DIDACTICS OF EXPERIMENTAL SCIENCES 1: PHYSICS, CHEMISTRY AND GEOLOGY

Topic 2. Matter and its transformations.

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0. Glossary

English term	**Pronunciation**	**Spanish term**	
Alloy	/ˈælɔɪ/	Aleación	
Amount	/əˈmaʊnt/	Cantidad	
Atom	/ˈætəm/	Átomo	
Balance	/ˈbæl.əns/	Equilibrio	
Beaker	/ˈbiː.kər/	Matraz de precipitación	
Boiling point	/ˈbɔɪ.lɪŋ/ /pɔɪnt/	Punto de ebullición	
Brightness	/braɪtnəs/	Brillo	
Brittle	/ˈbrɪt.əl/	Rígido, frágil	
Buoyancy	/ˈbɔɪənsi/	Flotabilidad	
Chemical equation	/ˈkem.ɪ.kəl/ /ɪˈkweɪ.ʒən/	Ecuación química	
Combustion	/kəmˈbʌstʃən/	Combustión	
Compound	/ˈkɒmpaʊnd/	Compuesto	
Density	/ˈdensɪti/	Densidad	
Elastic	/iˈlæs.tɪk/	Elástico	
Element	/ˈelɪmənt/	Elemento	
Flammable substance	/ˈflæm.ə.bəl/	Combustible	
Force	/fɔːs/	Fuerza	
Fossil fuel	/ˈfɒs.əl/ /ˈfjuː.əl/	Combustibles fósiles	
Friction force	/ˈfrɪk.ʃən/ /fɔːs/	Fuerza de rozamiento	
Gas	/gæs/	Gas, o gasolina (USA)	
Hardness	/ˈhɑrdnəs/	Dureza	
Height	/haɪt/	Altura, alto	
Inertia	/ɪˈnɜː.ʃə/	Inercia	
Length	/leŋθ/	Longitud	
Filtration	/fɪlˈtreɪ.ʃən/	Filtracion	
Magnitude	/ˈmægnɪtjuːd/	Magnitud	
Mass	/mæs/	Masa	
Matter	/ˈmætər/	Materia	
Measurement	/ˈmeʒəmənt/	Medida	
Measuring cylinder	/ˈmeʒ.ərɪŋ/ /ˈsɪl.ɪn.dər/	Probeta	
Melting point	/ˈmel.tɪŋ/ /pɔɪnt/	Punto de fusión	
Mixture	/ˈmɪkstʃər/	Mezcla	
Molecule	/ˈmɒlɪkjuːl/	Molécula	
Oil	/ɔɪl/	Aceite/ Petróleo	
Plastic	/ˈplæs.tɪk/	Plástico	
Pressure	/ˈpreʃər/	Presión	
Properties	/ˈprɒpətis/	Propiedades	
Product	/ˈprɒd.ʌkt/	Producto	
Reactant	/riˈæk.tənt/	Reactivo	
Scale/scales	/skeɪl/	Balanza	
State	/steɪt/	Estado	
Sedimentation	/ˈsed.ɪ.mənteɪʃən/	Sedimentación	
Settling	/ˈsetlɪŋ/	Decantación	
Specific	/spəˈsɪfɪk/	Específico/a	
Speed	/spiːd/	Velocidad numérica	
Stoichiometric coefficient	/ˌstɔɪkɪəˈmɛtrɪk/ /ˌkəʊ.ɪˈfɪʃ.ənt/	Coeficiente estequiométrico	
Sublimation point	/ˌsʌblɪˈmeɪʃən/ /pɔɪnt/	Punto de sublimación	
Substance	/ˈsʌbstəns/	Sustancia	
Temperature	/ˈtemprətʃər/	Temperatura	
Test tube	/test/ /tʃuːb/	Tubo de ensayo, probeta	
Time	/taɪm/	Tiempo	
Unit	/ˈjuːnɪt/	Unidad	
Velocity	/vəˈlɒs.ə.ti/	Velocidad (vector)	

Volume	/ˈvɒljuːm/	Volumen	
Weight	/weɪt/	Peso	
To weigh	/weɪ/	Pesar	
Width	/wɪtθ/	Ancho	

1. Matter

1.1. General properties of matter.

Definition of matter: Matter is everything that has mass and volume. It makes up all types of different materials (substances) found in the universe.

Matter exists in three different states: solid, liquid and gas.

Solids and liquids have a fixed volume, but gases can be compressed (their volume can be reduced). Liquids and gases do not have a fixed shape and can flow.

General properties of matter:

Defined as qualities that exist in all types of matter: mass and volume.
- mass (m): the quantity of matter in an object.
- volume (V): the amount of space that an object occupies.

Specific properties:
Defined as qualities that characterise a substance and differenciate if from other substances.
- density (d): mass/volume of an object. Unit: kg/l
- colour
- shape
- texture
- hardness
- brightness...

1.2. Measuring matter

The properties of matter that can be measured are called physical magnitudes.
- Fundamental magnitudes: Not obtained from others (mass, length, width, height, time...).
- Derived magnitudes: Can be obtained from others (e.g. surface: lenght x width; speed: lenght/time; volume: surface x height) and their units are also derived from the fundamental ones (e.g. surface unit is m^2).

To measure: to find the size, weight, amount, or speed of something (after Cambridge Dictionary). In science, to measure is to compare the amount of a certain magnitude in an object with a reference unit for that same magnitude and to to obtain a value.

There is an international agreement to use always the same reference unit for each magnitude. This is established by the International System of Units (SI, from the French). By using this system, the scientific comunity ensures that everyone uses the same reference value.

Each unit has multiples and submultiples. Its multiples and submultiples go from 10 to 10. You must be familiar with those multiples and submultiples for the seven fundamental magnitudes.

Example: The unit of length in SI is the metre (m).
Submultiples are the mm (milimiter=0.001 metre), cm (centimetre=0.01 metre) and dm (decimetre=0.1 metre).
Multiples are the dam (decametre=10 metre), hm (hectometre=100 metre) and km (kilometre=1000 metre).

Magnitude (English)	**Magnitud (Spanish)**	**Symbol of magnitude**	**SI Unit**
Mass	Masa	m	kilogram (kg) *kilogramo*
Length	Longitud	L	metre (m) metro
Time	Tiempo	t	second (s) segundo
Temperature	Temperature	T	Kelvin degree (K) Grados Kelvin
Electric current intensity	Intensidad de corriente eléctrica	I	Ampere (A) Amperio
Luminous intensity	Intensidad luminosa	Iv	candle (cd) *candela*
Amount of substance	Cantidad de sustancia	mol	mole mol

In the case of derived magnitudes, the multiples and submultiples may change differently. For example, in the case of surface area, the unit is the square metre (m^2) and the multiples and submultiples go from 100 to 100 (dam^2=100 m^2).

Direct measurements: Made directly with an instrument. Example: measuring lenght and width of an A4 with a ruler

Indirect measurements: Obtained mathematically from calculations using data form direct measurements. Example: calculating the surface of an A4 by multiplying lenght by width.

1.2.1. Measuring mass

Mass (m): the quantity/amount of matter in an object.

Unit in the SI: grams (kg).

Instrument to measure mass: scale (different types)

Confusion between mass (m) and weight (w): The mass of an object does not change. It is always the same, on Earth, on the Moon, anywhere. However, the weight depends on the gravity of the planet we are. The gravity is the stregth with which the planet attracts us to it.

On Earth, our mass is very similar to our weight. On the Moon, however, our mass is the same, but our weight is lower, as there is less gravity.

1.2.2. Measuring volume

Volume (V): the amount of space that and object occupies.

Unit in the SI: m^3 (cubic metre). Another unit, litre (l), is often used for volume (1l= 1dm^3)

Instrument to measure volume: containers like beakers, measuring cylinders, test tubes or meassuring cups.

1.2.3. Measuring density

Density has to be measured indirectly, by measuring first the mass and the volume, and then calculating it.

$$\text{Density (d)} = \frac{\text{mass (m)}}{\text{volume (V)}}$$

Unit: kg/m^3

Another unit, equivalent, is g/cm^3

An object floats when its density is lower than the density of water (buoyancy), and it floats when it is higher.

1.3. Structure and classification of matter.

1.3.1. Atomic and molecular structure of matter.

All matter, organic and inorganic, is formed by atoms. We are formed by atoms, like a table or a plant.

Atoms and molecules form substances (different types of matter

Atom: the smallest unit that an element can be divided into.
Atoms are formed by protons, neutrons and electrons. The number of protons of the atoms forming an element characterises an element.
Element: a substance formed by the same type of atoms.

All the elements that exist in nature can be found in the periodic table.

When two or more atoms are combined, they form a molecule. A molecule is therefore a chemical combination (binding) of two or more atoms of the same (e.g. O_2) or different elements (e.g. water, H_2O).

1.3.2. Classification of mater in pure substances and mixtures.

Pure substance: Matter formed by the same kind of particles.

Simple, pure substance: All the particules are atoms or molecules of the same element. Examples: oxygen (O_2), hidrogen (H_2), iron (Fe).

Compound, pure substance: All the particules are the same type of chemical molecules formed by atoms of different elements. Examples: water (H_2O), carbon dioxide (CO_2), salt (NaCl), sulphuric acid (H_2SO_4)

Mixture: Matter formed by two or more pure substances (different types of molecules).
- Homogeneous mixture: the individual substances can not be seen with the naked eye.
    - Solutions: liquid+solid, liquid+gas (e.g. water and salt (H_2O+NaCl))
    - Gas mixtures: gas+gas (e.g. air (N_2+O_2+Ar)
    - Alloys: two or more metals (steal (Fe+C))

- Heterogeneous mixture: visible components. Examples: mud (water and sediment), granite (quartz, feldspar and micah), dried fruts (peanuts, pistachios, almonds).

Mixtures have specific properties different from the properties of their components. That is why it is useful to separate the components of mixtures to study them.

1.4. Separation of mixtures

Mixture of solids and liquids
- Filtration/filtering: using a filter, where the solid particles will be trapped
- Sedimentation and settling/decantation: leaving the mixture at rest for a certain time, and solid particles will fall to the bottom.
- Evaporation: with time, the liquid will evaporate
- *Crystallisation: the solid particles chemically precipitate, forming crystals. Ex. water and salt. Most of the times, it is linked to evaporation.*
- Distillation: evaporation+condensation of the liquid, separating it from the solid substance.

Mixture of solids
- Sublimation
- Sieving (extraction)
- Magnetic Separation

Mixture of liquids
- Distillation: using different temperatures (boiling points) to evaporate two liquids
- Fractional Distillation: same thing but in more steps
- Gravity/density Separation: one of the liquids is more dense than the other, we leave them at rest and they will naturally separate (oil and water)

2. Changes in matter. Types.

Matter exists in three different states: solid, liquid and gas.

Changes in matter can be:

- physical: new substances do not appear (the chemical composition is not altered). Examples: changes of state, movements (forces), magnetic atraction...

- chemical: new substances appear (chemical reactions, the chemical composition is altered). Examples: oxidation of iron; changes within living cells.

- nuclear: the changes happen within the atoms, in their core. They are important for energy obtention. Examples: hydrogen atoms that combine with each other to form helium.

3. Physical changes

Physical changes can affect the specific properties or the state of a substance, but new substances do not appear (the chemical composition is not altered).

There are two main factors that may produce physical changes:

1) Temperature:

- Changes of state: substances can change their physical state (solid, liquid or gas) when cooled down or heated up.

- Expansion: many materials increase in volume when they are heated up.

2) Forces:

- Changes in movement: materials can change their position or the way they move when a force acts upon them.

- Deformations: materials can change shape when a force acts upon them. These changes can be temporary or permanent.

3.1. Physical changes: Changes of state

Matter exists in three different states: solid, liquid and gas.

Changes of state (also called phase) are physical changes caused by changes in temperature that lead matter to change from one state to another.

- Temperature of change from solid to liquid state: melting point
- Temperature of change from liquid to gas state: boiling point
- Temperature of change from solid to gas: sublimation point

The difference between evaporation and boiling is that evaporation only happens on the surface of the liquid, so it can happen at different temperatures. However, the boiling point is when all of the liquid is changed into gas, and the boiling point for each liquid is defined by a specific pressure and temperature.

3.2. Kinetic theory of mater

All particles have energy, and the energy varies depending on the temperature at which the sample of matter is in. This temperature determines if the substance is a solid, liquid, or gas. A change in state (phase) may occur when the energy of the particles is changed (temperature).

The temperature of a substance is a measure of the average kinetic energy of the particles (kinetic=movement).

Solid particles have the least amount of energy, and gas particles have the greatest amount of energy.

There are spaces between particles of matter. The average amount of empty space between molecules gets progressively larger as a sample of matter changes from solid to liquid and to gas states.

These ideas lead to the kinetic-molecular theory:
1) Matter is constituted by particles (atoms, molecules) that depending on the state of the body (solid, liquid or gas), will be or not be organised, and will sometimes be together, sometimes separated.
2) Particules within matter are in constant movement
3) Temperature is the manifestation of this movement

3.3. Solid state

Solid matter has a constant mass and volume. The particles are close to each other, so solids can not be compressed easily. This means that solid particles are organised geometrically, forming a structure. Most solids present a crystalline network (atoms are bound to each other forming a geometric design), but there are also amorphous solids (like glass or plastic) that do not have a crystalline structure, although their particles are still organised.

Solid particles have the least amount of kinetic energy and therefore, of movement. The particles have a very small range of vibration in their fixed positions, so solids can not be easily compressed.

As mentioned before, change in state (phase) may occur when the energy of the particles is changed (temperature).

When a solid body is heated, kinetic energy is transmitted to the particles. The particles vibrate faster, up to the point that they can get out of their fixed vibration position and intermolecular forces holding together the structure are weakened, so the solid becomes a liquid. This is called the melting point.

3.4. Liquid state

Liquid matter has a constant mass and volume as well, but not a constant shape. Liquids are able to flow. As mentioned above, the average amount of empty space between molecules gets progressively larger as a sample of matter changes from solid to liquid state.

This means that the particles in a liquid, although being organised in space, have more freedom of movement relative to each other, so they are slightly more separated than in the solid state and have a higher kinetic energy.

Evaporation affects only the topmost surface of the liquid. Those particles that have a higher kinetic energy can overcome the intermolecular forces and change to the gas state. For the whole liquid to become a gas, energy from the environment is needed (an increase in temperature).

Vaporisation (at boiling point) means the nearly complete breakage of the bounds among the liquid particles in order to become a gas, so the temperature (energy) needed for this change of state is higher than the one needed to change from solid to liquid.

3.5. Gas state

Solid particles have the least amount of energy, and gas particles have the greatest amount of energy. This means that the spaces between particles of matter in gas state are the largest.

The gas particles are in constant movement, very fast and in a random fashion. There are large empty spaces among them, and this is why gasses can be compressed.

Gas adopts the volume and shape of the container.

When a gas is contained in a recipient, its particles collide with the recipient. The force exerted by these collisions against the recipient is what we perceive as the gas pressure. If a gas is not contained, it can theoretically expand to an infinite volume.

Within a recipient, pressure increases with:
- the number of molecules colliding with the recipient (the amount of gas)
- the increase of energy (speed of movement) in the molecules (increase of temperature):

$e_c = A \cdot T$

e_c= average kinetic energy in gas particles
A= constant
T= temperature in Kelvin degrees

If two gases are at the same temperature, their molecules will have the same average kinetic energy.

If T=0ºK (-273ºC), the energy will be 0, meaning the particles are not moving. This is the lowest possible temperature.

3.6. Physical changes: Forces and their effects

Definition of force: interaction between bodies that produces a change in the movement or in the shape of a body (any cause that has an effect).

Forces are represented as arrows (vectors) that indicate where they act, in which direction and sense, and their intensity.

There are:
- contact forces: when contact between bodies is necessary to exert force.
- non-contact force: when no contact between bodies is necessary to exert force.

Most of the forces we can observe in our daily life are contact forces, except from gravitational forces (responsible for weight of bodies) and electromagnetic ones (responsible for electrical and magnetic phenomena).

Friction is the contact force in action when we rub two surfaces, and it always acts in the direction opposite to movement.

When several forces are applied upon a body, the effect will be that resulting of the combination of all of them (a force called *resultant force*).
Gravitational force depends on the mass of the objects attracted to each other and the distance between them. On Earth, gravity

3.6.1. Changes in movement

Materials can change their position or the way they move when a force acts upon them.

- Forces can make a body at rest start moving
- Forces can increase or decrease the speed of a body in motion
- Forces can change the direction of movement of a body in motion
- Forces can keep or break the balance (equilibrium state) between two bodies

3.6.2. Changes in shape

Materials can change shape when a force acts upon them.

These changes can be temporary or permanent, depending on the nature of the material.

Temporary changes happen to elastic materials. These materials are deformed by the force but recover their original shape once the force is removed.

Permanent changes happen to plastic and brittle materials. Plastic materials are deformed when the force is exerted, but they don't recover their original shape when the force is removed. Brittle materials break when we apply force to them.

3.6.3. Newton's Laws of motion

Forces and their effects are studied through Newton's Laws (1687).

1st Law: The law of inertia

- An object either remains at rest or continues to move at a constant velocity, unless acted upon by a force. This can only happen when there is no friction force (only under vacuum)

2nd Law: The basic law of dynamics

- When a force is exerted on a body, the body will acquire acceleration, either if it is at rest or moving.

The sum of the forces upon an object is equal to the mass (m) of that object multiplied by the acceleration (a) of the object: $F = m \cdot a$.

Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

3rd Law: The law of action and reaction

- When one body exerts a force (action) on a second body, the second body simultaneously exerts a force (reaction) equal in magnitude and opposite in direction on the first body.

4. Chemical changes

Changes in matter are chemical when new substances appear (chemical reactions, the chemical composition is altered). Examples: oxidation of iron; changes within living cells.

A chemical change is also called a chemical reaction.

As it was explained before:

- Pure substance: Matter formed by the same kind of particles.

- Simple, pure substance: All the particules are atoms or molecules of the same element. Examples: oxygen (O2), hidrogen (H2), iron (Fe).

- Compound, pure substance: All the particules are the same type of chemical molecules formed by atoms of different elements. Examples: water (H2O), carbon dioxide (CO2), salt (NaCl), sulphuric acid (H2SO4).

4.1. Equations and chemical formulae. Meaning.

There are two ways of naming a pure substance: its nomenclature or its chemical formula (plural=formulae).

Nomenclature: carbon dioxide
Formula: CO_2

The formula give us information not only about the elements forming the substance (carbon and oxygen), but also about the structure of its particles (there are two atoms of oxygen bound to one atom of carbon in each molecule of carbon dioxide)

In a chemical reaction, initial substances (reactants) are transformed into final substances (products). Atoms are rearranged, so chemical reactions are usually balanced, meaning that the total number of atoms is the same in both reactants and products. What changes is how the atoms of an element bounds to others, therefore, the molecules will change, but not the atoms.

Law of mass conservation: mass of reactants=mass of products.

The numbers we use to adjust (or balance) the molecules in a chemical reaction are called **stoichiometric coefficients**.

Ex. **2**H_2 + O_2 ---------> **2**H_2O

Reactants:
H_2= molecules of hydrogen in gas state
O_2= molecules of oxygen in gas state

Products:
H_2O= molecules of water

A molecule of water has two atoms of hydrogen per atom of oxygen.

In order to form 2 molecules of water, we need 2 molecules of hydrogen for each molecule of oxygen.

If we changed the reaction like this:

H_2 + O_2 ---------> H_2O

for the reaction to be balanced, we would need to add one O to the products, and oxygen atoms are not present as single atoms in nature, just as O_2.

Easy ways of balancing a chemical equation

- Using drawings of the atoms and molecules

- Using a table representing the number of atoms (reactants vs. products)

4.2. Oxidation and combustion reactions

Oxidation: chemical reaction that happens when a substance reacts with oxygen. It can take place within cells.

An oxyde is a compound formed by an element and oxygen.

Example: iron oxyde

Fe + O2 ---------> Fe2O3 (non balanced)

4Fe + O2 ---------> 2Fe2O3 (balanced)

Combustion: sudden and violent oxydation that liberates a large amount of energy (a flame).

Example: Methane+ oxygen ----> carbon dioxide +water

CH_4+ O_2 ----> CO_2 + H_2O (non balanced)

The substance that reacts with the oxygen in a combustion reaction is called a flammable substance or a combustible substance. Do not confuse this term with 'fuel', which is applied to flammable substances used specifically for the purpose of obtaining heat or other kind of energy.

4.3. Fermentation reactions

Fermentation: natural reaction usually induced by bacteria or yeast that transforms sugar in alcohol and carbon dioxide.

Sugar---> Alcohol (ethanol)+ CO_2

Sugar is the general term for a family of organic compounds, carbohydrates (C,H and O). The most usual sugar is sacarose, but the most important from the biological point of view is glucose ($C_6H_{12}O_6$).

Alcohol is the general term for a family of organic compounds (C,H and OH) simpler than the sugar compounds, that include ethanol and methanol. The most common alcohol is ethanol (or ethilic alcohol) (C_2H_5OH).

Anaerobic fermentation (in a non-oxygenated environment) is used to make wine. As CO_2 is produced, ventilation is crucial in wine cellars.

If oxydation takes place right after fermentation, we will obtain vinegar instead.

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