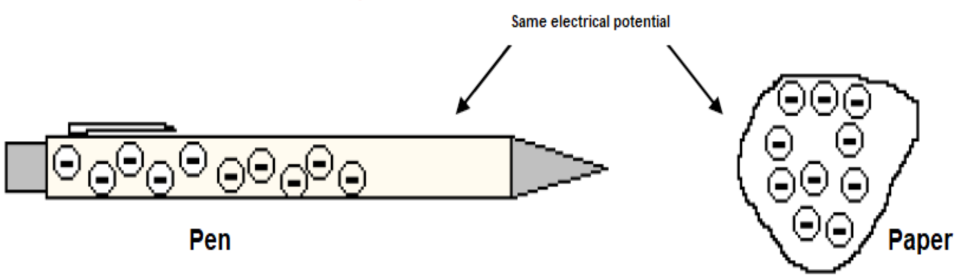
So here is what happens in a copper wire for example.



There is an exchange of free electrons between atoms, in different directions. Their displacement is amplified if we rub the material, heat it and press him.

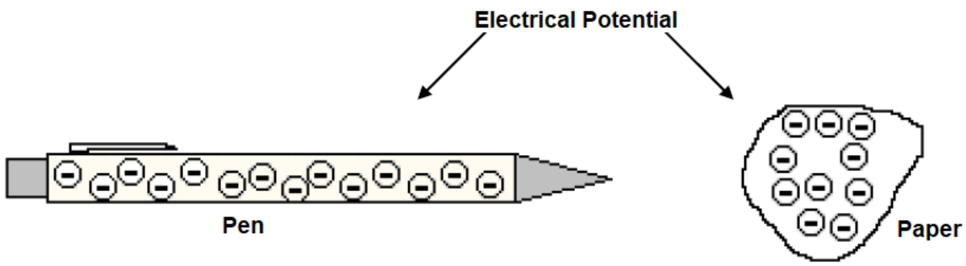
- ## Experience to illustrate this phenomenon

For this experience, a ballpoint pen and a small piece of paper are required. We remark, nothing happens if we just approach the pen of the paper pieces on the table. Because the two elements (paper and pen) have their atoms balanced. We say both objects have the same electrical potential.



Now we rub the pen energetically on the pants for a few seconds, and we approach the pen slowly from the paper.

We remark that the paper sticks to the pen, because the exchange of free electrons has been amplified.Free electrons from the pen went into the pants. So there are now more free electrons in the paper than in the pen. It is said that the two objects are not at the same electrical potential.



When the paper, pen was approached, a balance was created between the free electrons of the pen and paper.

Then, a few moments the paper falls, the balance is achieved and the two objects are to the same electrical potential.

In summary, there was an exchange of free electrons between the two objects, after rubbing the pen on the pants and after approaching the pen to the paper. This exchange occurred from the pen to the paper. Therefore, we can say that the pen has more electrons in the pen than the paper. Knowing that, the electron has a negative charge, therefore, the paper has a positive charge. The electrons moved from the pen which had a negative electrical charge to the paper which had a positive electrical charge, which is ***the principle of electricity***.

All the forces involved in the interactions between atoms can be explained by ***electromagnetic forces*** acting between electrically charged atomic nuclei and the electrons of atoms.

2.4.2. Electricity and magnetism

In 1820, the Danish physicist Hans Christian Ørsted was the first to demonstrate the existence of a link between electricity and magnetism. This man contented himself with publishing the results of his experiments which made the rounds of scientists of his time and led to a host of discoveries in the field of electromagnetism.

In his experiment, he approached a compass to a simple electrical circuit in which an electric current was flowing and found that the needle of the magnet was spinning (see photo).

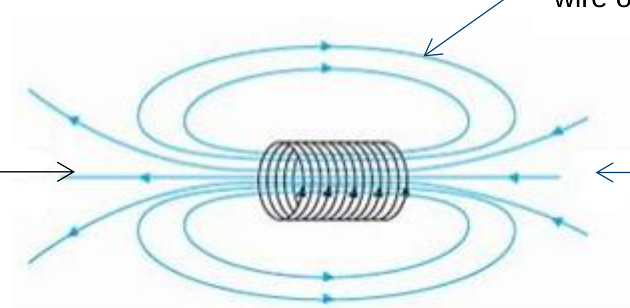
When the circuit is open, therefore no current flowing through the wire, the compass indicates the earth's magnetic north. If we close the circuit, so we let the current flow, then the compass needle points in another direction for north.

This simple experiment showed the connection between the movement of electric charges (i.e. electric current) and the generation of a magnetic field. So moving electric charges generate a magnetic field.

Magnetic fields generated by the passage of current passing through the wire of the coil.

South Face

North Face



With this experiment, Hans Christian Ørsted had just shown that the movement of electrical charges (later referred to as an electric current) produces a magnetic field.

Solenoid and magnetic field

A solenoid is a coiled helical thread, forming a long cylinder. When a solenoid is traversed by an electric current, it creates a magnetic field in its vicinity and especially within itself. This magnetic field is oriented according to the axis of the cylinder (Figure a).

The magnetic field, thus created by a solenoid is then similar to that created by a right magnet with a north pole and a south pole (Figure b).

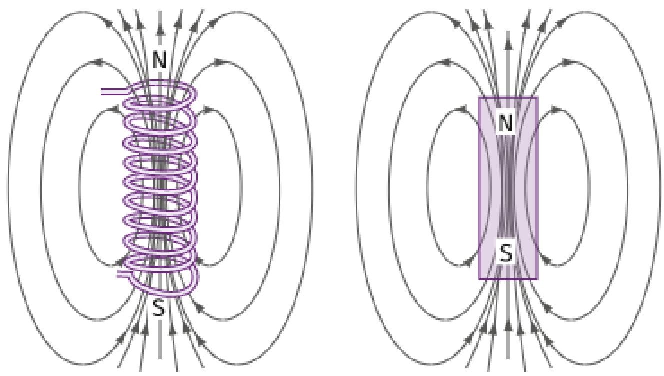


Figure a **Figure b**

Electromagnetic induction: The phenomenon of the appearance of an electrical voltage in a conductor subject to a variable magnetic field.

2.4.2. Electrical Circuit

2.4.2.1. Constitution

All electrical circuits are made up of at least four elements:

- **The generator:** a device that provides electrical energy (battery, alternator)
- **The receiver:** a device that receives electrical energy and transforms it into another Energy (all electrical devices)
- **The conductors**: elements which electrically connect the generator and the receiver (conductors, LP, switch, ...)
- **Protections**: which must interrupt the flow of current in the event of a short-circuit or overload (fuses, circuit breakers)

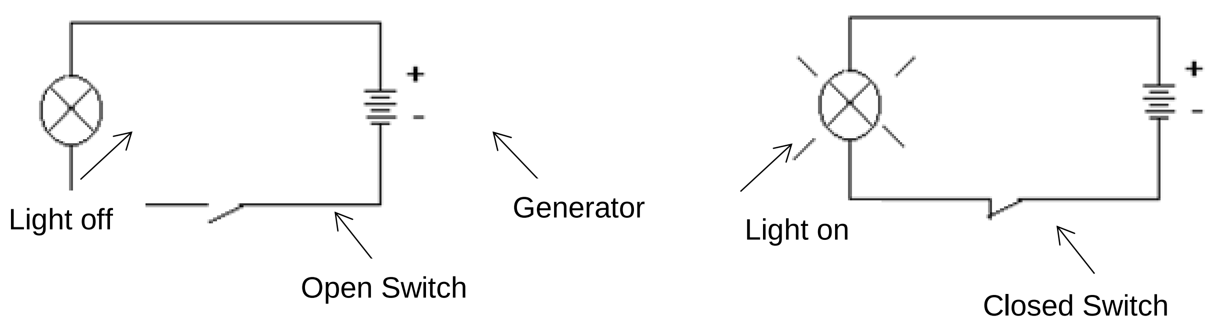
2.4.2.2. Conductors & insulators

Conductors: materials that conduct electric current, as example: copper, aluminum, brass... (all metals).

Insulators: materials that do not conduct electric current. Materials that do not conduct electric current (Exp. Plastic).

2.4.2.3. Representation

Open circuit and closed circuit



- Opened Circuit - **- Closed Circuit -**

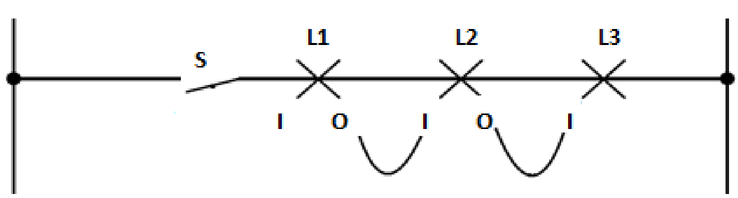
2.4.2.4. Serial and Parallel connection

There are two ways to connect the receivers in an electrical circuit.

- **Serial Circuit (And Function)**

Receivers are mounted in series, when they are connected end-to-end, i.e. when the end of the first is connected with the beginning of the second, and so on.

Example S → L1 and L2 and L3 (S a Switch that controls three lamps in series)



- S Switch
- I Input
- O Output

❖ **Application**

- **Christmas tree garlands**: All Lamps are serially placed for safety reasons. Indeed, each Lamp is designed to operate with a voltage of about ten volts.

In addition, it is easy to flash them because it is enough to interrupt the passage of the current in one place for all the lamps to go out.

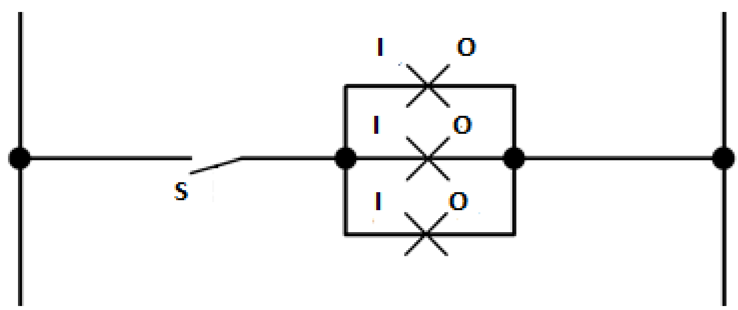
- **Generator grouping**: To plug in the battery components to form a battery.

We need to hook them up in series. Thus, 6 elements of 2V in series will give a battery of 12V.

- **Parallel Circuit (Or Function)**

Receivers are mounted in parallel when the two ends of each receiver are connected to each other on the same side each time.

Example S ---> L1 Or L2 Or L3 (a switch that controls three lamps in parallel)



❖ **Application**

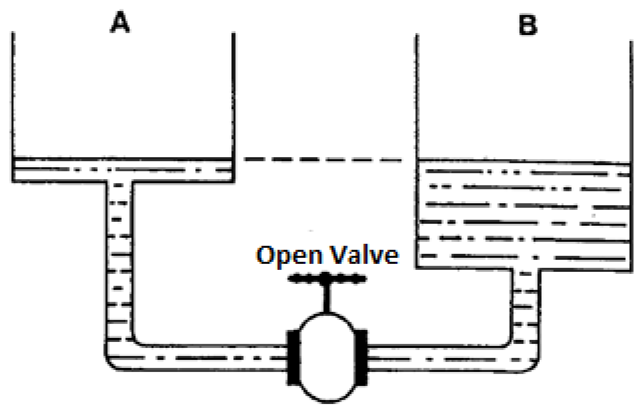
Connecting lamps and sockets in domestic installations

4.4.3. Voltage and Potential difference

Let's take the example of 2 A and B bins connected by a hose with a valve.

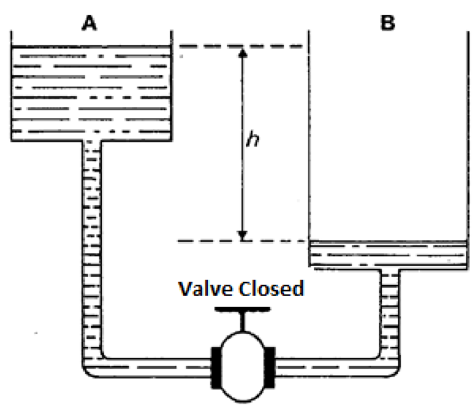
❖ Case of the two bins are at the same height

We remark that there will be no water circulation.

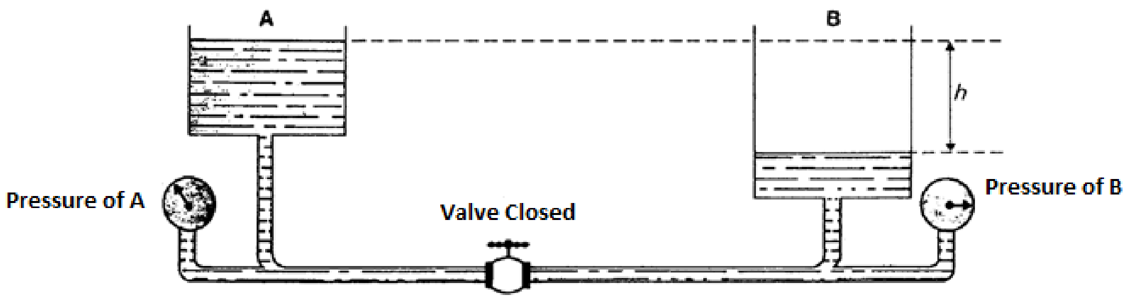


❖ Case where the valve is closed the 2 bins placed at different heights

It is noticeable that the opening of the valve causes the water to move from A to B.

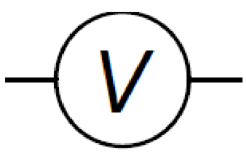


Indeed, if we want water to flow between the two bins, there must be a difference in h-level between them. This is the principle of communicating vases. Since the valve is closed, the difference in water height (h) between the two bins determines a difference in water pressure. When the valve is opened, it is this difference in pressure that will cause the water flow from tray A to bin B. The flow will stop when there is no more pressure difference: the levels will then be at the same height in the both bins.

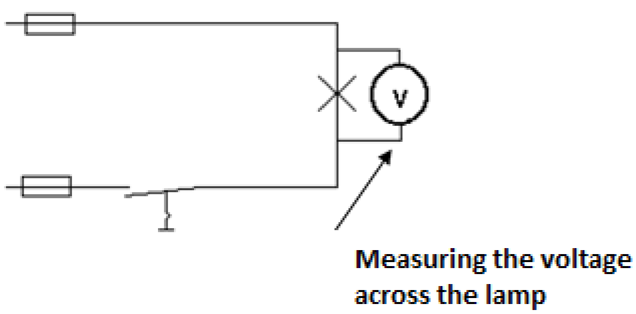


Likewise, in electricity, for a current to flow in a circuit, there must be an electrical pressure difference at its ends, called ***POTENTIAL DIFFERENCE*** or ***VOLTAGE*** at the circuit terminals.

The voltage is therefore the difference in the number of electrons between two points in the circuit. To measure voltage or Potential difference, in electricity, we use a voltmeter that is connected in parallel.



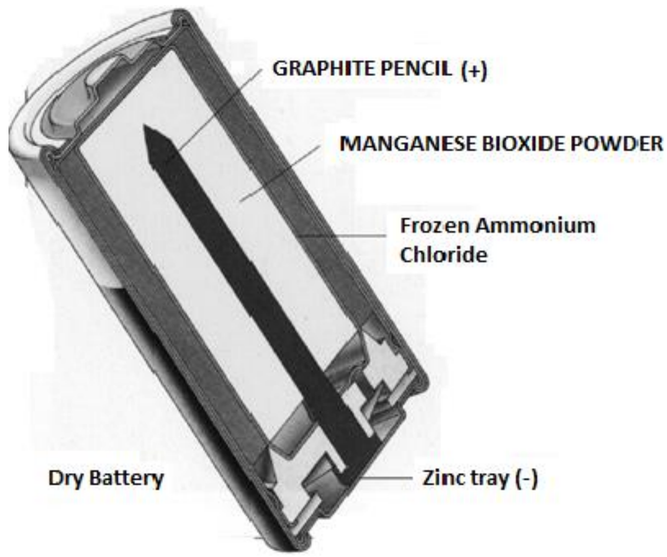
- Representation of the voltmeter -



We now know very well that electricity is a movement of free electrons in the same direction. In order for these free electrons to all move in the same direction, we have seen that there must be a difference in the number of electrons between the two ends of the electrical circuit. To maintain this difference in the number of electrons, a generator is used.

How ?

- By causing a chemical reaction between several materials. (Battery, chemical effect).



-
- Or by rotating a coil of copper wire in a magnet (Alternator, dynamo, ... magnetic effect).

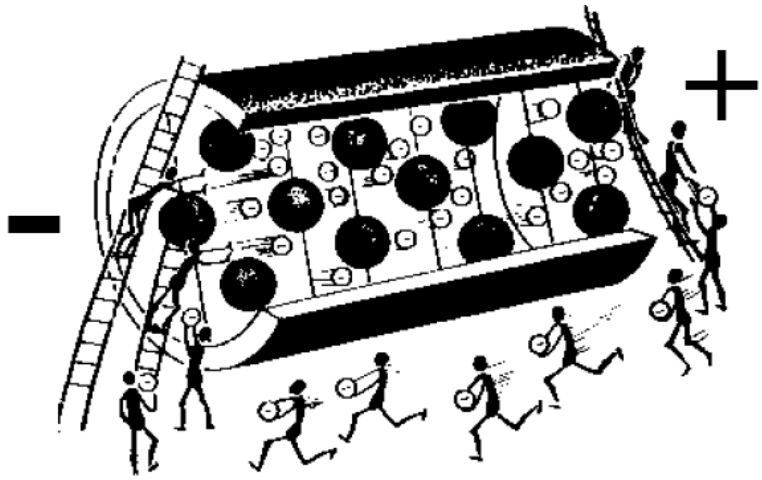
4.4.3.1. Generator function

- The generator has two poles where the charges of opposite names are concentrated (- and +). It maintains the difference in the number of electrons between the two terminals of a circuit, i.e there are always more electrons at the - terminal than at the + terminal.

- **The positive pole** carries a lack of electrons (compared to the - pole)
- **The negative pole** carries a large number of electrons.

The generator (+ pole) acts like an electron pump, which then sucks in and out. It has an inner strength that allows it to carry the electrons captured by the + pole towards the - pole from where they can start again in the circuit. This force is called: electromotive force (EMF).

Therefore, the generator develops a work that we call: electrical energy.



There is therefore always a difference in the number of electrons at the terminals of the generator and therefore of the circuit.

Reminder: It is this difference in the number of electrons that we call voltage or difference in potential.

Why is the - terminal negative and the + terminal positive?

Because, thanks to the internal chemical action of the cell, the free electrons flow to the negative terminal (-) and, therefore, there are more electrons at the - terminal than at the + terminal. As the electrons have a negative electric charge, the - terminal is therefore more negative than the + terminal.

4.4.4. Electric Current

An electric current is a group movement of carriers of electric charges, generally electrons, within a conductive material. These movements are imposed by the action of the electromagnetic force, whose interaction with matter is the basis of electricity.

By convention, in a single loop and direct current electric circuit, the electric current leaves the electric generator through the positive (+) terminal, passes through the electric circuit and returns to the generator through its negative (-) terminal. This convention is called "receiver" (the current flows in the direction of decreasing potentials, the voltage and the current are "directed" in the opposite direction)

This is called the conventional direction of electric current; it may be different from the actual direction of movement of charge carriers.

So when the charge carriers are electrons (the most frequent case), or anions their effective movement is from - to +, direction of movement of negatively charged particles therefore attracted by the positive.

On the contrary, cations and electron holes move in the conventional direction of the current.

In the so-called generator convention, the current flows in the direction of increasing potentials.

There are two types of electric current:

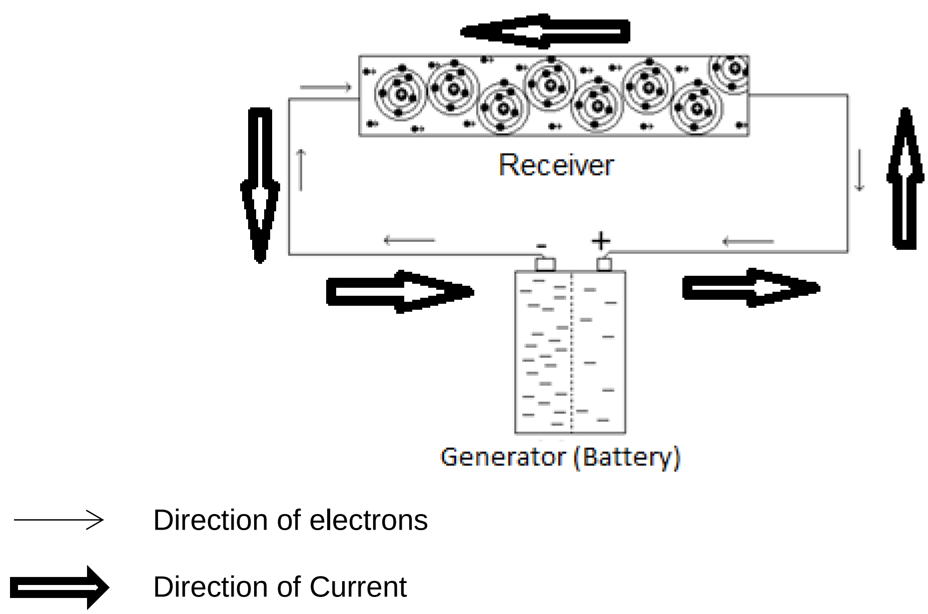
- **Direct current.** The electrons always move in the same alternately move direction from - to +.
- **Alternating current**. The electrons move alternately from - to + and from + to -.

4.4.4.1. Direction of movement of electrons in an electrical circuit

As in the positive generator's terminal, there is a lack of electrons; it therefore tries to capture electrons in order to restore its electrical balance.

Then, there is an orderly movement of free electrons in matter. They move from the positive terminal to the negative terminal.

Unlike the electric current the electrons move from the negative terminal to the positive terminal.



This movement of electrons will create reactions called: *effects of the electrical current.*

4.4.4.2. Effects of electric current

The movement of free electrons in the conductor will create reactions which themselves will generate effects which under certain conditions will give us either heat, light, magnetism, …

- **Calorific effect. (heat effect)**

When an electric current flows through a conductor, heat is released. This one varies depending on the amount of current flowing through the wire. The more current, the hotter the wire.

All electrical devices used to impart heat, protection of electrical installations by fusible wire.

Example Iron Sole

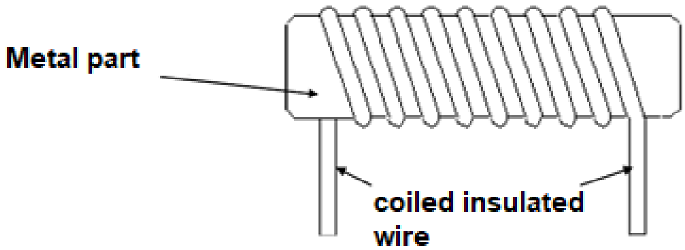
- **Light effect.**

When a lot of electric current is flowing through a conductor that is too small to flow so much current, There is a sharp rise in temperature causing reddening and even bleaching of the conductor. This varies depending on the amount of current flowing in the wire.

Example Incandescent Lamp**.**

- **Magnetic effect.**

When an electric current circulates in an insulated wire, wound around a metal part, this one becomes magnetized. Likewise, if the current is interrupted, there is no longer any magnetization.

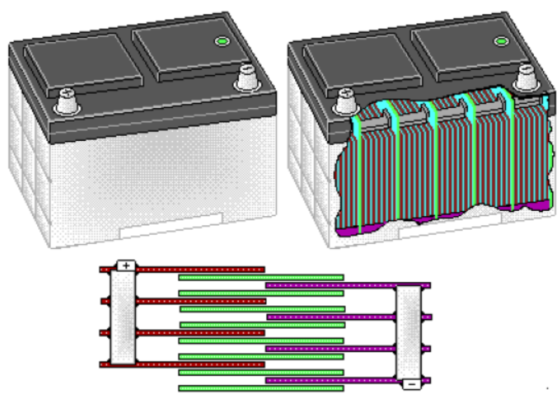


We call this: electromagnet: i.e. magnet controlled by electricity.

Example bells, relays, lifting cranes, circuit breakers, door opening, remote control switch...

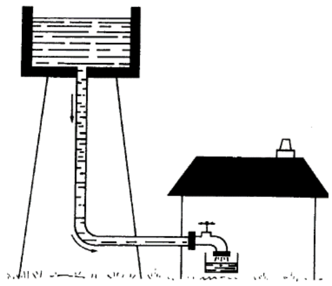
- **Chemical effect.**

Consider a zinc casing which is used as a negative plate, a carbon bar suspended in the middle of this casing serving as a positive plate and an ammonia chloride solution in a pasty form, which constitutes the electrolyte.



4.4.4.3. Electric current intensity

Take the example of a high water tank (See image)



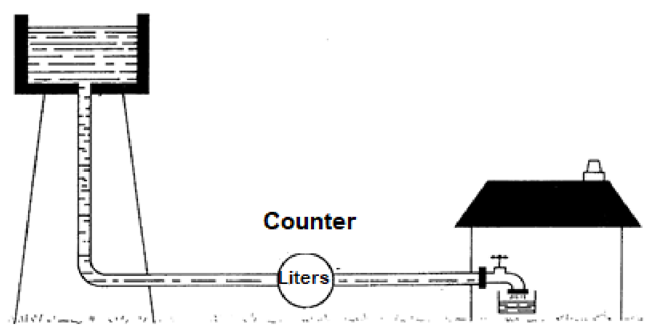
- The number of drops of water passing through a point in the pipe and called: **the flow.**

In an electrical circuit, the number of electrons that pass through a point in the circuit is called: **intensity of the electric current**.

The intensity of electric current is the number of free electrons which circulate in one second in a conductor.

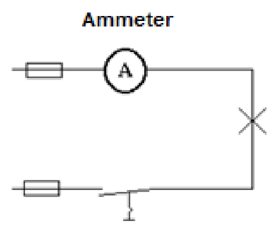
❖ Current intensity measurement

To measure the flow of water in a pipe, a meter is placed in the circuit.



Similarly in electricity, to measure the number of electrons at a point in the circuit, we use an **ammeter** that is placed in series in the circuit.

Representation of the ammeter:



The measure of electric current is Ampere, knowing that, **1 Ampere = 6,25 x 10^{18} Electrons.**

4.4.5 Resistance

All matter presents a certain opposition to electric current, which can be strong or low: this opposition is called resistance.

- Materials with low resistance easily give up free electrons.
- High resistance materials have difficulty giving up free electrons.

While moving, the electrons collide with the atoms of the conductor, this collision causes the conductor to heat up. The more current, the hotter the conductor.

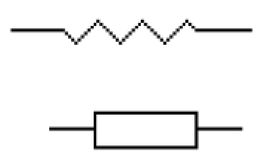
In a conductor subjected to Voltage, free-electrons range of atoms to atoms. They are constantly captured and then released by atoms.

When a voltage of 1 volt causes a current of 1 Ampere, the resistance is 1 ohm.

To measure the resistance of a conductor or an electrical component, we use an ohmmeter (off) that we connect to the terminals or ends of what we want to check. The measure of resistance is the ohm, denoted Ω, pronounced Omega.

Symbol: **R**.

Representation:



Multiple: KΩ (kilo-ohm) = 1000 x 1Ω = 1.000 Ohms.

MΩ (meg-ohm) = 1.000.000 x 1Ω = 1.000.000 Ohms.

4.4.5.1. Different Types of Resistances

Any conductor, whatever it is, offers a certain resistance to the passage of electric current: motor or transformer winding wire, wire carrying electrical energy, incandescence, etc...

There are two types of resistances:

- **Fixed resistances:** They keep the same value (Soldering iron, electric heaters, iron).
- **Variable resistance:** we can vary their value.

4.4.5.2. Reading a resistance

To know the value of an electrical resistance (in ohms Ω), there is an ohmmeter or ohm-meter, or the classic method is based on reading the color code drawn on the resistance. The international standard IEC 60757, titled Color Designation Code (1983), defines a color code to mark their value on resistances. The colors are associated with numbers or digits.

The following figure shows the fixed resistances found in electrical devices.

- **Color Code**

color	Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	white
Digit	0	1	2	3	4	5	6	7	8	9

Most often, a 4-ring resistance: - The first two rings each indicate a number (in the case of a precision resistance, these are the first three rings) - The penultimate (therefore the third) indicates a multiplication factor (more exactly with a power of 10) of the number formed by the first two. - The last (fourth, sometimes fifth) indicates the error tolerance or precision of the calculated value. This ring is sometimes further spaced from the previous ones. It is not always present, its absence signifying the greatest tolerance: 20%. - Sometimes an additional ring is coded for precision resistors, indicating a growth coefficient of electrical resistance as a function of temperature (in ppm / Kelvin or ppm / ° C).

Examples

- A Yellow, Orange, Red resistor, the corresponding numbers are: 4, 3, 2. The first 2 digits make up the number 43. The 3rd digit 2 is the power of 10 multiplier. The calculation to be carried out is therefore $43 \times 10^2 = 4300\Omega$

- A Blue, Yellow, Red, Brown, Brown resistor, which therefore corresponds to the numbers 6, 4, 2, 1, 1. The calculation to carry out is to know the value is $642 \times 10^1 \pm 1\% = 6420\Omega \pm 1\%$

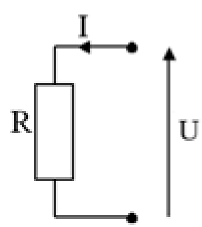
4.4.5.3. Ohm's law

This Law, discovered by George Ohm: German physicist (1789 - 1854), fixes the relationship between voltage, current and resistance.

The voltage (U) at the terminals of a circuit is equal to the product of the resistance (R) of the circuit times the intensity (I) of the current flowing in this circuit.

$$U = R \times I \Rightarrow R = \frac{U}{I} \qquad I = \frac{U}{R}$$

U: Volt (V), R: Ohm (Ω), I: Ampere (A)



Schematization of Ohm's Law

- **Definitions**

- The volt is the voltage or Potential Difference existing at the terminals of the generator which circulates a current of 1A in a resistance of 1Ω.
- The Ampere is the intensity of the current flowing in a 1Ω resistance circuit if the generator produces a Potential Difference of 1V.
- The Ohm is the resistance of the electrical circuit which allows a current of 1 A to flow at a potential difference of 1 V to the generator.

- **Voltage drop**

- When a resistance R is traversed by a current I, ohm's law tells us that we must find on both ends of the resistance a voltage. It is equal to the product R x I.

There is the potential difference between the input and the output of the resistance.

The flow of current, I, through this resistor R causes a loss of energy called voltage drop (u).

This loss of energy is manifested by heating of the resistance and the air in the vicinity of it. The voltage drop is therefore the result due to the passage of electrons in a resistance and it is defined by the relation:

$$\mathbf{u = R \times I}$$

Any circuit with resistance will be the site of a voltage drop.

4.4.6. Experiments

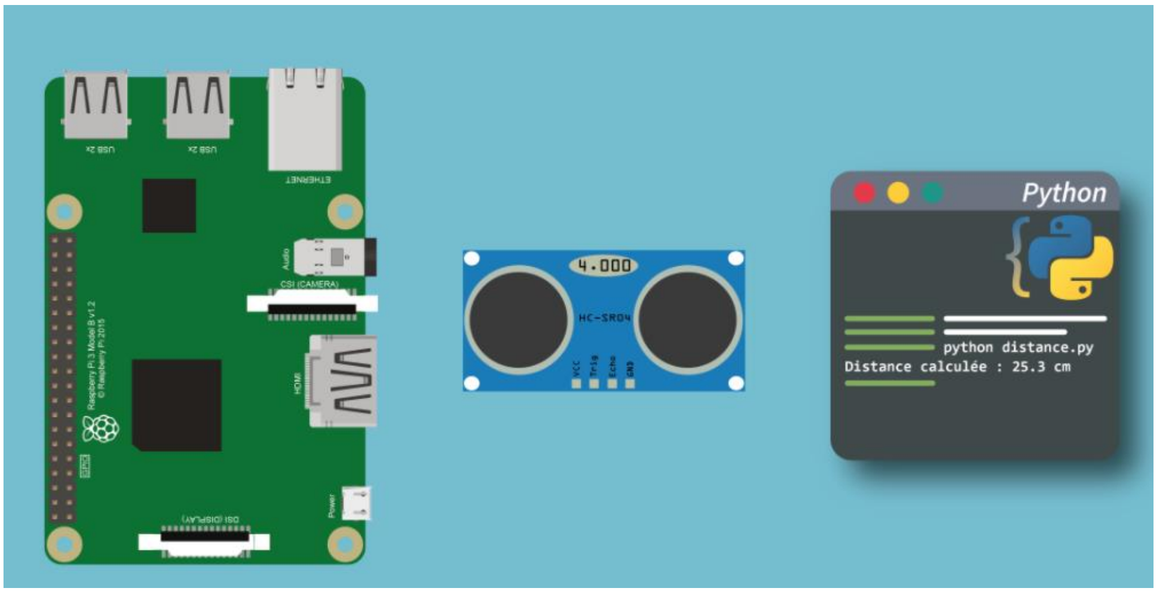
You're probably all familiar with the Raspberry Pi, this credit card-sized ARM microprocessor nanocomputer that can run different variants of a Linux system. Sold more than 10 Million copies at the end of 2016 this awesome little device is used in all sauces. Some make it a laptop, a weather station, a road traffic monitor, others a Plex or Kodi multimedia server, an audio network player, an Airplay/Bluetooth receiver, so on and the best, from the most wacky projects to the useful applications.

Raspberry Pi is a low-cost, basic computer that was originally intended to help spur interest in computing among school-aged children.

In this part, we present two examples of an electrical circuit based on Raspberry.

Example 1 Distance measurement with a HC-SR04 sensor and a Raspberry Pi

The HC-SR04 ultrasonic sensor can measure a distance of 2 to 400cm by sending sound signals at 40 kHz. Depending on the time between the emission and reception, the distance is calculated. The sensor is powered by 5V.



▪ Prerequisite

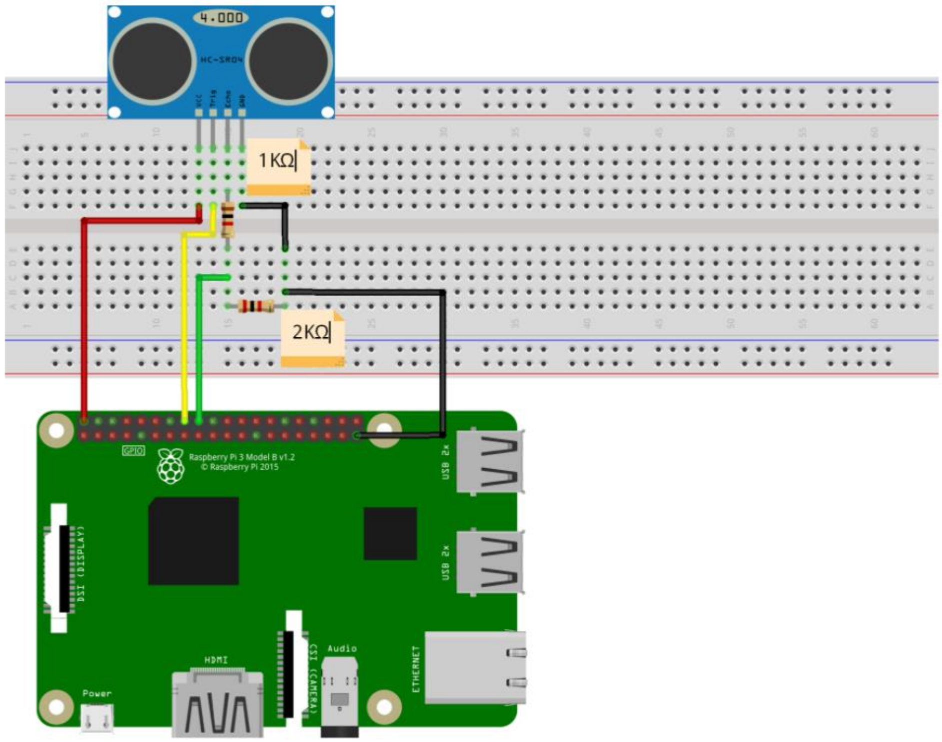
To use a HC-SR04 probe with a Raspberry, you need:

- A Raspberry Pi
- A HC-SR04 sensor
- Resistances 1K and 2K
- Cables

Once all the elements are together, you can switch to the connection.

▪ Sensor connection to Raspberry

The HC-SR04 sensor connects to the Raspberry with 4 PINs: VCC, Trig, Echo and GND. To connect it, we'll need two resistances: 1K and 2K. You can Connect the HC-SR04 as follows:



Once plugged in, just run a Python script to get the calculated distance between the sensor and the obstacle.

- ## Python Sensor Programming

```
import
RPi.GPIO
as GPIO

        import time

        GPIO.setmode(GPIO.BCM)

        print "+------------------------------------+"

        print "|Distance measurement by HC-SR04
        ultrasonic sensor |"

        print "+------------------------------------+"

        Trig = 23  #Trig input from HC-SR04 branch to
        GPIO 23#

        Echo = 24  #Echo Output of the HC-SR04 branch
        to GPIO 24#

        GPIO.setup(Trig,GPIO.OUT)

        GPIO.setup(Echo,GPIO.IN)

        GPIO.output(Trig, False)

        repet = input("Enter a number of measurement
        repetitions : ")

        for x in range(repet):    # We take the
        measure “repeat” times#

        time.sleep(1)  #We take the measure "repeat"
        time#

           GPIO.output(Trig, True)

           time.sleep(0.00001)

           GPIO.output(Trig, False)
```

```
while GPIO.input(Echo)==0:  ## Ultrasound
emission

      debutImpulsion = time.time()

 while GPIO.input(Echo)==1:   ## Return of the
 Echo

     finImpulsion = time.time()

 distance = round((finImpulsion -
 debutImpulsion) * 340 * 100 / 2, 1)  ## Speed
 of sound  = 340 m/s

 print "The distance is: ",distance," cm"

 GPIO.cleanup()
```

Example 2

- **Interface PIR Motion Sensor with Raspberry Pi**

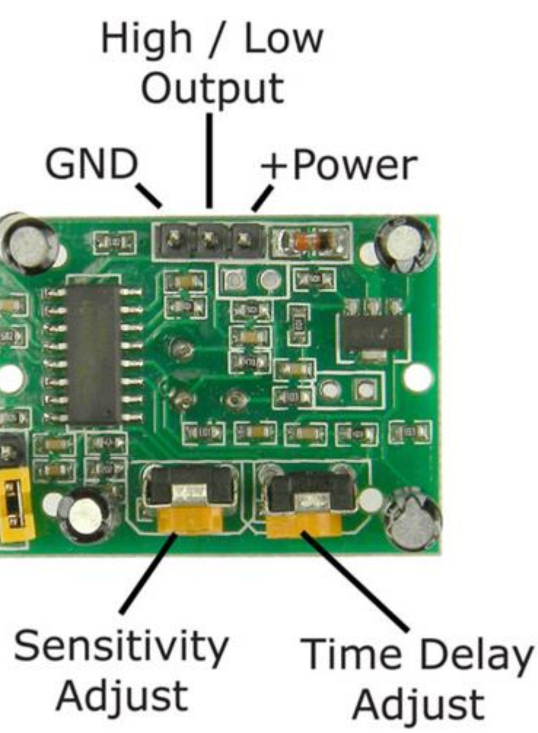
Demonstrate the use a PIR (Passive Infrared) sensor with the Raspberry Pi to turn on an LED when a person (or warm-blooded animal) comes within range.

Accessories

As the sensors already carry (almost) everything, apart from a resistor, not many additional accessories are required.

- HC-SR501 PIR
- 220Ω resistor
- Breadboard and jumper wires

HC-SR501 PIR

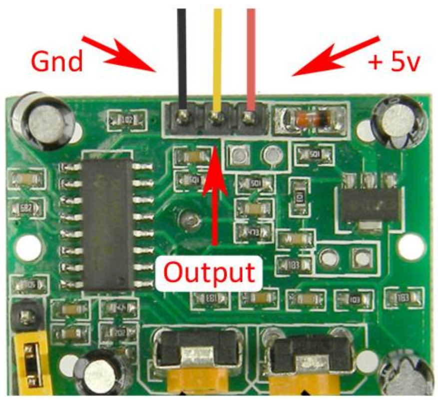


HC-SR501 PIR bottom view

We will use the HC-SR501 PIR motion sensor as it is inexpensive and easy to use. The sensor works by detecting movement of infrared radiation emitted from warm objects (people). In this project, we will turn on an LED when movement is detected.

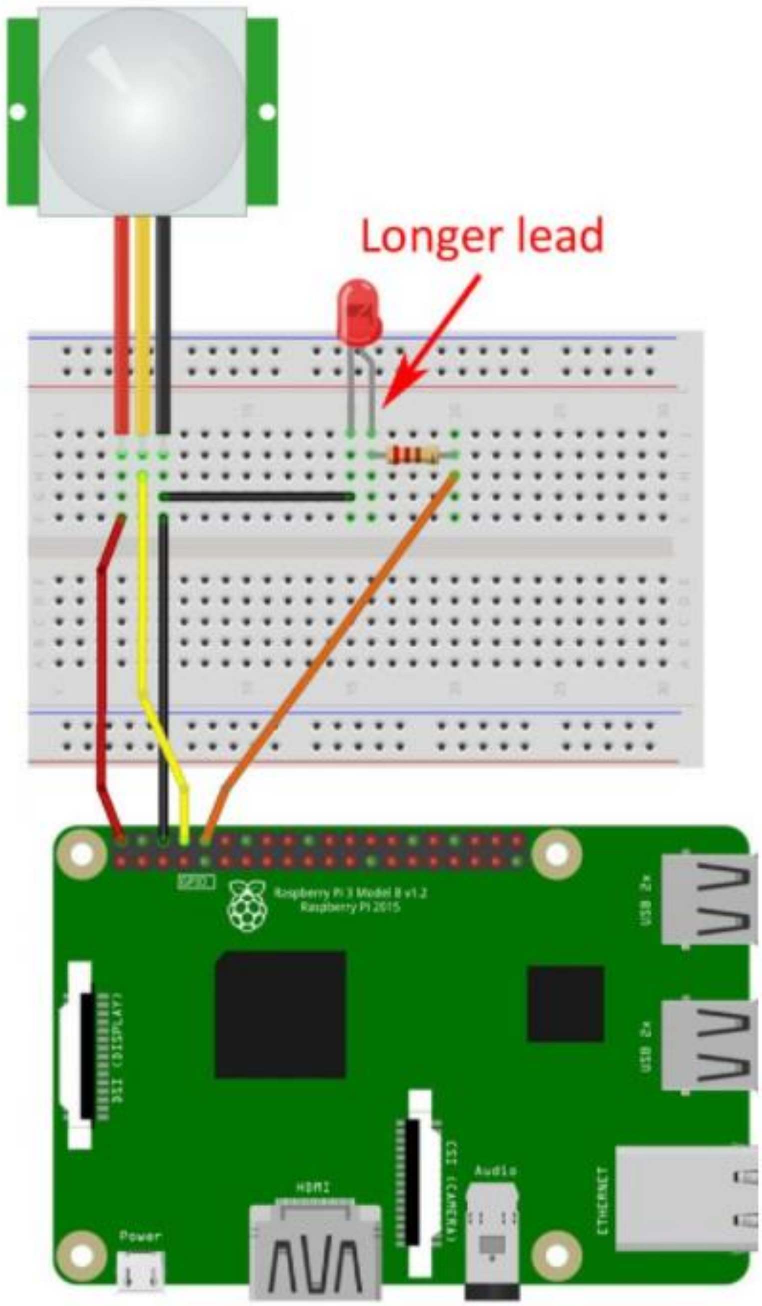
• Connecting the PIR to a Raspberry Pi

Interfacing to the Raspberry Pi requires only a few connections. Programming is done using Python language. Connect the Raspberry Pi as shown below.



HC-SR501 PIR bottom view

Connect the wires as shown above to the bottom side of the PIR. Turn the PIR over and then connect the PIR wires to the breadboard.



HC-SR501 PIR connections to Raspberry Pi

As always, double check your connections!! You do not wish to “fry” your Pi due to incorrect wiring.

- ## The Python Program

Following is the Python source code used for this project. Key the source code below into Raspberry Pi's Text Editor. Save it into the Pi folder as pir.py

```
# MBTechWorks.com 2017

# Use an HC-SR501 PIR to detect motion (infrared)

#!/usr/bin/python

import RPi.GPIO as GPIO

import time

GPIO.setmode(GPIO.BOARD) #Set GPIO to pin numbering

pir = 8 #Assign pin 8 to PIR

led = 10 #Assign pin 10 to LED

GPIO.setup(pir, GPIO.IN) #Setup GPIO pin PIR as input

GPIO.setup(led, GPIO.OUT) #Setup GPIO pin for LED as
output

print ("Sensor initializing . . .")

time.sleep(2) #Give sensor time to startup

print ("Active")

print ("Press Ctrl+c to end program")

try:

while True:

if GPIO.input(pir) == True: #If PIR pin goes high,
motion is detected

print ("Motion Detected!")
```

```
GPIO.output(led, True) #Turn on LED
time.sleep(4) #Keep LED on for 4 seconds
GPIO.output(led, False) #Turn off LED
time.sleep(0.1)
except KeyboardInterrupt: #Ctrl+c
pass #Do nothing, continue to finally
finally:
GPIO.output(led, False) #Turn off LED in case left on
GPIO.cleanup() #reset all GPIO
print ("Program ended")
```

- **Time to detect**

Once you have the Python program on the Raspberry Pi, launch the command Terminal and type the following command in the Terminal (in the same directory where you put the python program, which should be /home/pi).

sudo python pir.py

Step away from the sensor and let it timeout to turn LED off. Approach the sensor and it should turn LED on. Try changing the Sensitivity Adjust and Time Out Adjust as desired for sensor range and LED time on.

Press Ctl c to end the python program.

There you go. You have a Raspberry Pi that can sense an approaching person. Further programming and Pi configuration can be done to do other things in response, such as activating an alarm or annunciator, turn lights on / off, trigger a camera, . . .

4.5 Assessment

1- Electricity can be generated from:

a- Sun
b- Wind
c- Stones

2- The Resistance of a device that absorbs 5 A under a voltage of 220 V is:

a- 44 A
b- 88 A
c- 22 A

3- The Voltage to be applied to the terminals of a resistance of 100 Ω for which is travelled by a current of 0.05 A is:

a- 5V
b- 10V
c- 15V

4- The value of this resistance is:
a- 740 ohms +/- 1%
b- 470 ohms +/-10%
c- 074 ohms +/- 10%

5- Electricity and magnetism are two related phenomena produced by electromagnetic force. Together, they form electromagnetism (**True**/false)

6- A moving electric charge generates a magnetic field (**True**/false)

7- A magnetic field induces an electrical charge movement, producing voltage (True/**false**).

Answer: A magnetic field induces an electrical charge movement, producing current.

8- In a conductor whose terminals are connected to the terminals of a battery, the electrons move in the same direction from the positive terminal to the negative terminal (True/**false**).

Answer: In a conductor whose terminals are connected to the terminals of a battery, the electrons move in the same direction from the negative terminal to the positive terminal.

9- The electric current flows from a generator's positive terminal to its negative terminal (**True**/false)

10- The unit of Current is Volt (True/**false**)
Answer: The unit of Current is Ampere

11- The unit of Voltage is Ampere (True/**false**)
Answer: The unit of Voltage is Volt

4.6 Conclusion

This Module 3 is devoted to the fundamental concepts of Electricity and Magnetism. After a general introduction on this theme, where certain methods of electricity production have been introduced, the concepts on the constituents of matter are discussed. In this part, we have shown that Electricity is a displacement of free electrons from a negatively charged area (-) to a positively charged area. Then the link between electricity and magnetism was highlighted where the emphasis was placed on the fact that a moving electrical charge generates a magnetic field, and a magnetic field induces an electrical charge movement, producing an electric current. The rest of this module was devoted to the presentation of voltage, current and resistance in an electrical circuit. Before concluding, two examples to discover how to use PhysicsKIT and Raspberry Pi to carry out experiments and understand all the concepts discussed in this module through simple electronic montages.

4.7 Additional Resources

1- Raspberry Pi - How to Begin Coding Python on Raspberry Pi - YouTube
“ https://www.youtube.com/watch?v=xTIBG_KD88k”

2- Raspberry Pi 4 Getting Started - YouTube
“https://www.youtube.com/watch?v=BpJCAafw2qE”

3- Camera Module with Raspberry Pi4 - YouTube
https://www.youtube.com/watch?v=0hrF8Wq8SSQ

4- Raspberry Pi Tutorial 11 - Camera Setup - YouTube
“ https://www.youtube.com/watch?v=xA9rzq5_GFM3”

5- “Take your first steps into the world of digital electronics” Faites vos premiers pas dans le monde de l’électronique numérique - OpenClassrooms

6- “Introduce yourself to on-board electronics, sensors and actuators“ Initiez-vous à l'électronique embarquée, capteurs et actionneurs - OpenClassrooms

4.8 References

1- Basic Electricity (2011) “Electrical And Electronics Engineering Books, Education Books” pages 297, Technical Learning College.

2- Fundamentals of electricity (2015) “Cutler-Hammer”, pages 40

3- Basic Electrical & DC Theory (1992) ” DOE FUNDAMENTALS HANDBOOK” Electrical Science, Volume 1 of 4.

4- Introduction to Electricity “Microsoft PowerPoint - Intro to Electricity (nyu.edu)”

5- Introduction to Electronic Engineering, by Valery Vodovozov, pages 159.

6- Concept in electric Circuits, by Wasif Naeem, pages 87.

7- Electronic Measurements " Measurement Theory, Circuits and Sensors", by Geert Langerels.

8- Electricity and magnetism, by Purcell Edward, Berkeley Physics course-Volume 2.

9- Book Electricity and Magnetism, by Benjamin Crowell, Pages 218, Web Education. Book Electricity and Magnetism pdf - Web Education (xn--webducation-dbb.com).

10- Electricity and Magnetisme, by Sam Kinyera Obwoya Collection "AVU Resources En - Physics" https://oer.avu.org/handle/123456789/498

5. Waves

5.1 Glossary

Term	Definition
Amplitude	The maximum amount of displacement is known as amplitude. It is usually symbolized using the capital letter A. It can be measured by calculating the change in value from the point of equilibrium and the peak of the wave. In sound waves, the higher the amplitude, the higher the loudness and therefore the louder the music.
Frequency	The amount of time it takes for one oscillation to occur is known as the frequency of the wave. Frequency (f) is measured using hertz (Hz), which translates to the wave's rate (how many waves per unit time). Frequency is also known as the number of oscillations per unit time (waves per second).
Oscillation	A complete oscillation occurs when a wave begins from its rest position and then returns to it. The time for one oscillation is referred to as the Period (T). The period and frequency are reciprocal of each other.
Python	Python is an interpreted, object-oriented, high-level programming language. Python has simple, easy to learn syntax that emphasizes readability and therefore reduces the overall time needed to learn it and to develop and maintain a program. Python supports modules and packages, which encourages program modularity and code reuse. The Python interpreter

	and the extensive standard library are available in source or binary form without charge for all major platforms and can be freely distributed.
Raspberry Pi	Raspberry Pi is a credit card sized, fully functional computer which operates on Raspberry Pi OS.
Raspberry Pi OS	The operating system for Raspberry Pi.
Reflection	When a wave hits an object it cannot pass through, it is reflected on the object's surface. The angle at which the wave hits the barrier is calculated at 90^{o} from the objects surface from the direction the wave came from and it is called the angle of incidence (i). When the wave is reflected, it is reflected at an angle exactly the same at the angle of incidence and it is known as the angle of reflection (r).
Refraction	Waves that enter an object undergo what is called refraction. Refraction is simply the change of direction at which the wave is travelling when it enters a medium. However, the speed of the wave might also be affected as the wavelength of the wave might increase or decrease depending on the medium at which is travelling. The faster the wave is travelling, the bigger the wavelength, but if the wave is slowed down, its wavelength will decrease.
Sensor	A sensor is a device that measures physical input from its environment and converts it into data that can be interpreted by either a human or a machine. Most sensors are electronic (the data is converted into electronic data), but some are simpler, such as a glass thermometer, which presents visual data.

Waves	Waves are a form of disturbance that travels from one location to another. They transfer energy and information, but without transferring matter.
Wavelength	The wavelength as the name suggests is the length of one full wave. It is the distance between two consecutive crests or trough. In order to calculate the value of half a wavelength it would be the distance between a crest and the next available through or vice versa. It is symbolized using the Greek letter lambda (λ).

5.2 Introduction to Waves

5.2.1 Abstract

In this module, your will learn about waves and the differences between its types. Also, the theory of how waves travel and behave when traveling through different mediums will be explored. The learning material will cover wave equations, longitudinal waves, transverse waves, as well as their properties, similarities and differences. Along with the teaching material, you will find some experiments that you can perform using the Raspberry Pi and various other sensors. In addition, resources, references and other useful material have been included at the end of the chapter to improve your learning and understanding of the topic. By the end of this module, you should have a basic understanding of field of waves and the theory around it.

5.2.2 Introduction

Waves exist all around us, yet when people are asked to name a few examples of waves most of them can only name sound waves and micro waves. But what exactly is a wave to begin with?

Waves are a form of disturbance that travels from one location to another. They transfer energy and information, but without transferring matter.

Did you know that Wi-Fi uses radio waves to transmit information between the router and your phone?

However, not all waves work in the same way. Some waves can travel long distances, some waves can travel short distances and some can only be detected or produced by using special scientific equipment.

5.3 Learning Outcomes

- What is a wave
- Types of waves
- Anatomy of waves
- Properties of waves
- Wave equations
- Reflection, Refraction and Diffraction

5.3.1 Types of Waves

Transverse Waves

Transverse waves can be best described as waves that vibrate or oscillate at right angles of the direction of which the wave or energy is moving.

Examples: Light waves, water waves (ripples), S-waves from earthquakes.

Longitudinal Waves

Longitudinal waves are the opposite of Transverse, as their vibration and oscillations are along the direction of which the wave or energy is moving.

Examples: Sound waves, Compression waves.

The following diagram (Figure 1) visually demonstrates the differences between the two waves by using a slinky coil.

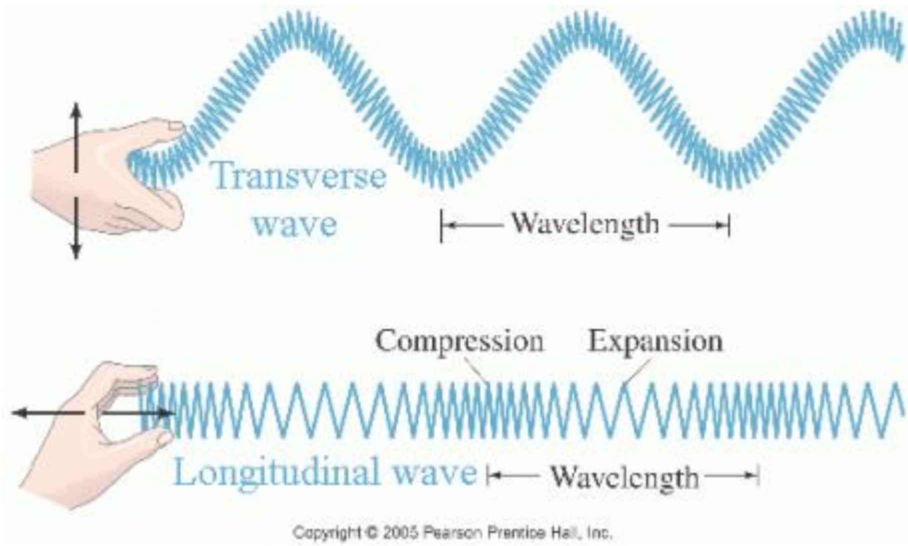


FIGURE 10 ADAPTED FROM PEARSON PRENTICE HALL

5.3.2 The anatomy of Waves

The three main properties of waves are amplitude, wavelength, and frequency. To be able to further explain these terms, it's important to first identify some waves elements that appear on graphs.

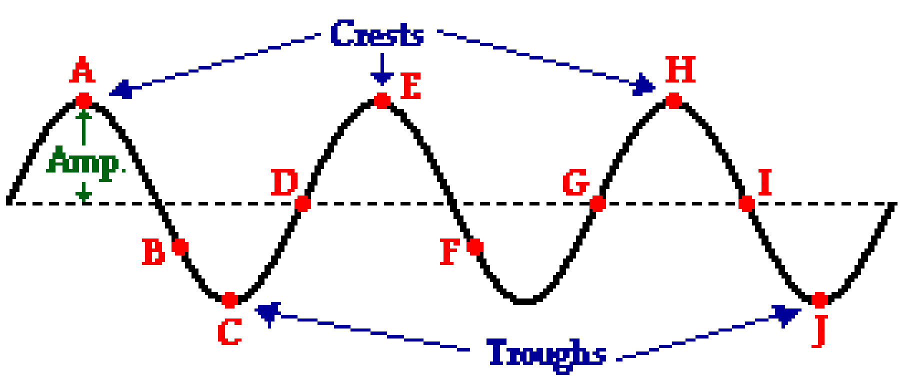


FIGURE 11 ADAPTED FROM PHYSICSCLASSROOM.COM

The example above (figure 2), is an example of a transverse wave. The horizontal dotted line at the centre of the diagram represents point zero and at that point the wave reaches equilibrium (also known as rest position). The points A, E and H are what is knowns as crests, which translates to the maximum positive point on the graph, whereas points C and J which show the maximum negative point on the graph are known as Troughs. Alternatively, they are sometimes referred to as maxima (crest) and minima (trough) and the point where the gradient on the graph changes is known as the turning point (in figure 2 that would be points A, C, E, H, J).

5.3.3 Properties of Waves

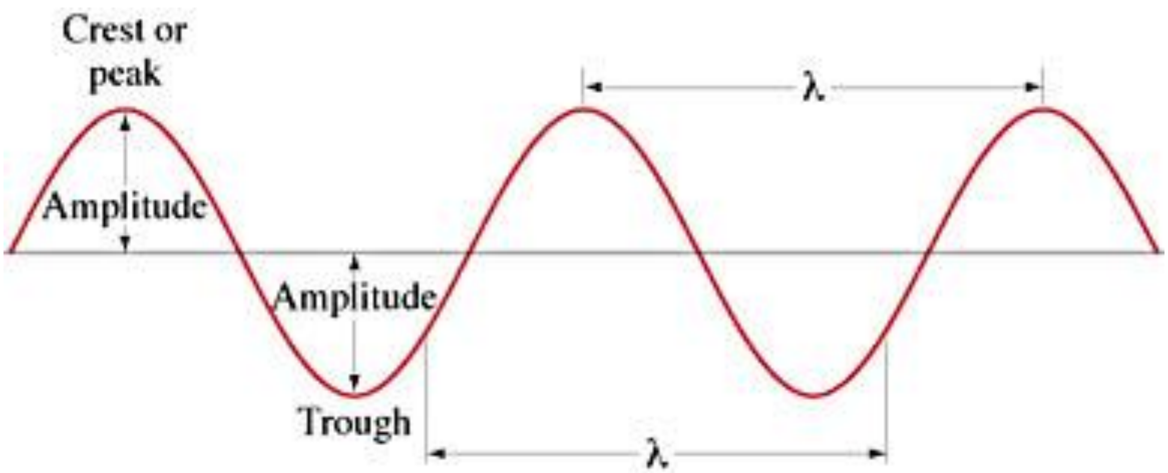


FIGURE 12 ADAPTED FROM NORTH WESTERN UNIVERSITY

Amplitude

The maximum amount of displacement is known as amplitude. It is usually symbolized using the capital letter A. It can be measured by calculating the change in value from the point of equilibrium and the peak of the wave. To better understand this, you can think of it by using music as an example. In sound waves, the higher the amplitude, the higher the loudness and therefore the louder the music.

Wavelength

The wavelength as the name suggests is the length of one full wave. It is the distance between two consecutive crests or trough. In order to calculate the value of half a wavelength it would be the distance between a crest and the next available trough or vice versa. It is symbolized using the Greek letter lambda (λ). Two examples of wavelengths can be found in figures 3 and 4.

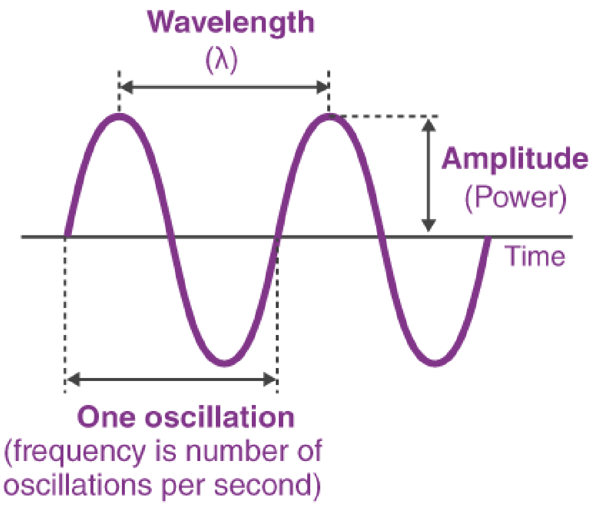


FIGURE 13 ADAPTED FROM BYJUS.COM

Frequency

The amount of time it takes for one oscillation to occur is known as the frequency of the wave. Frequency (f) is measured using hertz (Hz), which translates to the wave's rate (how many waves per unit time). Frequency is also known as the number of oscillations per unit time (waves per second). For example, a wave source that can create 10 complete waves each second has a frequency of 10 Hz.

Did you know? The audible human spectrum is between 20 Hz – 20 kHz (value may slightly vary per person).

Tip: 1 kHz = 1000 Hz

Oscillation

A complete oscillation occurs when a wave begins from its rest position and then returns to it (Figure 4). The time for one oscillation is referred to as the Period (T). The period and frequency are reciprocal of each other.

$$Period = \frac{1}{Frequency}$$

OR

$$Frequency = \frac{1}{Period}$$

FIGURE 14 ADAPTED FROM BUJYS.COM

5.3.4 Wave Equations

Speed

Now that we have looked at different elements associated with waves, let's take a look at how these elements relate to each other. As you may know from other modules, Speed = distance / time. This equation is applicable to waves as well but you might be thinking "how can I find the speed if I don't know the distance? Is distance related to waves? We didn't learn anything about distance". That is true, but also wrong at the same time. We did not mention distance, but we did talk about wavelength and frequency which can help us derive it.

Remember? Frequency is the number of oscillations per unit time and wavelength is the length of one full wave.

Therefore, if we know how many waves there are in a second, and the length of each wave, then we can calculate the distance by multiplying the two. Since frequency is calculated per second, X divided by 1 is still X. This means that by simply multiplying the frequency and the wavelength we can get the speed of a wave (Figure 6).

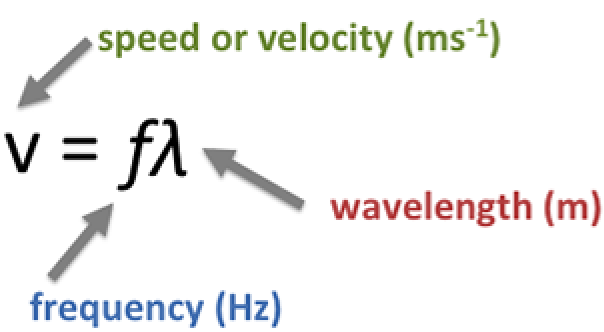


FIGURE 15 ADAPTED FROM THEPROPERTIESOFWAVES.WEEBLY.COM

Tip: Wavelength is measured in metres and speed in m/s. However, if the value of the wavelength is in cm, you might have to give the speed in cm/s or make adjustments to your calculations.

Distance

One of the first things we learn in physics is that we can calculate the distance between two objects by multiplying speed and time.

Distance = speed * time

Waves can be used to calculate the distance between two objects. Since we already know how to calculate the speed of a wave, all we need to do is multiply it by the time it takes for it to reach an object.

5.3.5 Reflection, Refraction and Diffraction

Reflection

When a wave hits an object it cannot pass through, it is reflected on the object's surface. The angle at which the wave hits the barrier is calculated at 90º from the objects surface from the direction the wave came from and it is called the angle of incidence (i). When the wave is reflected, it is reflected at an angle exactly the same at the angle of incidence and it is known as the angle of reflection (r). Figure 7 demonstrates an example of how a wave gets reflected on a flat surface. The arrows on the diagram show the traveling direction of the wave. As you can see the angle of incidence and the angle of reflection are exactly the same.

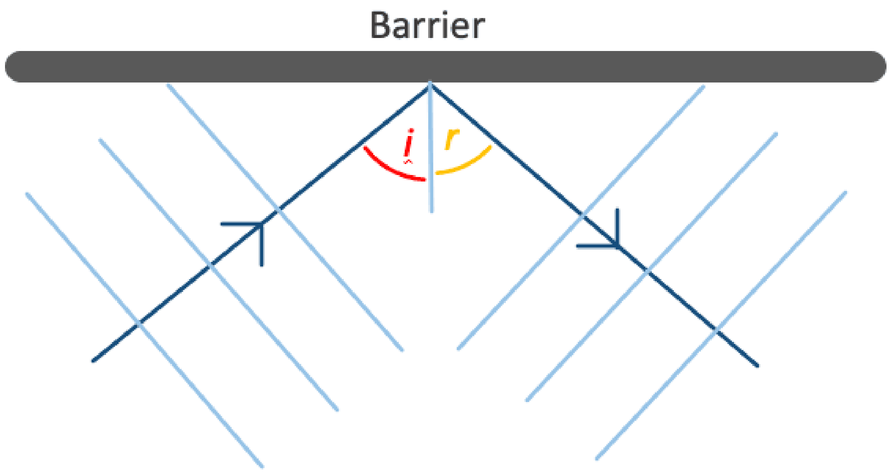


FIGURE 16 ADAPTED FROM SAVEMYEXAMS

Did you know? In the case of a perfect mirror, light will be reflected perfectly. Shiny objects shine because they have smooth surfaces and can reflect light waves in the same directions. Whereas uneven/rough objects disperse the waves in different directions which can make objects appear dull. This process is also known as diffuse reflection (Figure 8). When you wax a car, it appears shinier because the wax fills in the small holes on its surface and makes it smoother, causing less light diffusion.

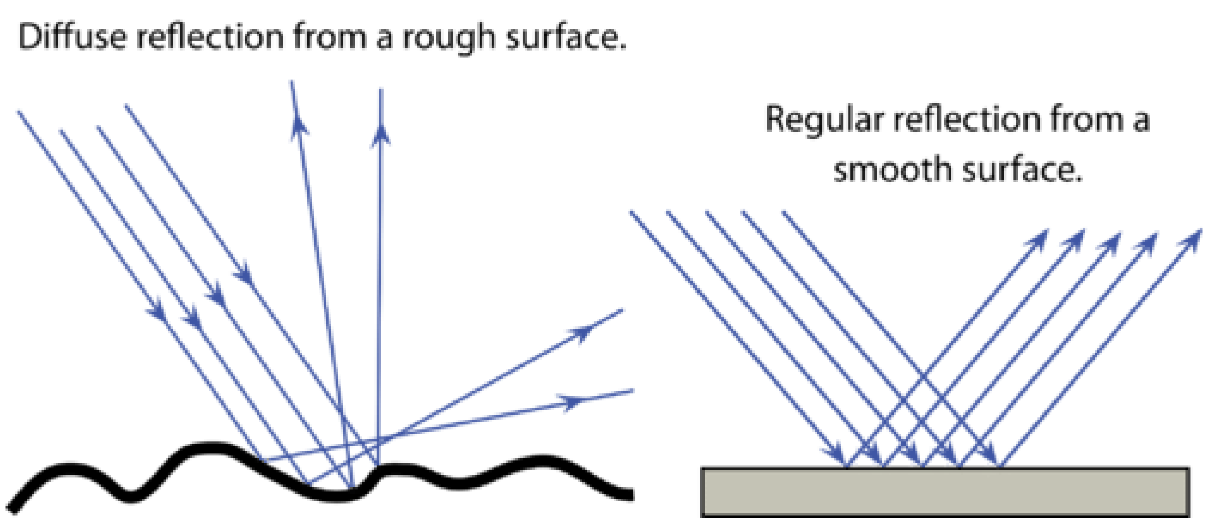


FIGURE 17 ADAPTED FROM CK-12

Refraction

Waves that enter an object undergo what is called refraction. Refraction is simply the change of direction at which the wave is travelling when it enters a medium. However, the speed of the wave might also be affected as the wavelength of the wave might increase or decrease depending on the medium at which is travelling. The faster the wave is travelling, the bigger the wavelength, but if the wave is slowed down, its wavelength will decrease. Keep in mind that depending on the barrier or medium the wave comes in conduct with, it is possible for partial reflection to occur during refraction and vice versa. Figure 9 illustrates this case and it also shows how a ray of light changes direction as it enters and exits a medium.

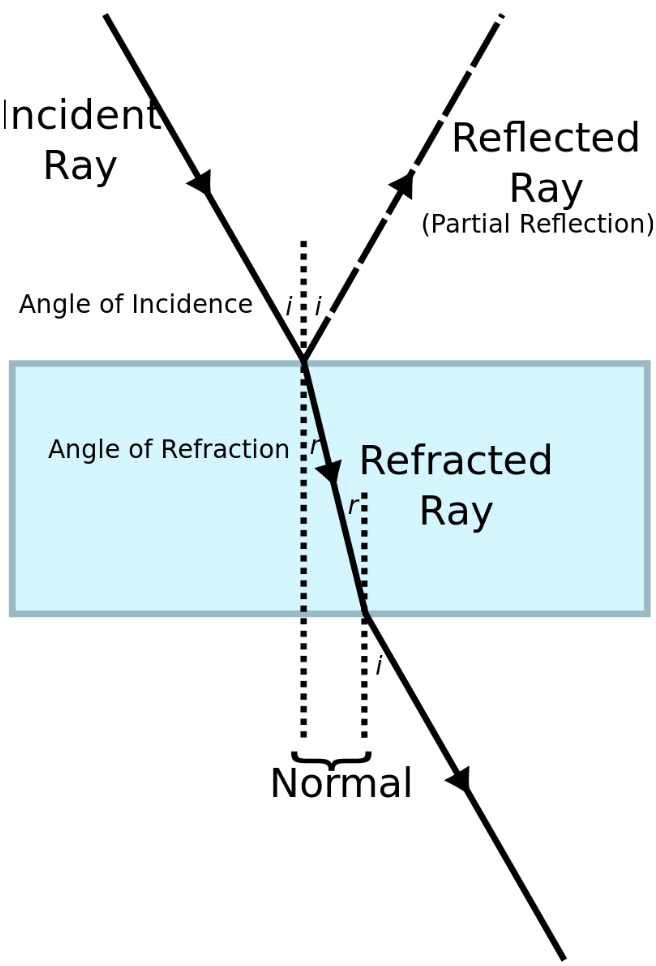


FIGURE 18 BY BOWERUK - OWN WORK, CC BY 3.0, HTTPS://COMMONS.WIKIMEDIA.ORG/W/INDEX.PHP?CURID=26331438

Did you know? The reason you cannot hear people clearly when you are underwater in a swimming pool is because the sound waves are affected by refraction.

5.3.7 Experiments

This section, will provide the hardware setup as well as the coding in order to connect and program using Python an ultrasonic sensor for measuring the distance from an object. We will learn how to connect the HC-SR04 ultrasonic sensor to the GPIO pins and measure the distance by using the speed which sound waves travel. Apart from the sensor, a few jumper wires, a GPIO Extension board and a breadboard, no other tools are needed.

Before we begin the experiments, some background knowledge of the electronics we'll be using is required. First of all, a Raspberry Pi is an open-source, fully functional, credit card sized computer made by the Raspberry Pi Foundation.

The Raspberry Pi has 40 open GPIO pins which will be used for connecting and controlling electronics and sensors. GPIO stands for “General Purpose Input/Output” which means that these pins send and receive electrical signals to control hardware or read sensor data.

Secondly, we use Python to program these sensors. Python is an object-oriented programming language. No prior knowledge in programming is required as the programs we will create are very simple and use the simplest of Python commands.

Now let us dive into the experiments.

Experiments – Measuring Distance with an ultrasonic sensor

For this experiment we will need:

- Raspberry Pi 3 (RPi)
- 1 GPIO Extension Board
- 1 Full+ Breadboard
- 1 Ultrasonic Sensor – HC SR04
- 4 Jumper Wires (Male to Female)

The HC-SR04 Ultrasonic Sensor uses SONAR (Sound Navigation and Ranging) to determine the distance of an object. This technique is also what bats uses and enables them to 'see'. The particular sensor offers excellent contactless distance detection with high accuracy (an accuracy of 3mm) from 2cm to 400cm. This sensor is widely used in a variety of applications that require distance measurement or object detection.

The HC-SR04 Ultrasonic sensor is a four-pin module with the pin names Vcc, Trigger, Echo, and Ground, as shown below:

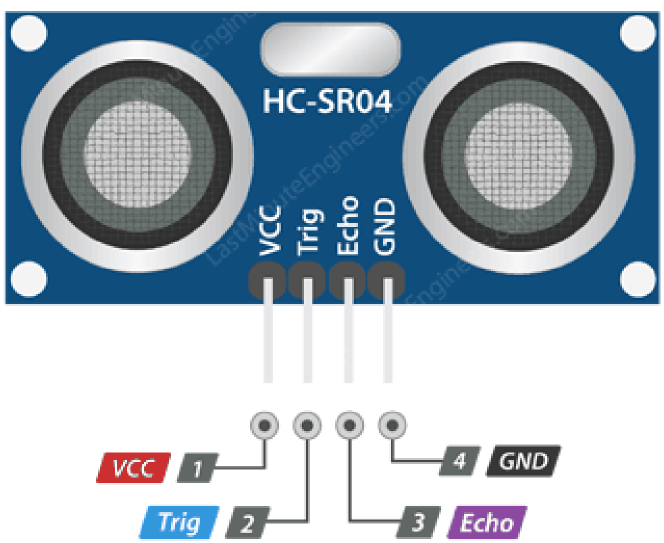


FIGURE 19: ULTRASONIC SENSOR

https://lastminuteengineers.com/arduino-sr04-ultrasonic-sensor-tutorial/

- VCC is the power supply for HC-SR04 Ultrasonic distance sensor which we connect the 5V pin on the Raspberry Pi.
- Trig (Trigger) pin is used to trigger the ultrasonic sound pulses.

- Echo pin produces a pulse when the reflected signal is received. The length of the pulse is proportional to the time it took for the transmitted signal to be detected.
- GND should be connected to the ground of Raspberry Pi.

How it will work in theory:

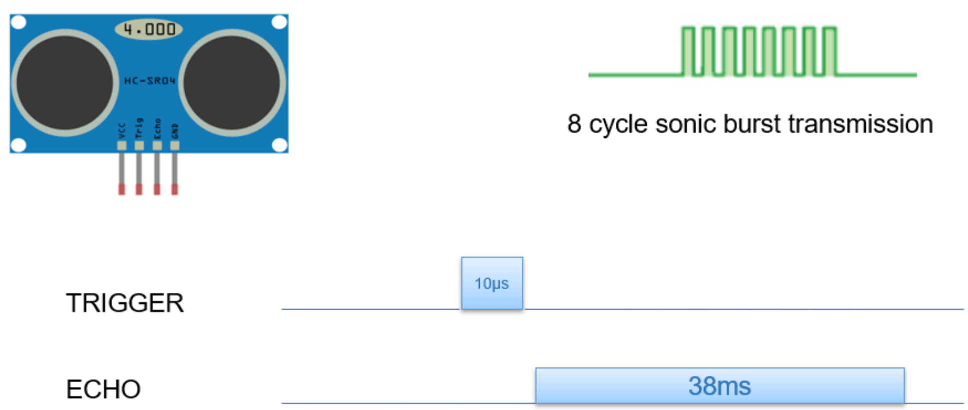


FIGURE 20: HOW THE ULTRASONIC SENSOR WORKS

When a pulse of at least 10 µS (10 microseconds) in duration is applied to the Trigger pin, the sensor responds by emitting an eight-pulse sonic burst at 40 KHz. This 8-pulse pattern distinguishes the device's "ultrasonic signature," allowing the receiver to distinguish the transmitted pattern from ambient ultrasonic noise. The eight ultrasonic pulses travel away from the transmitter through the air. Meanwhile, the Echo pin is set to HIGH to begin forming the echo-back signal.

If those pulses are not reflected back, the Echo signal will timeout and return LOW after 38 mS (38 milliseconds). As a result, a 38 mS pulse ensures that there is no obstruction within the sensor's range. On the other case where those pulses are reflected back, the Echo pin goes LOW as soon as the signal is received and results in a pulse with a width ranging from 150 mS to 25 mS, depending on the time it took to transmit the signal. We then can use this pulse to calculate the distance since we know the speed of sound.

The Ultrasonic transmitter and receiver are formed by two eye-like projects on the front of the module. The one acts as a transmitter and sends out 40 KHz ultrasonic sound pulses, which travels through the air and is reflected back toward the sensor when it encounters any material. The other acts as a receiver and detects this reflected wave. After receiving the reflected wave, it produces an output pulse whose width can be used to determine the distance the pulse travelled.

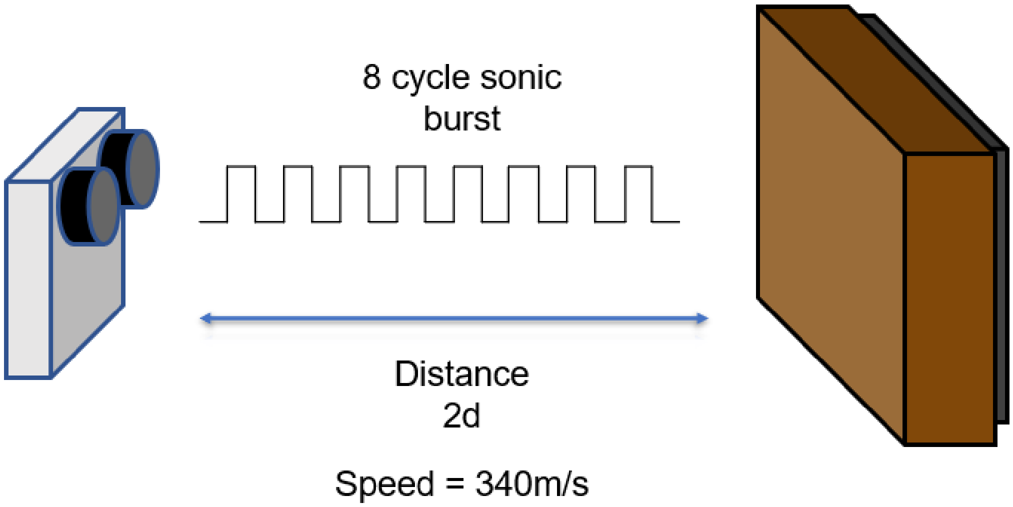


FIGURE 12: HOW IT MEASURES THE DISTANCE

The sensor is based on a simple well-known formula:

Distance = Speed x Time

Since we know that our wave is moving with the speed of sound which is 340m/s and since we have the value of time, we can easily calculate the distance.

*We have to convert the speed of sound into cm/μs in order to calculate the distance (0.034 cm/μs)

*Our Distance parameter is twice as the size we want calculate (2d), because the single come and goes twice.

2d = 0.034 x Time

d = 0.017 x Time

How it will be connected:

Back to our experiment, we need to connect the sensor with the GPIO pins of our Raspberry Pi. To do that, we need to plug four wires from the ultrasound sensor pins into the GPIO board as shown below:

- The VCC will be connected to the 5V pin (# 2 or # 4)
- Trig will be connected to GPIO 23 (#16)
- Echo will be connected to GPIO 24 (#18)
- GND will be connected to the GROUND pin (#6,9,14,20,25,34,39)

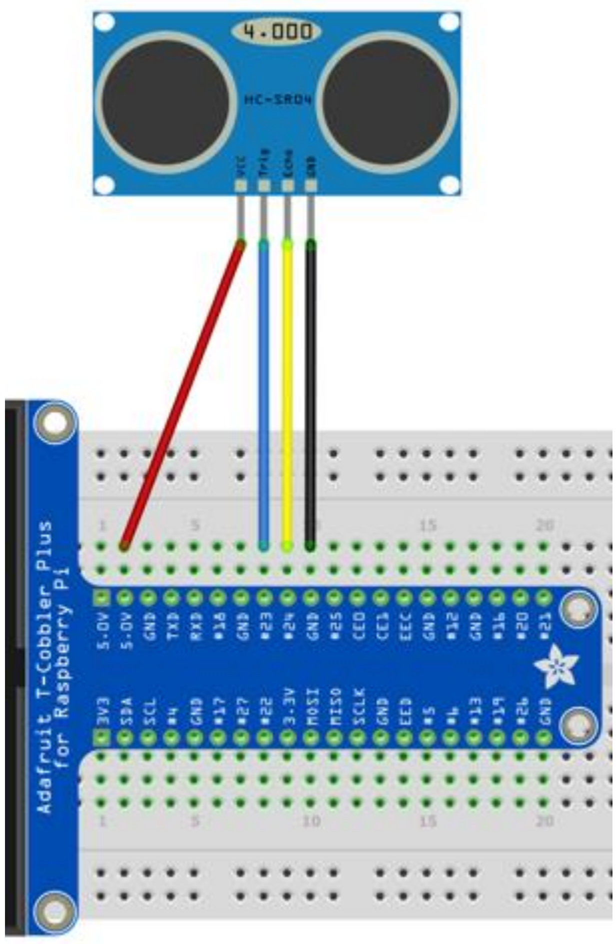


FIGURE 22: HOW IT WILL BE CONNECTED

	Pin No.		
3.3V	1	2	5V
GPIO2	3	4	5V
GPIO3	5	6	GND
GPIO4	7	8	GPIO14
GND	9	10	GPIO15
GPIO17	11	12	GPIO18
GPIO27	13	14	GND
GPIO22	15	16	GPIO23
3.3V	17	18	GPIO24
GPIO10	19	20	GND
GPIO9	21	22	GPIO25
GPIO11	23	24	GPIO8
GND	25	26	GPIO7
DNC	27	28	DNC
GPIO5	29	30	GND
GPIO6	31	32	GPIO12
GPIO13	33	34	GND
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
GND	39	40	GPIO21

FIGURE 21B: GPIO PIN NUMBER

When our circuit is ready, we can start writing our program in Thonny Python (IDLE) which will control the Ultrasonic Sensors. We open Thonny Python, and we save our file as *ultra.py. Then* we will need to write the following program:

```
#################################################################
#Give access to the GPIO pins
import RPi.GPIO as GPIO
#Give access to the time module
import time

#Set the board numbering scheme starting from 1 to 40(top left is
1 and top right is 2)
GPIO.setmode(GPIO.BOARD)
#The location of the trigger pin
trigPin = 16
#The location of the echo pin
echoPin = 18
#This is the maximum measuring distance in centimeters which the
sensors can measure
maxDistance = 400

#Calculate timeout according to the maximum measuring distance/
the time which the sensor will stop waiting for a signal if the
distance from an object is larger than the maximum
timeOut = maxDistance*58.82

#Get the pulse time of a pin under timeOut
def pulseIn(pin,level,timeOut):
      time0 = time.time()
      while(GPIO.input(pin) != level):
            if(time.time() - time0) > timeOut*0.000001):
            #Return 0 if the time is greater than the timeout time
                  return 0
      time0 = time.time()
      while(GPIO.input(pin) == level):
            if(time.time() - time0) > timeOut.0.000001):
            #Return 0 if the time is greater than the timeout time
            return 0
      #Calculate the pulse time
      pulseTime =(time.time() - time0) * 1000000
      return pulseTime
```

```
#Get the measurement results of ultrasonic module in centimeters
def getResponse():
      #Set trigPin to output 10us at HIGH level
      GPIO.output(trigPin,GPIO.HIGH)
      #Wait for 10us
      time.sleep(0.00001)
      #Set trigPin to output at LOW level
      GPIO.output(TrigPin.GPIO.LOW)
      #Store the pulse time of echoPin
      pingTime = pulseIn(echoPin,GPIO.HIGH,timeOut)
      #Calculate the distance with sound speed 340m/s
      distance = pingTime * 340.0 / 2.0 / 10000.0
      return distance

def setup():
      print('The Ultrasonic Sensor program is starting…')
      #Use Physical GPIO numbering
      GPIO.setmode(GPIO.BOARD)
      #Set trigPin to OUTPUT mode
      GPIO.setup(trigPin, GPIO.OUT)
      #Set echoPin to INPUT mode
      GPIO.setup(echoPin, GPIO.IN)

def main_loop():
      while(True):
            #Get the distance from an object
            distance = getResponse()
            #Print the distance
            print("The distance is : %.2f cm "%(distance))
            time.sleep(0.5)

if __name__ == '__main__':
      setup()
      try:
            main_loop()
      #Press CTROL+C to end the program
      except KeyboardInterrupt:
            #Release the GPIO resources.
            GPIO.cleanup()
```

##

Experiment #1 – Measuring the Distance of an object ~ 10 cm

- Attach the ultrasonic sensor to a steady object (e.g., a box)
- Place another object across the first object.
- Using a ruler try and place the second object 10 cm away from the sensors.
- After you've written the above python code, double-checked for errors and try running it and checking the output the sensor is printing.

*** Note: Use smooth objects without curves.**

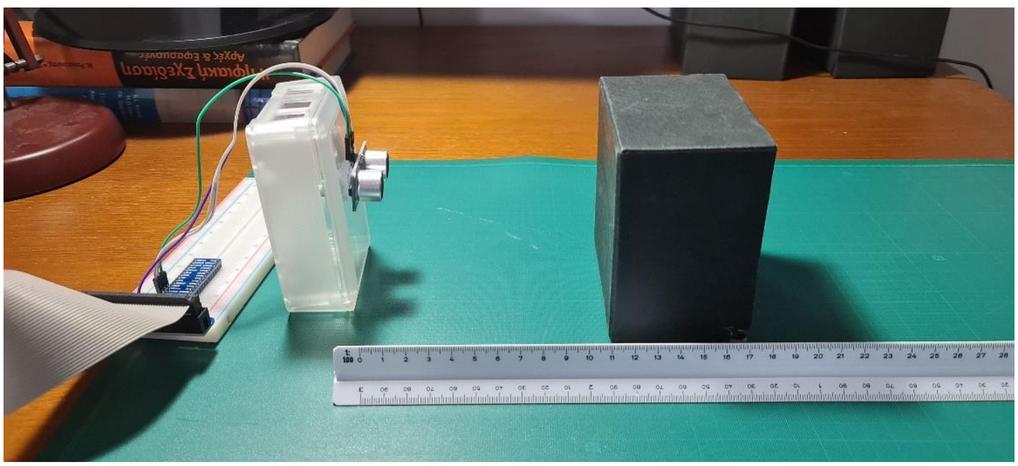


FIGURE 23: EXPERIMENT #1

You should be able to see the distance between the sensors and your second object after running your program. Move the object until it reaches a distance of about 10cm, as shown in Figure 16.

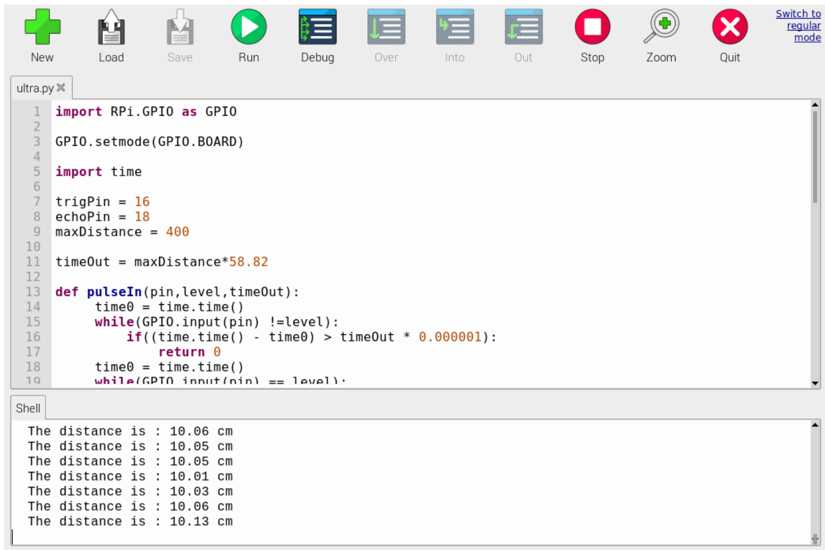


FIGURE 24: PROGRAM OUTPUT EXPERIMENT #1

Experiment #2 – Measuring the Distance of an object with a 90 degrees angle ~ 30 cm

- Rotate the second object to the right by 45 degrees.
- Observe the output of the program.

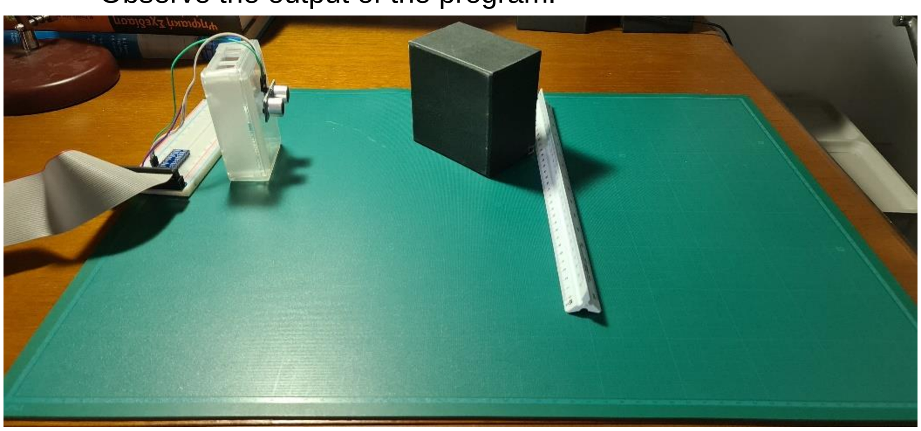


FIGURE 25: SECOND EXPERIMENT

You'll note that the distance has gotten bigger. This is due to the reflection phenomenon. The ultrasound wave reflects and switches direction on the second, then hits a new object before returning to the sensor via the second object again. Most likely the new object is yourself. To see how the distance shifts, try going back and forth to test it.

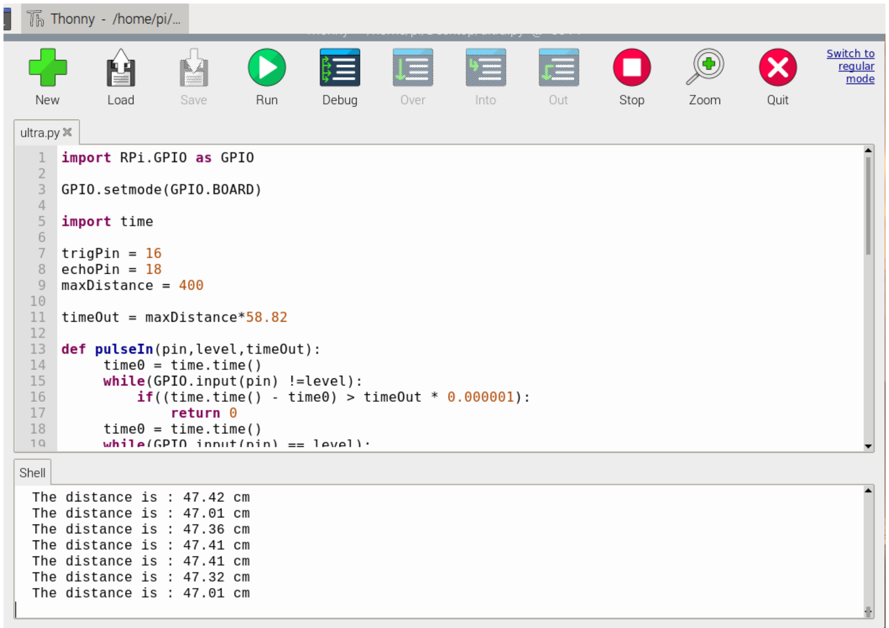


FIGURE 26: OUTPUT OF THE PROGRAM FOR EXPERIMENT #2

If the previous attempt failed, position a new object across the second object in the opposite direction of the first, as seen in Figure 19. Establish a distance of 30cm using the same technique as

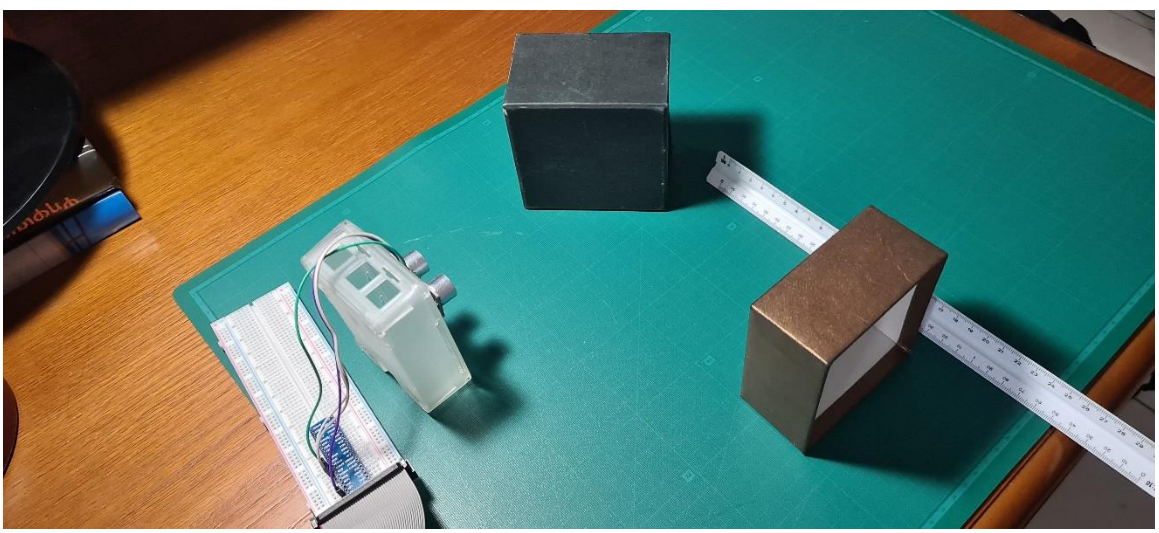


FIGURE 27: SECOND EXPERIMENT SETUP

the first experiment with the ruler.

Rerun your software with the new setup and see how close you came to reaching the 30cm mark.

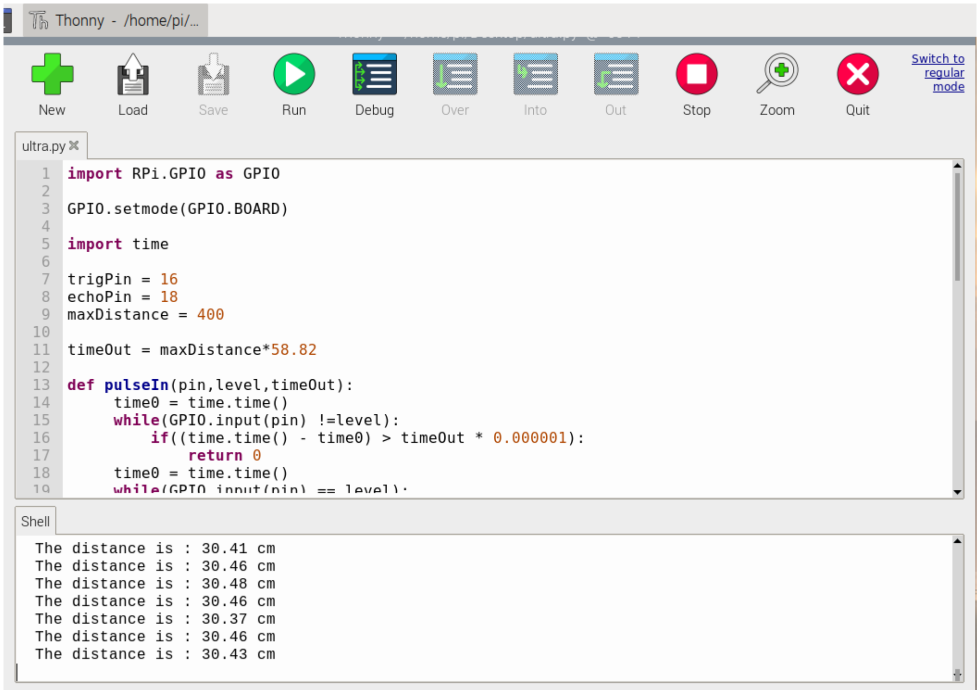


FIGURE 28: SECOND EXPERIMENT RESULT

5.4 Exercises and Activities

1. How many main types of wave do exist?

   a. One

   b. Two

   c. Three

2. A resistor …

   a. Improves the electric current in the circuit

   b. Helps the electric current to flow faster

   c. Restricts the flow of the electric current

3. The wavelength as the name suggests is the length of -------- full wave

   a. **One**

   b. Five

   c. Ten

4. The reflection phenomenon happens when a wave…

   a. Enters an object undergo

   b. Hits an object it cannot pass through

   c. Stops transmitting

5. The refraction phenomenon happens when a wave…

   a. **Enters an object undergo**

   b. Hits an object it cannot pass through

   c. Starts transmitting

6. We use the jumper wires:

   a. On the breadboard

   b. On the LED light

   c. On the resistor

7. The HC-SR04 sensor uses ultrasonic waves.

   a. True

   b. False

8. Which is not a pin connected to the HC-SR04 sensor.

   a. Trig
   b. SDA
   c. Echo
9. The maximum amount of displacement is known as ---------------.
   a. Echo
   b. Reflection
   c. Amplitude
10. How much the speed of sound is?
   a. 1km/h
   b. 340m/s
   c. 300m/s

5.5 Conclusion

Module 4 explored the fundamental concepts of Waves. We learned about the various forms of waves, their anatomy and their properties. We also saw how the equation of the speed and distance is applicable to waves. In addition, we became familiar with terms such as reflection, refraction and diffraction. On a more practical side, we also learnt how the PhysicsKIT can be used to perform experiments related to the topic of Waves. Finally, we strongly encourage educators as well as students to self-explore these concepts of physics and find new ways of using the PhysicsKIT and the Raspberry Pi to conduct experiments and learn physics through hands-on educational play.

5.6 Additional Resources

- Intro to Waves - https://www.youtube.com/watch?v=aCu4VRKMstA
- Refraction - https://www.youtube.com/watch?v=UUc44Vg5pCI
- Frequency - https://www.youtube.com/watch?v=UPuFx_pVlHU
- Frequency and Wavelength - https://www.youtube.com/watch?v=KWzyQKcJBYg
- Reflection - https://www.youtube.com/watch?v=WDBtOeXUdWQ
- Ultrasonic sensors - https://www.youtube.com/watch?v=JNQAH3VMFTU
- Ultrasonic Sensor Projects - https://www.youtube.com/watch?v=KuTsn66Yf7M
- https://components101.com/sensors/ultrasonic-sensor-working-pinout-datasheet
- https://lastminuteengineers.com/arduino-sr04-ultrasonic-sensor-tutorial/

5.7 References

[1] Physicsclassroom.com

https://www.physicsclassroom.com/class/waves/Lesson-2/The-Anatomy-of-a-Wave#:~:text=The%20amplitude%20of%20a%20wave%20refers%20to%20the%20maximum%20amount,position%20to%20the%20trough%20position.

[2] Longman Physics IGCSE, Brian Arnold, Steve Wooley and Penny Johnson

[3] North Western University

https://faculty.wcas.northwestern.edu/~infocom/Ideas/waves.html

[4] Byjus.com

https://byjus.com/physics/waves/

[5] thepropertiesofwaves.weebly.com

https://thepropertiesofwaves.weebly.com/universal-wave-equation.html

[6] The Audible Spectrum

https://www.ncbi.nlm.nih.gov/books/NBK10924/#:~:text=Humans%20can%20detect%20sounds%20in,to%2015%E2%80%9317%20kHz

[7] Savemyexams

https://www.savemyexams.co.uk/igcse-physics-edexcel-new/revision-notes/properties-of-waves/waves/

[8] CK-12

https://www.ck12.org/c/physics/reflection/lesson/Reflection-of-Light-PHYS/

[9] Boweruk - Own work, CC BY 3.0,
https://commons.wikimedia.org/w/index.php?curid=26331438

6. Gravity

6.1 Glossary

Term	Definition
Acceleration	Rate at which velocity changes per unit of time
Accelerometer ADXL345	Is a low-power, 3-axis MEMS accelerometer modules with both I2C and SPI interfaces
Applied force	A force applied to an object or being.
Force	A push or pull action.
Gravitational force	The force of attraction between every mass in the universe; it is the name given to the attraction of our planet's mass for bodies that are close to its surface
Gravity	The force of attraction that causes to bodies to be drawn to each other.
Gravity center	It's an imaginary point where, by convenience, the weight of the body may be considered to be concentrated.
Isaac Newton	An English mathematician who originated the theory of forces.
Magnetic force	The force created by a magnet.
Mass	The amount of matter in an object.
Motion	The action of changing a location or being moved.
Newton	The SI unit of force
Opposing forces	These are forces which work against each other.
Python	Python is an interpreted, object-oriented, high-level programming language. Python has simple, easy to learn syntax that emphasizes readability and therefore reduces the overall time needed to learn it and to develop and maintain a program.

	Python supports modules and packages, which encourages program modularity and code reuse. The Python interpreter and the extensive standard library are available in source or binary form without charge for all major platforms and can be freely distributed.
Raspberry Pi	Raspberry Pi is a credit card sized, fully functional computer which operates on Raspberry Pi OS.
Raspberry Pi GPIO	Raspberry Pi GPIO is the row of pins along the top edge of the board. A 40-pin header is found on all current Raspberry Pi boards. Most of the functionality of the Raspberry Pi comes from these pins which can be configured and controlled using a programming language. Any of the GPIO pins can be designated in software as an input or output pin and used for a wide range of purposes such as to control LEDs, buzzers, motors, servos, to interact with sensors, to communicate with other devices, etc.
Raspberry Pi OS	The operating system for Raspberry Pi.
Sensor	A sensor is a device that measures physical input from its environment and converts it into data that can be interpreted by either a human or a machine. Most sensors are electronic (the data is converted into electronic data), but some are simpler, such as a glass thermometer, which presents visual data.
Volume	The amount of space that an object or substance takes up
Weight	Is a measure of the force of gravity pulling on an object

6.2 Introduction to Gravity

Gravity is a force that surrounds us and it is responsible for attracting two objects towards each other.

This force has been around since the beginning of the universe, and it works the same way everywhere. It is this force that prevents from falling off the Earth and what keeps Earth and all other Solar System planets orbiting around the sun. It was thanks to the gravitational force that the sun was formed, four and a half billion years ago.

In the 17th century, Isaac Newton discovered that the strength of the gravitational force increases the closest two objects are of each other. If the objects are moved apart, the gravitational force strength lowers.

Gravitational force also varies with the mass of the objects. If an object has a greater mass, it will have a stronger gravitational force.

This helps to explain why we can feel the Earth pulling on us but cannot feel the gravitational force of the Moon. This happens because the Moon is smaller and further away. However, the Moon’s gravitational force is strong enough to cause the tides in our planet.

6.3 Learning Outcomes

Students will understand gravity as a force we cannot see and that that pulls things towards the object’s center. They will recognize that this force can pull through big distances and that it has an effect in every object that has a mass, including our planet. They will also realize that the gravitational pull is as much stronger as an object has a greater mass or as closest to each other two objects are.

In the end of this module, students will be able to understand what gravity is, overall, how the gravitational force works and what can change this force’s strength.

They will also be able to correctly use the vocabulary and terms regarding the gravity topic, such as gravity, mass, weight, force, attraction, por example.

In this chapter there will also be an experiment that you can perform using the Raspberry Pi and other sensors to provide a more clear and practical understanding of this topic.

6.4 Theory

6.4.1 What are forces?

A force is defined as a push or pull move which can make things move, change direction, or change shape. A force has both magnitude and direction. It is measured in newtons and represented by the symbol F.

Forces can be identified everywhere in our world. For example, there is an object in our house, let us say a box. When the box stands still there are two forces applied to it, a force which pulls the object to the ground ensuring the box does not float in the air and an equal and opposite force pushing the box from the ground. When we try to change the box's position, we apply another force to it, which causes the box to move and change position. At the same instance, another force resists us pushing the box. There are also other forces applied to the box or us which are equally important to learn.

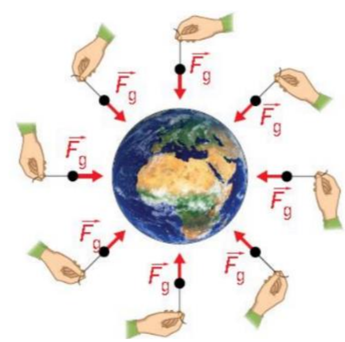
6.4.2 What is the gravitational force?

Any object that is dropped will fall on Earth and is falls due to a force.

This force, that acts on the body at distance, attracting it to Earth, is called gravitational force.

The gravitational force exerted by Earth on an object, wherever that object is, has:

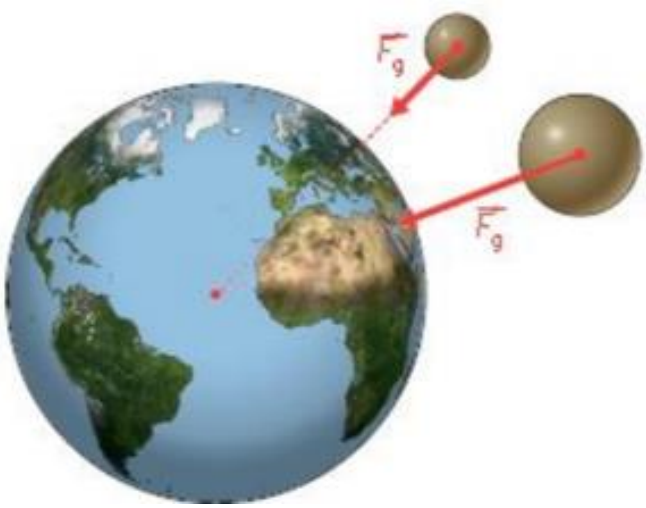
- The direction of the line that goes through the center of the object and the center of the planet Earth;
- The sense of the body to the Earth.

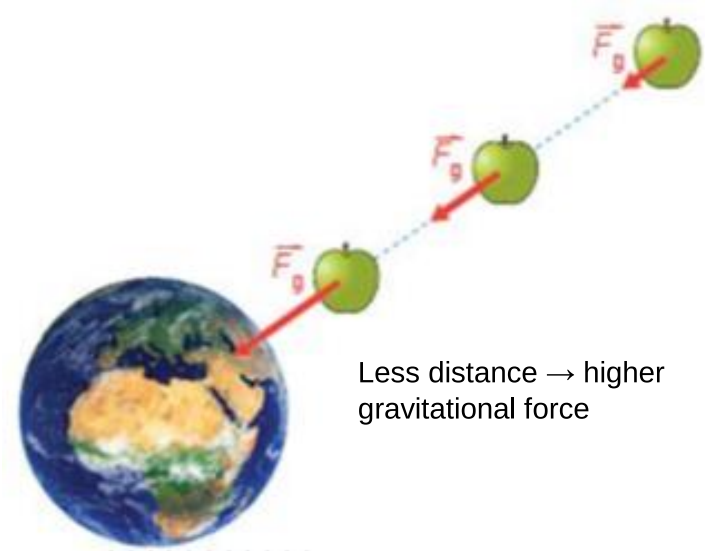


The intensity of this force depends on:

- The mass of the object;
- The distance between the object and the center of Earth;

Bigger distance → lower gravitational force





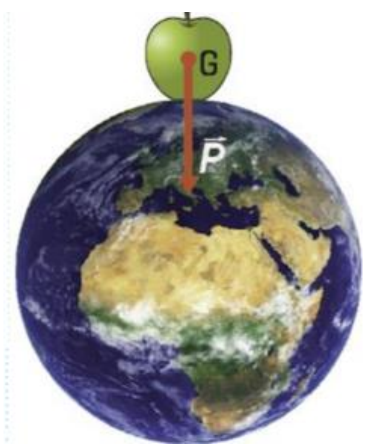
Less distance → higher gravitational force

6.4.3 What is the difference between mass and weight?

Physicists name **weight** of an object to the force that attracts this object to the Earth.

The weight of an object can be represented by a vectorial:

- **Application point** – the center of gravity of the G object.
- **Direction** – vertical, the same direction of the line that goes through the center of the object and the center of Earth;
- **Sense** – downwards, from the object to Earth;
- **Strength** – the value of the weight.



The SI unit of **weight** is the same as that of force: **N**, the **newton**.

Mass is a property of matter that is fully understandable by its value. It is a scalar physical greatness.

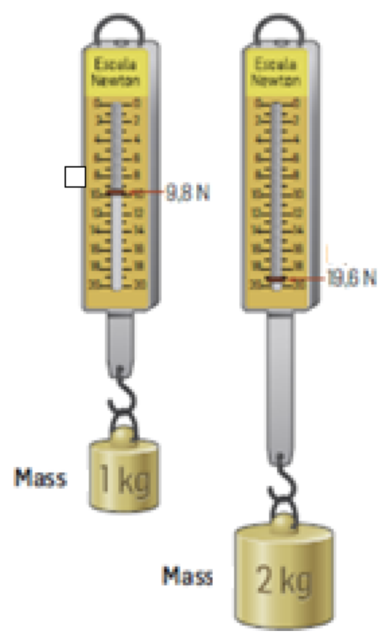
The SI unit of mass is the kilogram, kg.

We measure an object's mass using scales:

Precision scale

Plate scale

Analitical scale



In the same place of the planet, the weight of an object is proportional to its mass. This means that as the mass increases, the weight will also increase.

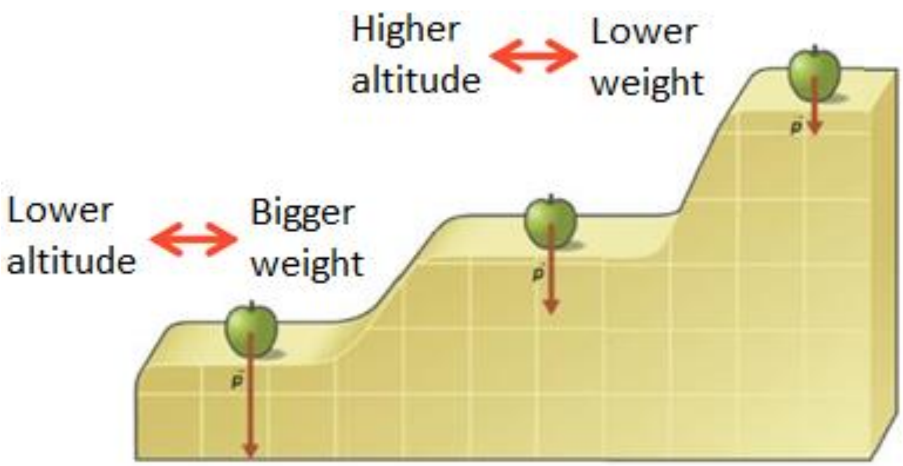
If we divide the weight of these objects, that is in N, by each of their mass, that is in kg, we get the same result:

$$\frac{9{,}8\ N}{1\ kg} = \frac{19{,}6\ N}{2\ kg} = 9{,}8\ N/kg$$

$$\frac{weight}{mass} = constant$$

On Earth, the gravitational force is approximately $9,8\ N/s^2$.

Since weight is the force the attracts an object to Earth, its value depends on the distance between the Earth center and the center of the body.



6.4.4 Gravity force in our Solar System

The intensity of the gravitational force also depends on the mass of the planet that is attracting the object.

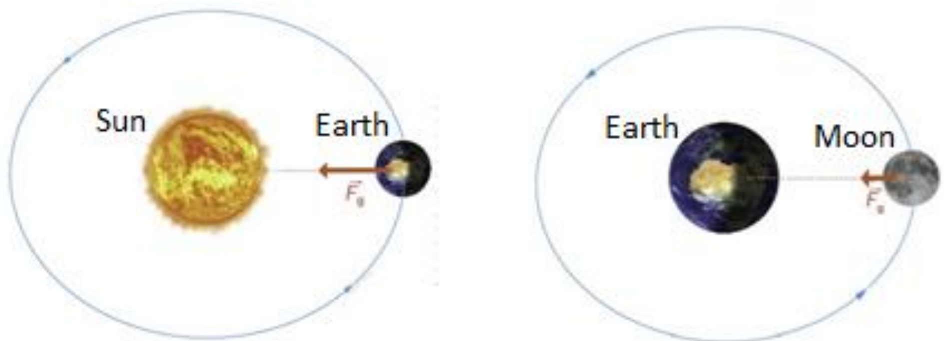
The biggest the mass of the planet, the strongest is the intensity of the force that pulls an object towards the planet.

On the Moon, $\vec{F}_g$ is lower than on Earth…

On Earth…

On Jupiter, $\vec{F}_g$ is higher than on Earth…

The intensity of the gravitational force depends on the mass of the two celestial objects and the distance between them. This force is more intense the bigger the mass of the objects and the closest they are from each other.



The intensity of the gravitational force that the Sun exercises on Earth and on the Moon	>	The intensity of the gravitational force that Earth exercises on the Moon
The mass of the Sun and Earth	>	The mass of Earth and the Moon

(even though the distance is smaller between the Earth and the Moon)

6.4.5 How to calculate the weight or mass of an object.

We call weight to the measure of the force of gravity pulling on an object. To determine the weight we use Newton's second law:

$$W = m \times g \ ,$$

in which ***m*** is the mass of the object, in *kg* and ***g*** is the measure of the force of gravity that, on Earth, is around ***9,8 m/s²***.

Since weight is the measure of a force, we can write:

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

With this formula, we can determine both the weight or the mass of as object, since we know the value of the gravity.

6.4.6 Experiments

Experiment #1: Weightless water

This activity will help students to understand a little bit more about gravity and the gravitational force and to see the effect of this force on objects.

For this experiment, we will need:

- Cups (plastic or Styrofoam)
- Scissors or another sharpened object (to make holes in the cups)
- Water
- Tray or big container

How to implement the experiment: (this experiment must be done in a place that can get messy because there will be a lot of water spilling).

Divide the class into small groups and start by asking them what they know about gravity.

Then, give them a scissor and a cup for group and ask the students to make two holes on the cup, near the bottom of the cup, in such way that they can cover them with their fingers.

Ask one of the students in the group to put the cup inside the tray and then to cover the holes of the cup. Then, pour water up to the line before the top rim of the cup.

Repeat in every group and then ask the students what will happen if they take their fingers from the hole.

Ask them to remove the fingers for a moment, to verify their hypothesis. Tell the students to cover the holes again and refill the cup to the same place it was before.

Ask the students what they think will happen if they drop the water glass, allowing it to fall into the tray.

Ask one student of each group to get on a chair (with the fingers covering the holes in the cup) and drop the water cup to the tray, on the floor.

No water falls from the wholes of the cup during the fall. Discuss with the students why does this happen.

Conclusion: The gravitational force pulls the water through the hole in the container if the container remains motionless. When the container is dropped and allowed to free fall toward the empty tray, the water remains inside the container because there is an equal amount of gravity being exerted on the container and the water inside the container. This way, both the water and the cup will fall at the same speed.

Experiment #2: Free fall detection

The goal for this experiment is for the students to be able to use an accelerometer to detect objects that are free falling.

For this experiment, we will need:

- Raspberry pi
- Breadboard
- Jumper cables
- ADXL354 accelerometer

How to connect the accelerometer to the Raspberry Pi:

- Wire the GND pin of the Accelerometer to Physical Pin 6 (GND) on the Raspberry Pi.
- Wire the VCC pin of the Accelerometer to Physical Pin 1 (3v3) on the Raspberry Pi.
- Wire the SDA pin of the accelerometer to Physical Pin 3 (SDA) on the Raspberry Pi.
- Wire the SLC pin of the Accelerometer to Physical Pin 5 (SCL) on the Raspberry Pi.

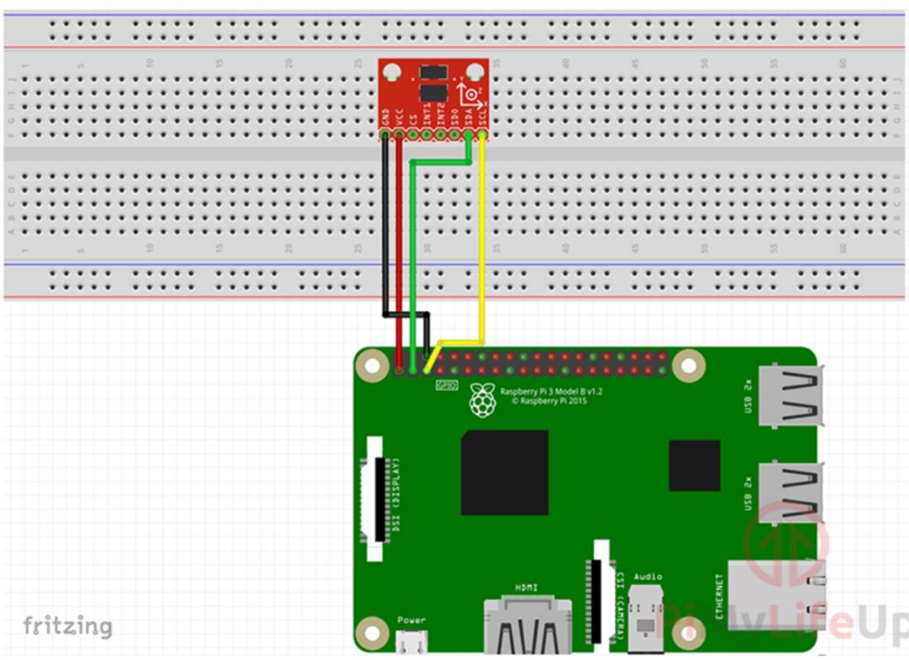


Figure 1 – Assembling the ADXL354 accelerometer to the Raspberry Pi

Python installation of the ADXL34x Library

It's now time to install the **Adafruit_Blinka** library that will give you access to the the CircuitPython support in Phyton.

Star by running the following command:

```
sudo pip3 install adafruit-circuitpython-adxl34x
```

When the priviest step is done, we can begin to code our Python script.

Let's start writing this file by tipying the following command.

```
Nano~/accelerometer.py
```

Now let us write the following lines of the code:

`import time` (we impot the "time" library so that we can put the script to sleep for a short period)

`import board` (this library is designed to quickly know what pins are available on a device).

`import busio` (this module contains a variety of different libraries to handle various serial protocols)

`import adafruit_adxl34x` (this library contains all the code needed to read the information from the ADXL345 accelerometer)

`i2c = busio.I2C(board.SCL, board.SDA)` (this prepares the I2C connection for our current boards SCL and SDA pins.)

The next line will instantiate the ADXL345 library into the "accelerometer" object. This object will be used to read and obtain information from our sensor.

```
accelerometer = adafruit_adxl34x.ADXL345(i2c)
```

Now, use the command "**while True**" to begin an infinite loop:

In this infinite loop, we need to print the acceleration values from the X, Y and Z that the library has recovered from the accelerometer:

```
while True:
    print("%f %f %f"%accelerometer.acceleration)
    time.sleep(0.5)
```

Once we have printed the X, Y and Z values, we then put the script to sleep for half a second.

We sleep the script to stop it from flooding the command line with values provided by the accelerometer.

The code is finished, and we can now press **CTRL + X** then **Y** followed by **ENTER**.

To run the script use the command:

```
python3 ~/accelerometer.py
```

Let us explore the Adafruit's ADXL345 accelerometer library by using the following command:

```
nano ~/accelerometer.py
```

Find the line:

```
accelerometer = adafruit_adxl34x.ADXL345(i2c)
```

Now, let us add:

```
accelerometer.enable_freefall_detection(threshold=10, time=25)
```

This code line makes sure that the libraries can detect the freefall events. It has under consideration two different variables, the threshold, and the time.

The **threshold** sets the maximum value, on all axes, that acceleration can take so that the movement made is read as a freefall. Taking the scale factor as 62.5mg, this means that **10*62.5=625 mg.**

In the same logic, the **time** variable sets the maximum value that time, on all axes, must be under than the threshold so that it registers and a drop. In our example, since the scale factor is 5ms, the time is **25×5=125ms**

```
accelerometer.enable_motion_detection(threshold=18)
```

This code line, that only takes one variable, the threshold, will allow the libraries motion detection to star working.

In this case, the **threshold** variable sets the minimum value that acceleration on all axes can assume, for a motion to be detected. This value can be changed whether it is to sensitive or not enough. For a threshold of 18, since the scale factor is 62.5mg, we get **18*62.5=1125 mg.**

```
accelerometer.enable_tap_detection(tap_count=1,threshold=20,
duration=50, latency=20, window=255)
```

This line above is what enables the libraries tap detection event.

The **tap_count** variable sets if it should detect one tap (1) or a double tap (2).

To define how sensitive the tap is, use the **threshold** variable. The highest the value of the threshold, the less sensitive the code will be to detect the tap. Remember that the scale factor is also 62.5mg.

The next variable to be defined is the **duration**, that needs to be set in ms. This sets the length that the movement should occur. Is you set a value too high, is might not be detected as a tap.

The **latency** variable sets the time that the code should search for the second tab to occur, after the first one was detected. We use ms to define this value.

Even though it might seem similar, the **window** variable defines how much time should the code look for the second tab. This value should also be in ms.

Let us find the line

```
print("%f %f %f"%accelerometer.acceleration)
```

After we found it, the following lines should be added after:

```
print("Dropped: %s"%accelerometer.events["freefall"])
    print("Tapped: %s"%accelerometer.events['tap'])
    print("Motion detected: %s"%accelerometer.events['motion'])
```

These are the lines that will let us know if any events are being triggered.

Typically, you will not be checking for all these events at one time

When you are happy all the code is correct you can save it by pressing **CTRL + X** then **Y** followed by **ENTER**.

With the code now done, let us go ahead and run the script by running the following command.

```
python3 ~/accelerometer.py
```

When you run this code, you will get information about the **X**, **Y,** and **Z** positions that the accelerator registers. You are also able to understand the status of all the events.

```
0.235360 0.353039 8.355266
Dropped: False
Tapped: False
Motion detected: False
```

6.5 Assessment

11. What is the direction of the gravitational force?

a. The same as the line that goes through the center of the object and the center of the planet Earth.

b. Always to the right

c. It is impossible to know.

12. The intensity of the gravitational force depends on (select all the correct options):

a. The size of the object.

b. The mass of the object.

c. The distance between the object and the center of Earth.

13. Complete the sentence correctly: “The biggest the distance to Earth…”

a. the biggest the gravitational force.

b. the lowest the gravitational force.

c. the closest is the object.

14. The SI unit of mass is:

a. km

b. g

c. kg

15. The SI unit od weight is:

a. **Newton**

b. Jule

c. Isaac

16. We calculate the weight of an object using the formula:

a. $\vec{F} = \frac{m}{a}$

b. $\overrightarrow{W} = m \times v$

c. $\boldsymbol{\vec{F} = m \times g}$

17. The Sun's gravitational force keeps the rest of the Solar System planets in orbit:

a. True

b. False

18. Gravity is the same in all the planets of the Solar System:

a. True

b. False

19. The accelerometer:

a. detects movement.

b. measures distances.

c. weights an object.

20. How much is the gravitational force on Earth:

a. 15 m/s^2.

b. 9,8 $\boldsymbol{m/s^2}$.

c. 2 m/s^2.

6.6 Conclusion

Module 5 explores the concept of Gravity.

With this module we learnt about the effect of gravity, about the gravitational force and how to calculate it.

We also understood the difference between weight and mass since one is a force and the other is a scalar physical measure.

With the experiments, we got to see some properties of gravity, like the way gravity affects a still object or a moving object. We also used the PhysicsKIT and a accelerator to detect a body that is falling under the effect of gravity – freefalling.

Students can explore the gravity concept using the PhysicsKIT and some sensors and get to know a little bit more about gravity and the properties of gravity.

6.7 Additional Resources

Here you can find some interesting links to help explore the topic about gravity:

- https://www.youtube.com/watch?v=xICEt51A-Ac -What is gravity?
- https://www.youtube.com/watch?v=U78NOo-oxOY – Explanation about weight, force, mass, and gravity.
- https://www.youtube.com/watch?v=cHySqQtb-rk – seeing the effect of gravity in the universe.
- https://www.teachengineering.org/activities/view/cub_mars_lesson04_activity1 - STEM experiment about the escape velocity (velocity to escape the gravity pull)
- https://www.youtube.com/watch?v=hqDhW8HkOQ8 – Experiments to determine the centre of gravity of different objects.
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