DIDACTICS OF EXPERIMENTAL SCIENCES 1: PHYSICS, CHEMISTRY AND GEOLOGY

Topic 3. Energy and its transfer

0. Glossary

English term	Spanish term	Observations
Electrical circuit	Circuito eléctrico	
Electrical current	Corriente eléctrica	
Electrical energy (J)	Energía eléctrica (J)	
Electrical power (W)	Potencia eléctrica (W)	
Energy	Energía	
Energy consumption	Consumo energético	
Gravitational	Gravitacional	
Greenhouse effect	Efecto invernadero	
Heat	Calor	
joule (J)	julio (J) (medida de energía eléctrica)	
Kinetic energy	Energía cinética	
Label	Etiqueta	
Light	Luz	
Ozone	Ozono (O_3)	
Pollution	Contaminación	
Potential energy	energía potencial	
Power plant	Central eléctrica	
Power supply	Suministro eléctrico	
(electrical) Plug	Enchufe (lo que enchufamos, al final de un cable)	
(electrical/ power) Socket	Enchufe (donde se enchufan cosas)	
Sound	Sonido	
watt (W)	vatio (W): medida de la potencia eléctrica	
Wave	Onda en física, ola en otros contextos	
Thermal energy	Energía térmica	
Thermal waters	Aguas termales, calientes	
Transfer	Transferencia, traspaso	
Utility	Institución que suministra al público agua, gas y/o electricidad	
Utility bills	Facturas de agua, gas y/o electricidad	

1. Energy

1.1. Energy and its manifestations

Definition of energy:

Energy is needed for physical or chemical changes to happen, so it is something that can produce a change in matter.

Energy: a magnitude that allows systems to produce or experiment changes or transformations (Vílchez, 2016).

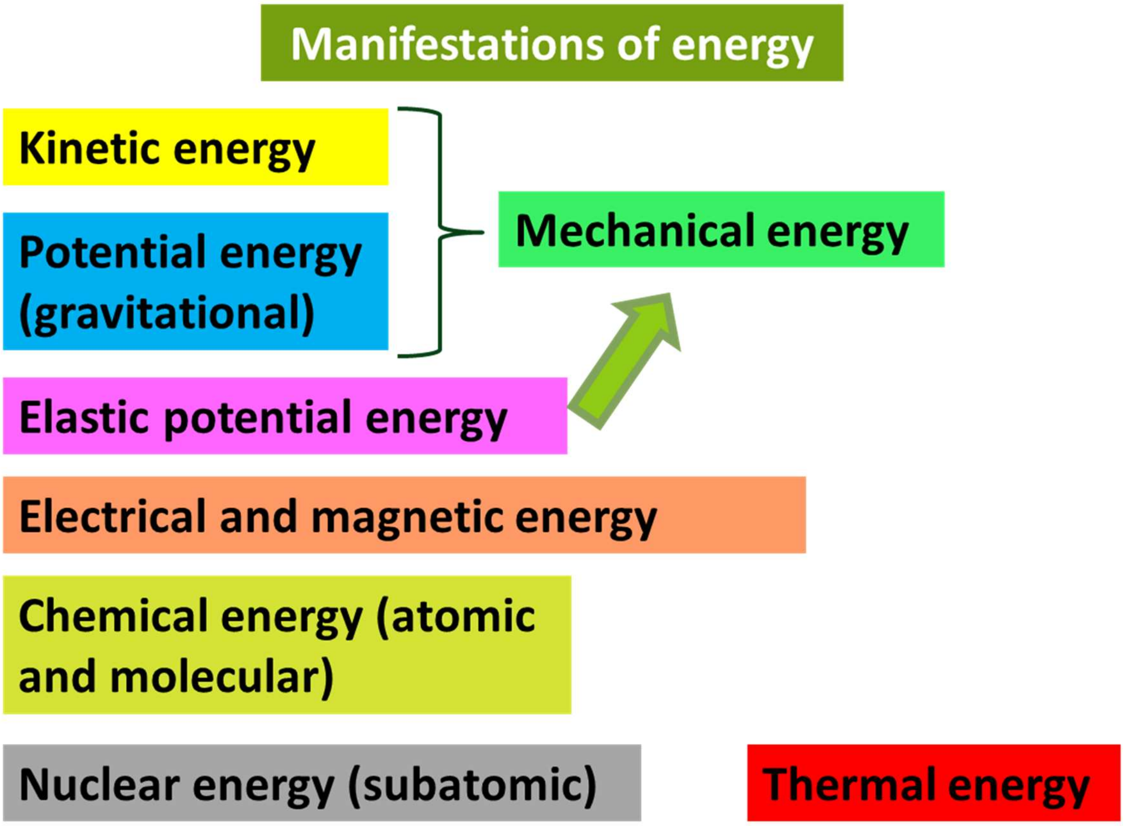
Characteristics of energy

1) Energy has got no mass or volume. You cannot see energy, only its effects. But you can measure it.
2) Energy can be contained within matter and transferred from one type of matter to another.
3) Energy cannot be destroyed, it can only be transformed.
4) Energy can be perceived in different ways

In the SI, energy is measured in joules (J)

There is only one kind of energy, but we perceive it through its effects or manifestations.

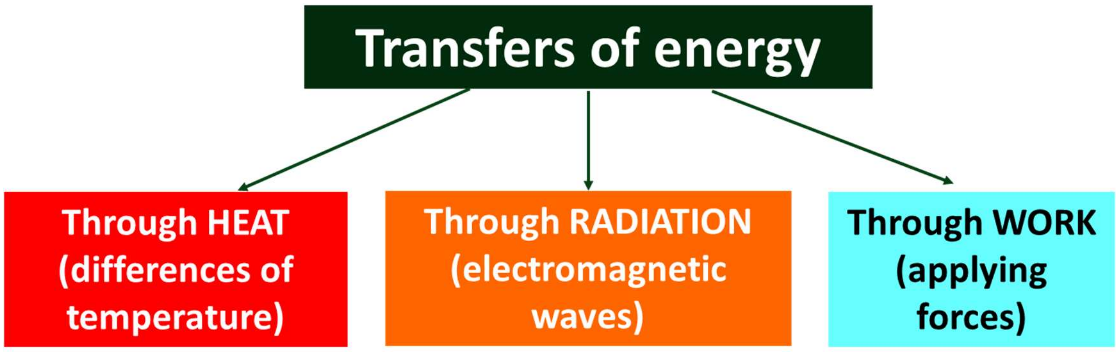
The different manifestations depend either on the source of the energy or the effect that it produces. Thus, it is recommended to avoid using the expressions 'forms of energy' or 'types of energy'.



Energy	
Previous conception	**Correct idea**
Energy is responsible for anything that happens (Is what make things happen) e.g. Is what makes something work	Energy is just responsible for changes in matter
Energy is the final product or result of a process e.g. It appears in smoke after combustion	Energy is needed for changes to happen, it's not a result of those changes
Energy is a fuel, something needed for things to live, work or move e.g. a car needs energy to function e.g. children use a lot of energy e.g. old people don't have a lot of energy	It's not the energy, but its transformations what produces movement Car, sportman: Transformation from chemical to mechanical energy

List of misconceptions from Vílchez-González (2015).

1.2. Transfers of energy: Heat, work and radiation



Heat, radiation and work: ENERGY TRANSFERS, PROCESSES by which energy IS TRANSFERRED from an object to another (not stored in a body)

1.2.1. Transfers of energy as heat

Heat is the transfer of energy due to differences in temperature.

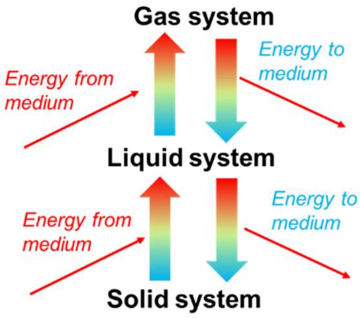
Heat can transfer through:
- Convection (in fluids: liquids and gases)
- Convection (in fluids: liquids and gases)
- Radiation (electromagnetic waves)

Just for being at a temperature above 0ºK, a body emits radiation (vibration of particles)

Heat transfers always occur from the warmer to the colder system/medium.

Remember that a change of state: Physical change in a substance produced by changes in its temperature (heat transfers)

Therefore, an energy transfer (heat) is needed from the medium to the system or viceversa for a change of state to happen.



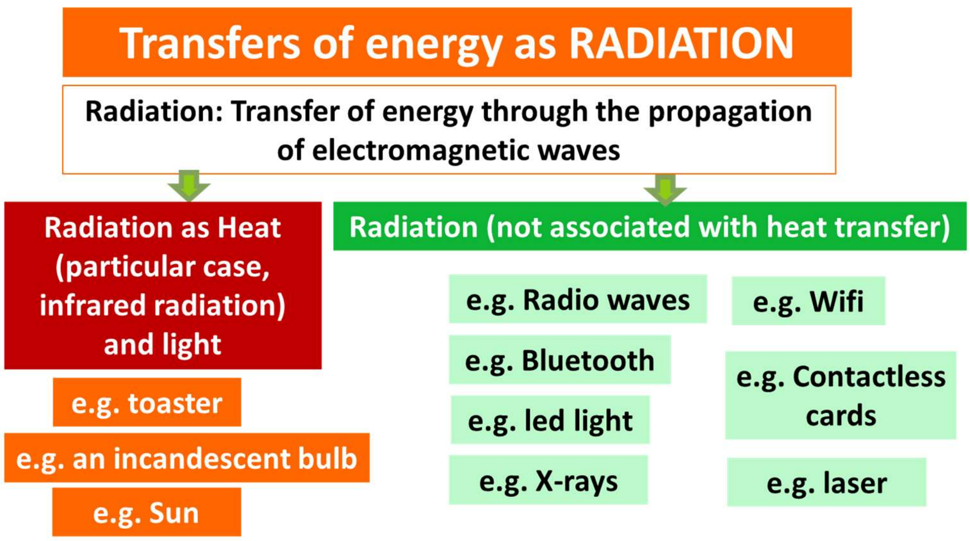
It is important to remember that once the necessary T for a change of state is reached, T will remain constant until the change is complete.

Heat	
Previous conception	**Correct idea**
Heat is the same than temperature	Temperature is a measure of the thermal energy, the energy that a body has due to the vibration of its particles, while heat is not a manifestation of energy, it's an energy transfer
Heat has a material nature and moves through empty spaces within bodies	Heat is an energy transfer, a process, and the energy is transferred among the particles of bodies
Heat can be stored in bodies	Heat is an energy **transfer**, so it can't be stored. Thermal energy can be stored, but not heat
Cold is a substance, and can move from one body to another	Cold is not a substance. It is a perception of when an object has lower temperature than another.
We feel cold because cold gets into our body	We feel cold as a result of the heat transfer from our body to the medium
Heat causes changes in bodies by entering or exiting them (dilatation, changes of state)	Heat is not a substance, what causes the changes is the exchanged thermal energy
Temperature varies during changes of state	Once the needed T is reached for a change of state, it remains constant in the substance until the change is complete.
Representation of temperature (red=hot, blue=cold)	In nature, objects start with red and as they warm up, they change into white and then blue

Heat can also be transferred as Radiation: Transfer of energy through propagation of electromagnetic waves

1.2.2. Transfers of energy as radiation

Any body with temperature >0ºK will emit radiation (all kinds)



We call

Heat: near infrared beams that our eyes can't see
Light: visible beams

1.2.3. Transfers of energy as work

Transfers of energy as WORK

Work: Transfer of energy due to movement or deformation

Electrical energy *(Section 3.2)*
-movement/flux of electrons
- atraction-repulsion among electrical charges

Mechanical energy (movement or deformation) *(Section 3.3)*

Sound (mechanical waves) *(Section 3.5)*

Magnetic energy (atraction-repulsion forces) *(Section 3.2)*

Work: Energy produced when a force is applied to produce movement or deformation

1.3. Principle of conservation of energy

Principle of conservation of energy: Energy can't be created nor destroyed, it only changes.

In an isolated system, the energy won't vary, it will only vary how it manifests.

In a system related to a medium, there may be exchange of energy, but the total balance will remain constant.

1.4. Energy degradation

After an energy transformation, part of the transformed energy is released into the medium, so the system won't be able to use it again.
The total balance system-medium still remains the same

2. Electrical energy

2.1. Electrical current

When we connect a metallic wire (conductor) to both poles of an electrical generator, a movement of charges (electrons) is produced: this is called an electrical current.
Electrons (charges) always move from the negative to the possitive pole. An electrical generator does NOT create these charges (e-), it only provides energy for them to move within the conductor body (wire), so a closed circuit is established.

The differential of potential between the two poles is necessary for the movement of electrons, that is, for the current to happen. Electrons move freely from one atom to another (the atoms don't move, it's not a fluid!)

For historical reasons, the electrical current (I) sense is represented from the positive to the negative pole, opposite to the sense of movement of the electrons.

The current may be direct (DC, *continua*, charges always moving in the same sense) or alternating (AC, *alterna*, charges change sense of movement cyclically)

Direct current:
- electronic devices fed with cells/batteries
- anything with a charger (phone, ipad...) that converts AC into DC

Alternating current:
- circuits fed with the electrical network
-the frequency may be 50 or 60Hz (50 or 60 cycles per second)
- most alternating-current electrical outlets in the world supply power at 210–240 V or at 100–120 V
- a transformer may be used to increase or decrease AC electricity from the primary (input) side to the secondary (output) side

2.2. Basic concepts in electrical circuits

Potential difference (V):
- In Spanish, *diferencia de potencial, ddp*.
- The S.I. unit is the volt (voltio), represented as V
- It is defined as the difference of energy that a charge has between two points of the circuit

Current intensity or current (I):
- In Spanish, *intensidad de corriente*.
- The S.I. unit is the ampere or amp, represented as A

- It is defined as the amount of charges that go through a section of the conductor body per time unit:
I=q/t
q= quantity of charge (related to number of electrons)
t=time in seconds

Resistance (R):
- In Spanish, *resistencia*.
- The S.I. unit is the ohm (ohmio), represented as Ω
- It is defined as the resistance that a conductor presents against the current passage.

$$R = \rho\, L/S$$

where:
ρ = electrical resistivity, specific resistance of a material to the passage of current
L=length of conductor (in meters)
S= transverse section (in m^2)= thickness

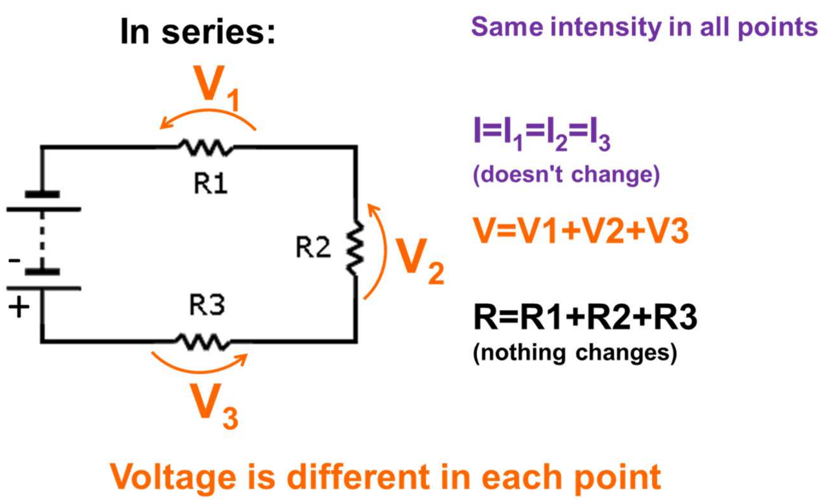
$$\boxed{\uparrow L,\ \uparrow S,\quad \downarrow R}$$

Ohm's Law:

$$\mathbf{I = V/R}$$

The current intensity (I) circulating through a metallic conductor will increase when the potential difference (V) applied between its ends increases, and will decrease when the resistance (R) of the material increases.

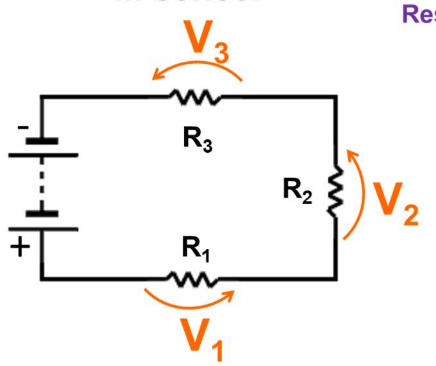
Types of circuits:



$I = V/R$

In series:

Same intensity in all points
Resistors don't change their R



$V = I \cdot R$

$V_1 = I \cdot R_1$

$V_2 = I \cdot R_2$

$V_3 = I \cdot R_3$

$V = V_1 + V_2 + V_3$

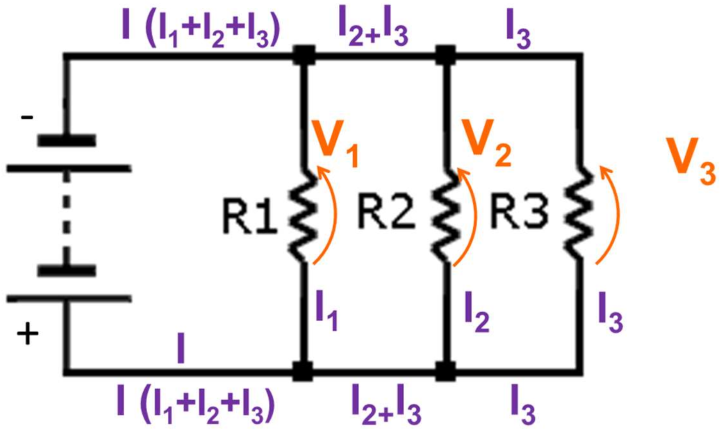
Voltage (potential difference) is different 1, 2 and 3 because there are resistors ('obstacles for current') between battery and measuring points

Electrical circuits

$I = V/R$

In parallel:

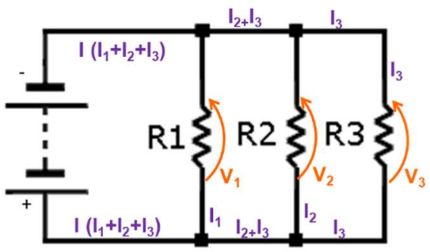
R1 and R2 and R3 don't change their value



$V = V_1 = V_2 = V_3$
(nothing between power source and points measured) Always measuring between poles of battery)

$I = I_1 + I_2 + I_3$

$I = V/R$



$$I = I_1 + I_2 + I_3 = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) = V \cdot \frac{1}{R}$$

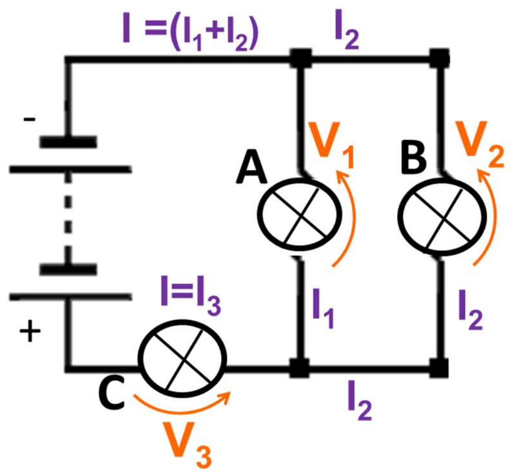
$I_1 = V/R_1$

$I_2 = V/R_2$

$I_3 = V/R_3$

$$I = \frac{V}{R}$$

$I = V/R$

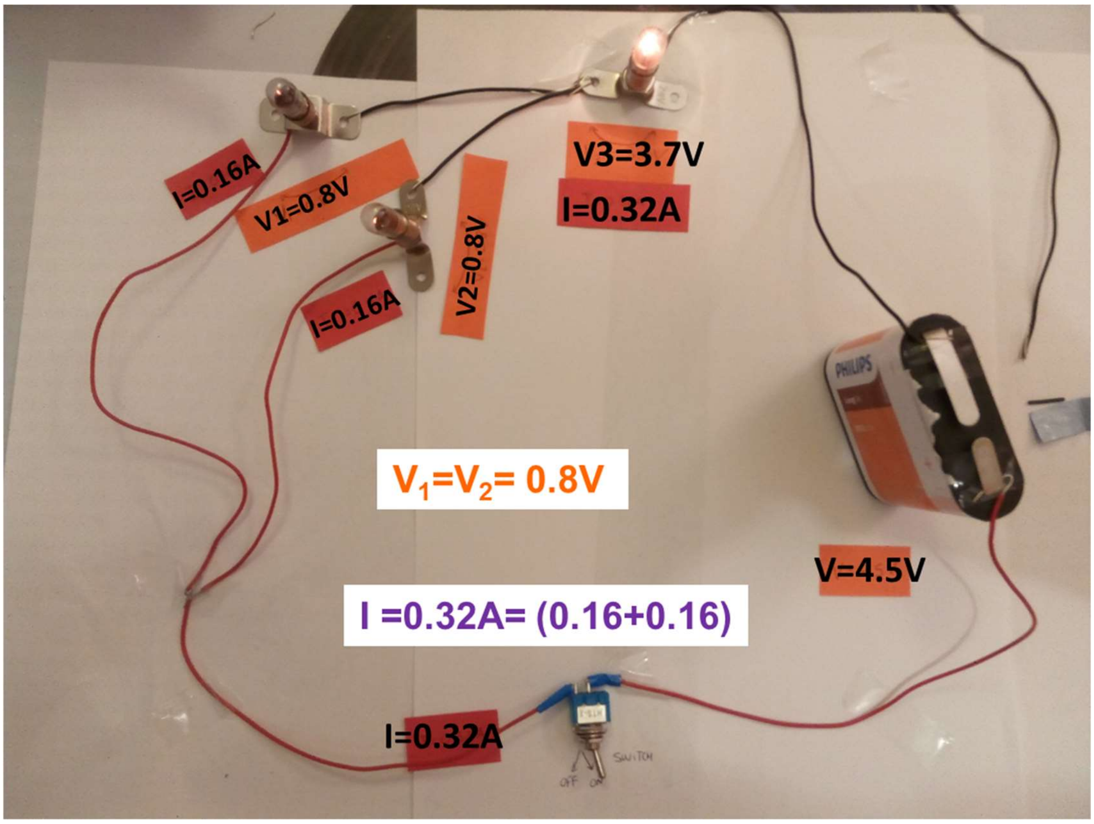


R1 and R2 and R3 don't change their value, they are identical lamps

$I = I_3 = (I_1 + I_2)$

$V_1 = V_2$ A and B, same brightness

$V = V_3 + V_1$

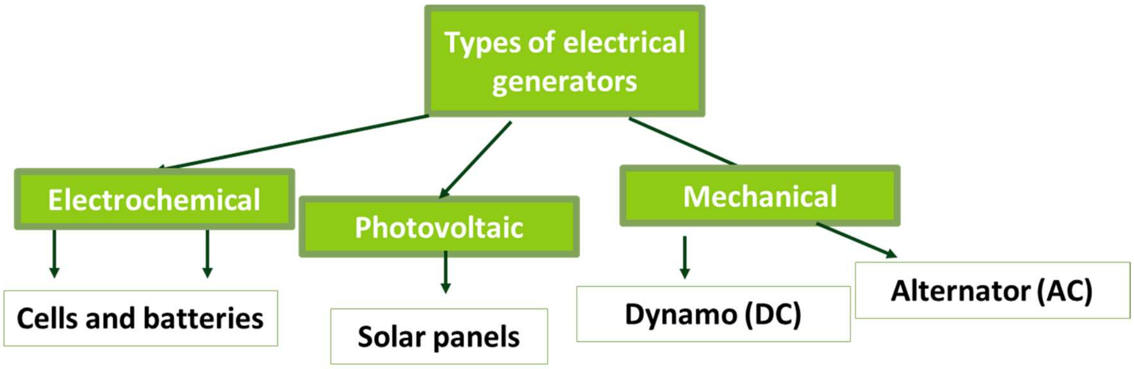


Electricity	
Previous conception	**Correct idea**
Electrical current is a flow similar to water, going from a higher to a lower position	The electrons move in a flux, but the atoms remain in the same spot, they don't move. Moreover, the voltage is not a difference in height, but a difference in energy.
Battery is the only electrical generator known	There are other generators (power supply, alternators, dynamos, solar panels)
Battery supplies a constant current (I) independently of the circuit to which you connect it	The battery will supply more o less current intensity depending on the elements of the circuit (see next slide). The more current intensity, the faster the battery will run out
The current supplied by the battery is 'spent' along the circuit (decreases)	The current intensity that goes out of the battery is the same than the one that comes back to it, independently of the elements of the circuit

2.3. Electrical energy production

Electrical energy is the preferred one in our society:
- It's 'high quality' energy: allows more transfers with a higher rendering
- the cleanest, when it's not obtained from thermal power plants
- easy to transport long distances

As we said before, an electrical generator does NOT create charges (e-), it only provides energy for them to move within the conductor body (wire), so a closed circuit is established.



Electrochemical accumulators (DC):
- They accumulate chemical energy in one or more 'cells' (liquid and metallic plates)
- They produce a continuous current
- Cells and batteries (*pilas y baterías*)

Power supply (fuente de alimentación)
- a device that connects to the electrical network and allows you to vary the voltage and the intensity
- usually DC
- integrated converter

Solar panels (placas solares)(DC):
- they accumulate photovoltaic energy
- They convert incoming light (radiation) into electrical energy to produce a continuous current
- Solar parks need conversion equipment (inverters) to convert DC into AC

Dynamo (dinamo)
- a device that generates electricity (DC)
- a powerful, permanent magnet that's free to rotate at high speed, wrapped by a tight coil (bobina) of copper wire
- the result of the rotation is that electricity is produced
- to generate electricity, either the wire has to move past the magnet or vice-versa

Let's see how electricity relates to magnetism...

Magnetism: the property of some metallic objects (magnets) to attract other metallic objects or attract/repel other magnets.

All magnets have two opposite poles (called north and south). If you cut a magnet in two, each piece will have two opposite poles (magnets with one pole do not exist).

Poles of opposite signs ('unlike poles') are attracted to each other, but poles of the same sign ('like poles') will repel each other.

Magnets generate a magnetic field that will attract metals and attract or repel other magnets.

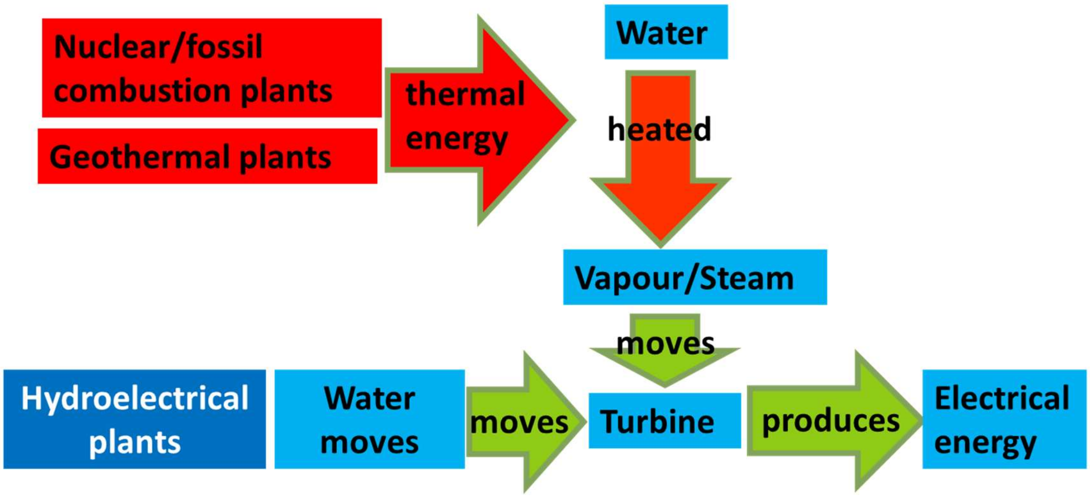
This magnetic field can be visualised as forces that go from the north to the south pole. Earth has a magnetic field because of the of the metallic materials in inner layers.

Remember, an electrical current is a flux of electrons. If we surround a magnet with a metallic conductor, we create an electrical current. That is how a dynamo works.

Alternator (alternador)
- a device that generates electricity (AC)
- it produces alternating current by changing the position of the opposite poles
- it's the generator most used in industrial processes

2.4. Electrical power plants

Types of electrical power plants (*centrales eléctricas*):
- Thermal power plant: energy released from combustion of fuel
- Nuclear power plant: energy released from nuclear fission reactions
- Geothermal power plant: thermal energy from Earth is used (geothermal gradient)
- Hydroelectrical power plant: mechanical energy from water
- Solar power plant (also called solar park): electromagnetic energy from Sun
- Aeolian power plant (windmills): mechanical energy from wind
- Tidal power plants (*mareomotriz*): mechanical energy from tides



2.5. How do we use electrical energy

In the city: Electrical energy into light and mechanical energy (lamp posts, traffic lights, road barriers, parking meters).

At home: Electrical energy into mechanical, thermal, light, sound...
Domestic white goods:
- microwave
- oven
- dishwasher
- washing machine, tumble dryer
- hob/aga
- blender
- hoover (vacuum cleaner)

White goods= domestic appliances=Mod cons (informal, modern conveniences)

Other household electrical devices: lamps, radio, TV, computer...

Power (potencia)

P=energy (work done) per unit of time

$$P = \underbrace{V \cdot Q/t}_{} \longrightarrow \text{Energy/time (J/s)}$$

$$P = V \cdot I$$

S.I. unit= Watt (vatio)

where:
Q is electric charge in coulombs
t is time in seconds
I is electric current in amperes
V is electric potential or voltage in volts

In electrical companies, they measure electricity usage with a unit they have made up:

kW·h

e.g. a radiator of 1000W on for 1 hour consumes 1kW·h

3. Sources of energy

Sun: provides energy to ecosystems (where fossil fuels were originally produced)

Fossil fuels: coal, oil and natural gas (methane
- Coal: dead plants in swamp that with time, temperature and pressure became mineralised
- Oil and gas: dead microorganisms (plants and animals) that once buried and with time, temperature and pressure produce hydrocarbons

Renewable resource: is a natural resource which can be used repeatedly and replaced naturally at human time scale. In other words (Wikipedia's words...), a natural resource which replenishes to overcome resource depletion caused by usage and consumption, either through biological reproduction or other naturally recurring processes in a finite amount of time in a human time scale.

Non-renewable resource (finite resource):
is a resource that does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time-frames.

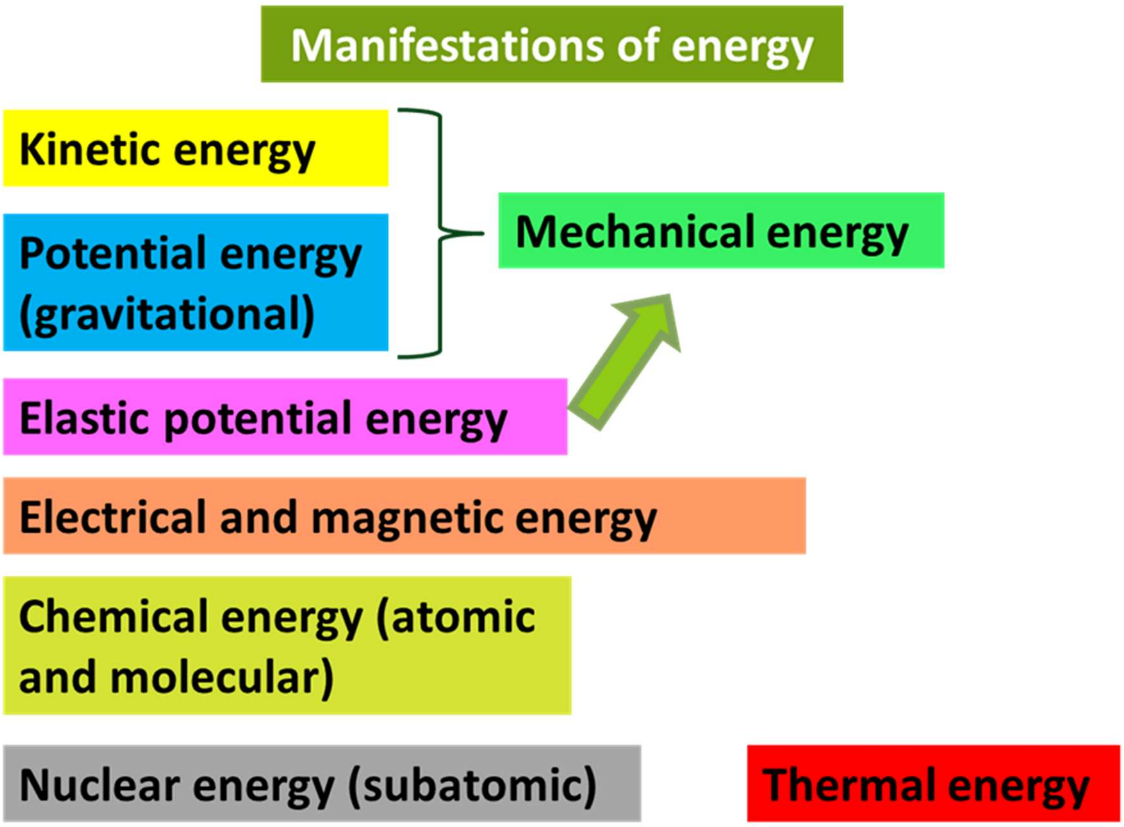
Renewable resources	Non-renewable resources
Sun's radiation	Fossil fuels (coal, oil, natural gas)
Hydraulic energy	Nuclear energy
Tidal energy	
Wave energy	
Biomass	
Geothermal energy	
Aeolian (wind) energy	

A certain resource may become non-renewable if it's exploitation is not sustainable at a human time scale (e.g. wood, freshwater).

4. Work and machines

4.1. Mechanical energy, work and machines

Work: Energy transferred when a force is applied to produce movement or deformation.



4.1.1. Kinetic energy (*energía cinética*)

Energy that a body possesses due to its motion

It can be represented both as Ec or Ek

$$Ec = \frac{1}{2}\, mv^2$$

where:

m=mass of the object
v=velocity of the object

4.1.2. Potential gravitational energy (energía potencial gravitatoria)

The energy associated with gravitational force that an object has for being at a certain height (from Earth's surface).

$$Ep = mgh$$

where:

m=mass of the object
g=gravitational acceleration=a
h=heigth of the object

As long as an object is on Earth, it will have some Gravitational Potential Energy (mechanical energy) ---To simplify, we consider that any object on the ground has Ep=0

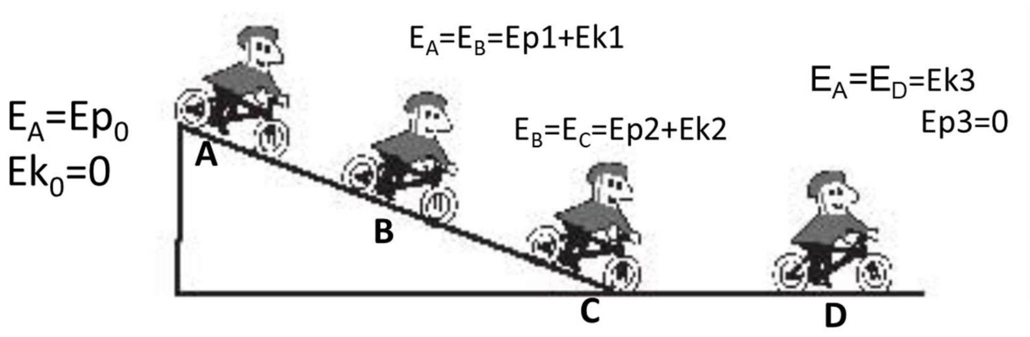
4.1.3. Mechanical energy

It's the combination of kinetic and potential energy in an object.

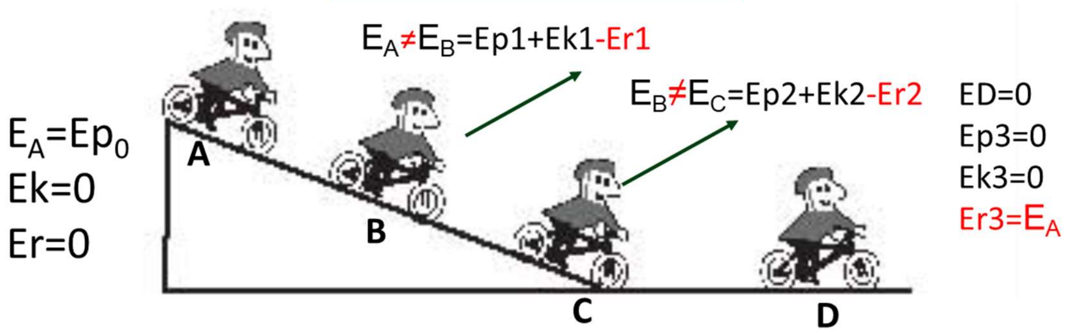
Mechanical energy (E)= Ep+Ek

In an object that moves from a higher position to a lower position, the potential energy will transform into kinetic energy. The mechanical energy will be conserved if there is not friction and the only elements considered are the mass of the object, the height at which it is at a precise moment and the velocity at which it moves. If there is friction, some of the energy will be "lost" from the object to the medium.

NO Friction: $E=Ep+Ek$



Friction: $E=Ep+Ek-Er$



Base sketch modified from Vílchez-González, 2015.

4.2. Types of machines

Work: exchange of mechanical energy (movement or deformation) → **Machines transfer energy as work**

$$W=F\cdot d$$

Where:
W=work in J
F= force (N)
d= distance (m)

$$P=W/t$$

Where:
P=power (potencia) in W (watts)
W= work (J)
t= time (s)

A body/machine can do work, but they can't have work nor store it, it's not energy!

Machines: devices in which transfers of mechanical energy happen amongst its elements

Machines change forces (their direction and/or their value) in order to make our life easier

Simple machines	**Compound machines**
One or few elements combined	**Simple machines combined with other elements**

4.3. Simple machines

- Inclined plane *(plano inclinado)*
- Wedge *(cuña)*
- Wheel and barrow *(torno)*
- Screw *(tornillo)*

4.4. Simple machines: levers

The elements of a lever are a fulcrum and an arm.

- Effort (potencia o esfuerzo): input force
- Resistance (resistencia): output force
- Load (carga): the object that we need to move
- Fulcrum (fulcro, punto de apoyo): support point, still

There are three classes of levers (géneros de palancas) depending on where the fulcrum, effort and load are in the machine:

- Class 1. Effort-Fulcrum-Load. Example: scissors (tijeras)
- Class 2. Effort-Load-Fulcrum. Examples: nutcracker (cascanueces), wheel barrow (carretilla)
- Class 3. Fulcrum-Effort-Load. Examples: stapler, chinese sticks

4.5. Simple machines: pulleys

A pulley is a machine formed by a round wheel and a rope that facilitate lifting weights.

There are two types of single pulleys:

- Fixed single pulley: the effort needed to lift the object is the same that without the pulley, but the movement is easier

- Moveable single pulley: the effort needed to lift the object is half the weight but the length of rope needed is double.

4.6. Compound machines: *polipastos* (combined pulleys) and engines

4.6.1. Combined pulleys

A combined pulley (polipasto en español) is a combination of several single pulleys (moveable and fixed) that makes it easier to lift a weight (load).

With just 2 pulleys (one moveable and one fixed), the effort is the same than with a mobile pulley (although easier to pull).

The more pulleys you combine, the less the effort you need to lift the load.In a 4 pulley machine, the input force will be a fourth of the output one.

Examples of combined pulleys used in daily life: bike gears, crane, lift.

4.6.2. Engines

An engine is an autonomous machine that uses some kind of fuel or electricity to transform energy into mechanical energy (work), such as coal, oil, gas, other chemical fuels or electricity.

Heat engine: thermal machine that develops work by transferring thermal energy from a warm source to a cold sink. The first ones to be used where the steam machines (steam ships, steam trains).

Reverse heat engine (refrigeration machines): thermal machines that needs work to transfer thermal energy from a cold source to a warm reservoir

5. Light and sound

5.1. Light and sound as energy transfers in wave form

Light and sound are energy transmitted through waves, which means that energy is transported, but not matter.

A sudden input of energy in a system (disturbance) on a specific spot (focus) can propagate as a wave.

Waves have the following characteristics:
- Amplitude (*amplitud*).
The amplitude, a, of a wave is the distance from the centre line (or the still position) to the top of a crest or to the bottom of a trough. Be careful with this quantity - the centre line is not always given in a diagram. Amplitude is measured in metres (m).
The greater the amplitude of a wave then the more energy it is carrying.

- Wavelength (*longitud de onda*)

The wavelength of a wave (λ) is the distance between a point on one wave and the same point on the next wave (in meters). It is often easiest to measure this from the crest of one wave to the crest of the next wave, but it doesn't matter where as long as it is the same point in each wave.

Frequency (*frecuencia*):

The Frequency (f) of a wave is the number of waves produced by a source each second.

Frequency is measured in Hz (hertzs) (*herzios*)

Velocity

The velocity of a wave (v) indicates how far the wave travels in a certain time, and it is measured in m/s.

All the electromagnetic waves (including light) travel at 300,000,000 m/s (3 x 108 m/s).

However, sound, that is a mechanical wave, travels at about 340 m/s.

Period (período)

The period of a wave (P) is the time for a particle on a medium to make one complete cycle of wavelength, in seconds.

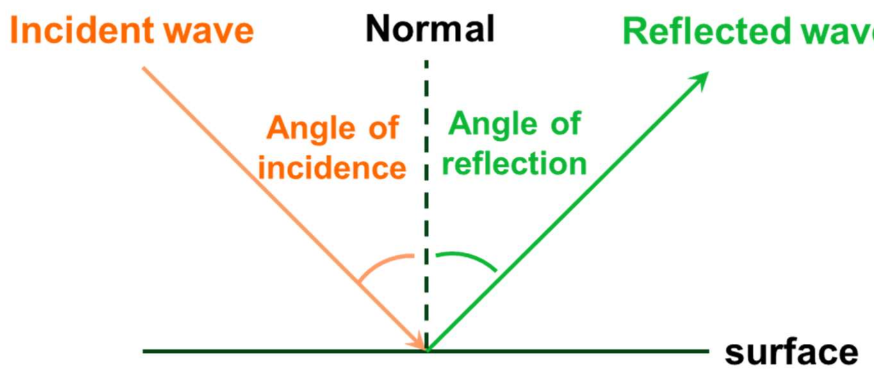
$$\text{period} = \frac{1}{\text{frequency}} \qquad \text{frequency} = \frac{1}{\text{period}} \qquad \boxed{1\text{Hz} = \frac{1}{s}}$$

Relation between frequency, wavelength and velocity of propagation

$$\boxed{\lambda(m) = \frac{v\ (\mathrm{m/s})}{f\ (1/s)}}$$

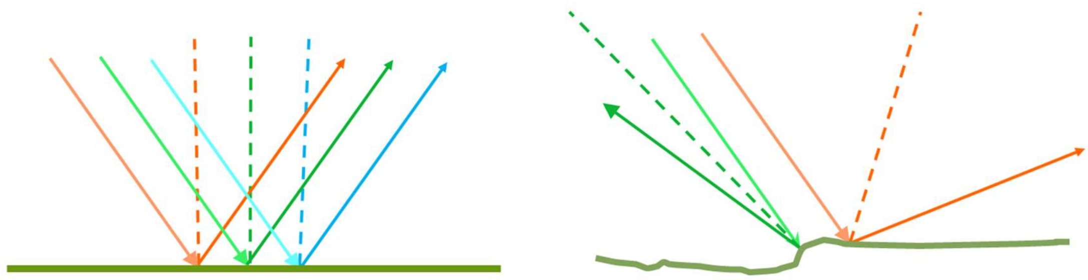
5.2. Reflection and refraction of waves

Reflection: a phenomenon that takes place when a wave incides on a surface



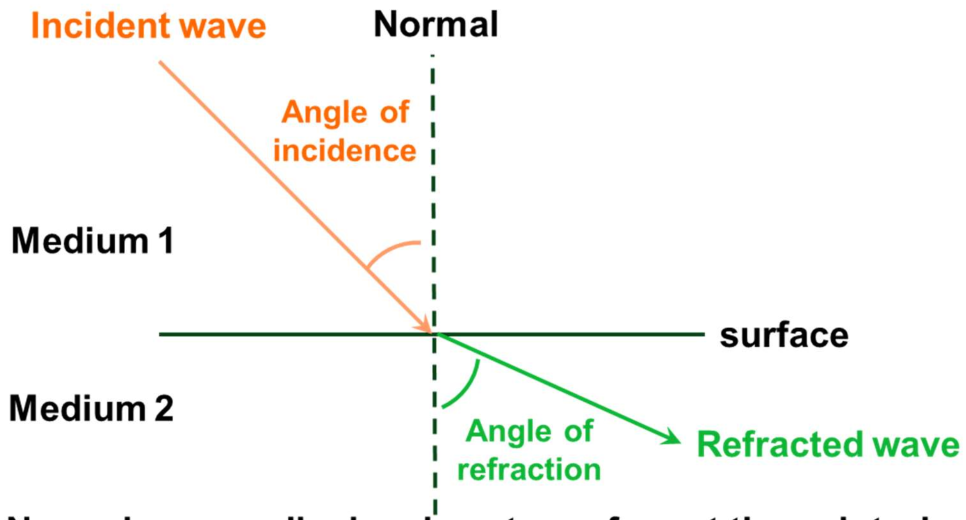
Normal: perpendicular plane to surface at the point where the wave incides

Reflexion laws:
1) The incident wave, the normal and the reflected wave are on the same plane
2) The incidence and reflection angles are always the same



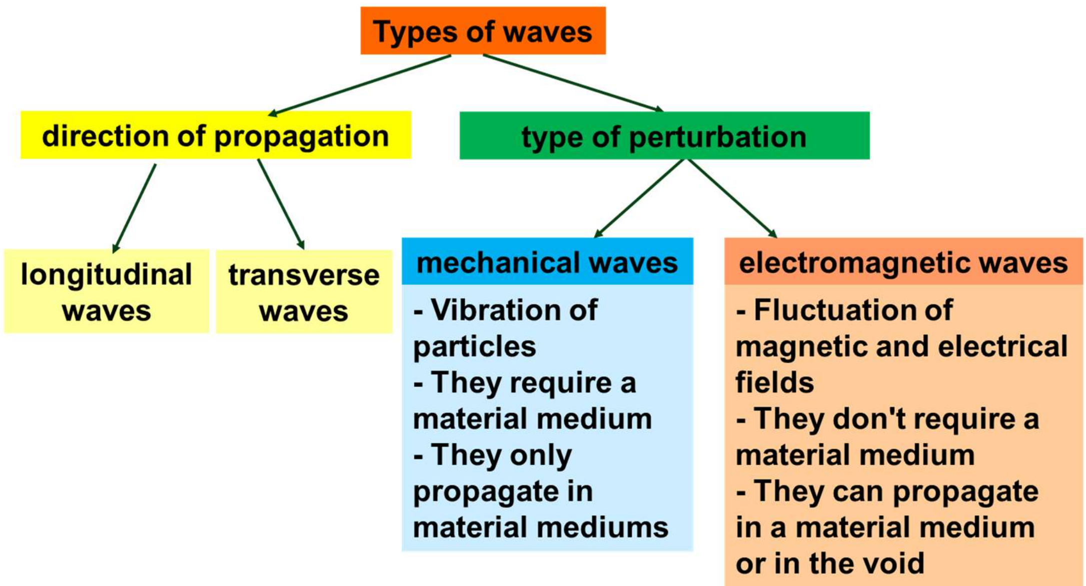
Remember: the key is that the normal is always 90º with the surface where the wave incides

Refraction: a phenomenon that takes place when a wave changes between mediums of different densities



Normal: perpendicular plane to surface at the point where the wave incides

Waves can be of different types:



Depending on the direction of propagation, we can have:
- Longitudinal waves: they propagate because of the compression and dilation of particles in matter in a longitudinal direction. This is how sound propagates.
- Transverse waves: they propagate because of undulating movements that are lateral (transverse) to the direction of propagarion. This is how light propagates.

5.3. Sound as a wave. Interaction of sound with matter

Sound, as other mechanical waves (sea waves, seismic waves):
- Propagates through vibration of particles
- Requires a material medium to propagate (sound can't be hear in outer space)

Each particle moves, transferring the energy to the next one

Characteristics of sound:
- Volume or loudness (*volumen*)=sound intensity (depends on amplitude)
- Pitch *(tono, nota musical)*=depends on frequency
- Quality or Timbre (*timbre*) =same sound, depends on source (different instruments playing the same musical note)

Noise is a sound in which several waves interfere.

We only hear it if the reflected wave takes more than 0.1 s to reach our ear (depends on distance). Bats and ship/submarines sonars use echo to locate near objects (collocation).

Reverberation is a multiple echo, it happens if the reflecting wall is less than 34 m far and if walls don't absorb the waves.

Sound	
Previous conception	**Correct idea**
Sound is considered "noise"	Sound propagates through harmonic waves, while the waves of noise are compound of smaller ones
Voice, the best known source for sound, but no knowledge about how it is produced	Students need to learn how the voice is produced in the larynx
Sound identified by its source (emission) and its effects (detection)	Sound is a wave, so appart from the source and the detector, the wave itself needs to be taken into consideration
Sound is not identified as the propagation of a perturbation	Students need to learn what kind of perturbation (mechanical) produces the sound waves
Sound is not thought of as a propagation of waves	Students need to learn how sound is the longitudinal propagation of a wave

5.4. Light as a wave. Interaction of light with matter

Electromagnetic waves, that include light:
- Are formed by fluctuation of magnetic and electrical fields
- They don't require a material medium
- They can propagate in a material medium or in the void (and in outer space)

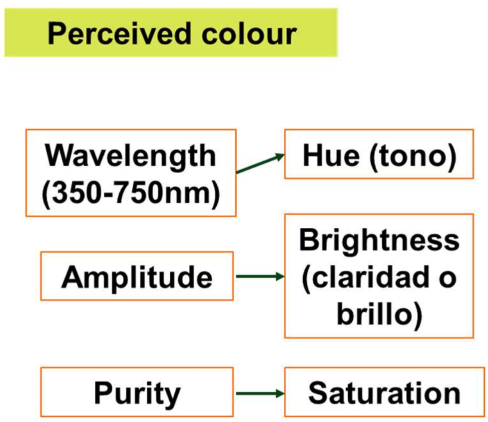
Two different transverse waves that travel together, perpendicular to each other, one corresponding to an electrical field and another corresponding to a magnetic field.

Electromagnetic waves with long wavelengths have low frequencies, so they have low energy. The type of electromagnetic wave and its potential uses its determined by its wavelength.

Examples of electromagnetic waves:
- radio
- microwave
- infrared
- visible light
- ultraviolet
- X-ray
- gamma ray

The human eye can only perceive the visible light range of wavelengths, which goes approximatedly from 350-750nm.

We can talk about colour from an objective point of view (Spectral colour, an objective measurement of the wavelength of colour) or from our perception point of view.



Sun emmits white light, that includes all wavelengths that we can see. When we see a colour in an object, it is because the object is absorbing all the colours (wavelengths) except the one we see.

Light can suffer reflexion and difraction as any other wave. If we use a prism, we can divide a white light, through refraction, into all the different wavelengths (colours) that it has. We can also use difraction as a way of separating white light into its components, using a spectroscope.

REFERENCES:
Vílchez- González, J.M. (Coord.). 2015. Didáctica de las Ciencias para Educación Primaria. I. Ciencias del espacio y de la tierra. Editorial Pirámide, 248pp.