Explainer: Chemical Analysis

In this explainer, we will learn how to identify and describe the different types of chemical analysis and explain their importance in scientific fields.

In every branch or field of chemistry, it is important to identify and quantify the substances in a material or mixture. The substance being identified and/or quantified is called the analyte.

Definition: Analyte

The analyte is the substance in the sample that is being investigated.

Here are some examples of scientists and science professionals determining the composition of different chemical substances:

- Doctors, pharmacists, and chemists analyze what compounds are present in a medicine and in what amounts or concentrations. Medical health professionals also analyze the composition of blood and bodily fluids to diagnose different illnesses. Doctors can, for example, analyze the content of lipids in blood samples to determine if a patient will develop a cardiovascular disease and to determine if the patient needs to take any medication.
- Farmers and soil scientists analyze the properties of farmable soil. Soils can differ in many ways, and farmers need to understand a particular soil's elemental composition and acidity or basicity. This helps farmers to choose the best fertilizers for their fields.
- Food chemists and nutritionists analyze the composition of foods to determine what nutrients they contain and in what proportions.
- Environmental chemists study environmental materials such as soils, gases, and bodies of water to determine if pollutants are present and in what proportions. They analyze toxic substances like carbon monoxide and sulfur dioxide gases and heavy metals such as arsenic and mercury, and they even analyze pesticide and herbicide contamination of foodstuffs.
- Mechanical engineers and metallurgists investigate the metals and chemical compounds that are present in ores and in machinery components. This helps them to improve the strength of machines and improve metal extraction processes.

Example 1: Identifying Which Scientific Field Analyzes Levels of Glucose in the Human Body

Chemical analysis can be used to determine the amount of glucose present in a person. In which scientific field is this analysis important?

A. Environmental

B. Agricultural

C. Industrial

D. Food chemistry

E. Medical

Answer

Glucose levels in a person's body, for example blood glucose levels, are important in maintaining optimal health. Analysis of the amount of glucose present in blood is important in the medical field. The correct answer is E: medical.

A chemical sample is a small and easy-to-handle quantity of a bulk material. Samples are always made to be reasonable mimics of the bulk materials they represent. The sample and bulk material should have the same, or essentially the same, physical and chemical properties.

Definition: Sample

A sample is a limited quantity of a material which is intended to be similar to and represent that material.

Chemical samples can be analyzed with qualitative or quantitative analysis techniques. Qualitative chemical analysis techniques are used to determine the identity of a substance or substances in a chemical sample.

Qualitative Analysis

Qualitative analysis methods are used to identify substances in chemical samples.

The sample is defined as being pure if it contains a single chemical substance. The sample is defined as being a mixture if it contains more than one chemical substance. Most solid materials, liquids, and gases can be classed as mixtures, because they are made up of at least two different chemical substances. Qualitative analysis methods can be used to determine what substances have combined together to make a mixture. The components can be elements, such as nitrogen, or compounds, such as water and carbon dioxide. Many real-life mixtures (like soil, air, or blood) are complex mixtures that contain lots of different component elements and molecules.

Sample	Components
Table salt	Na^+ ions and Cl^- ions
Polluted air	N_2, O_2, H_2O, and CO_2 and small amounts of Ar, NO, NO_x gases, and CO, etc.
Blood	Red blood cells, H_2O, white blood cells, platelets, cell components, hormones, Na^+, Cl^-, Mg^{2+}, $Ca^{2+}$and various other ions, sugar ($C_6H_{12}O_6$), CO_2, urea, cholesterol, and many other substances
Oranges	Citric acid, H_2O, sugars (sucrose, fructose, and glucose), vitamin E, D, K, C, and many other compounds, such as limonene, octanal, ethyl butanoate, decanal, hexanal, (S)-linalool, hydrocarbons, alcohols, aldehydes, and esters

Pure samples have a set of unique chemical and physical properties that distinguishes them from other substances. Physical constants such as the melting point, boiling point, solubility, and molar mass can be used to determine if a known substance is pure or contaminated with impurities.

Chemists could use the known boiling point of water molecules to determine if a sample of water is contaminated with impurities. Pure water boils at a temperature of 100°C if the pressure is exactly equal to one atmosphere (atm). Contaminated samples of water boil at a slightly higher temperature, because they contain chemical impurities. Samples of water can be boiled to determine if they are pure or if they contain chemical impurities.

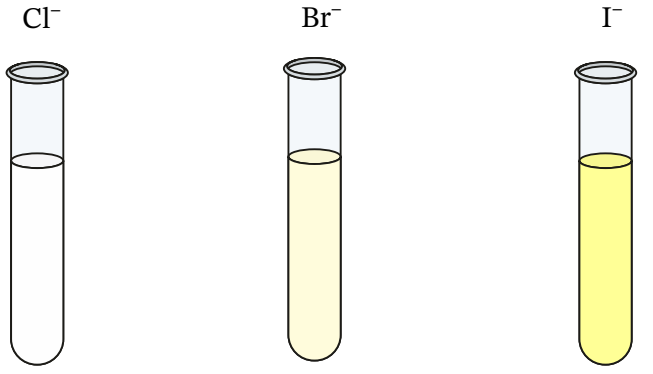
Chemists can also use the known molar mass values of organic compounds to determine the composition of a plant extract. Mass spectrometers provide information about the molar masses of different analytes. Molar mass information from mass spectrometers can be compared with reference data to determine the content of a plant extract.

Silver nitrate can be used to test for the presence of most halide salts, because silver ions form a colored precipitate when they react with chloride, bromide, or iodide ions. Silver nitrate forms a white precipitate when it reacts with chloride ions. Silver nitrate forms white-yellow and yellow precipitates when it reacts with bromide and iodide ions. The equation below explains the reaction that occurs between chloride ions and silver nitrate.

$$\underset{\text{Halide ion}}{Cl^-(aq)} + \underset{\text{Silver nitrate}}{AgNO_3(aq)} \longrightarrow \underset{\text{White precipitate}}{AgCl(s)} + \underset{\text{Nitrate ion}}{NO_3^-(aq)}$$

The following table and figure explain the reactions between silver nitrate and fluoride, chloride, bromide, and iodide ions.

Ion Present	Observation
F^-	No precipitate
Cl^-	White precipitate
Br^-	White-yellow precipitate
I^-	Yellow precipitate



White Precipitate AgCl(s)

White-yellow Precipitate AgBr(s)

Yellow Precipitate AgI(s)

Chemists are sometimes uncertain about the chemical composition of food products, and they want to know if food items contain starch molecules. Yellow-brown droplets of iodine solution can be added to food samples to determine if they contain any starch molecules. The iodine droplets leave blue-black blemishes on food products if they contain starch. The following image shows how iodine droplets can be used to test for the presence of starch molecules in a sample of a food product.

Single tests can be inconclusive, and we usually need to perform at least two different chemical tests to determine the identity or quantity of a substance in a sample. The limitations of single chemical tests can be understood by considering how metals can yield similar-colored flames in flame tests.

Lithium, calcium, and strontium metals all yield red flames in flame tests. Single flame tests cannot be used to determine if a sample contains lithium, because calcium and strontium metals produce similar flame colors. The flame test has to be combined with another form of chemical analysis to confirm that a substance contains lithium and not calcium or strontium metals.

Example 2: Identifying the Statement That Does Not Describe Qualitative Analysis

Which of the following is **not** an example of qualitative chemical analysis?

A. Identifying the functional group in a molecule
B. Identifying the cationic groups in a compound
C. Identifying the anionic groups in a compound
D. Determining the concentration of a compound in a solution
E. Determining the elemental composition of a molecule

Answer

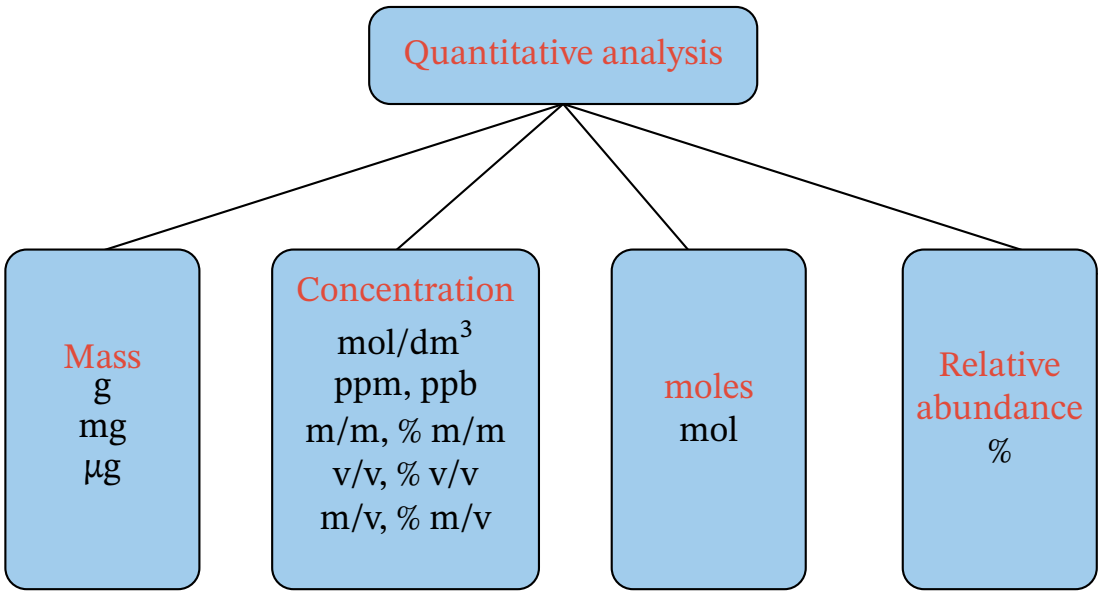
Qualitative analysis is the identification of the constituent substance or substances (elements, ions, compounds, or the functional groups in a compound) in a sample. According to this definition, we can rule out options A, B, C, and E which all refer to identifying parts of a compound. Answer D is not an example of qualitative chemical analysis but rather quantitative chemical analysis, since concentration can be quantified. Concentration can be measured and expressed in different units such as moles per liter. We can use these statements to determine that option D is the correct answer for this question.

Analytical chemists usually want to know the content and composition of a chemical substance. They want to know what a substance contains and in what proportions. Quantitative chemical analysis techniques can be used to study the abundances of elements and compounds in chemical samples.

Definition: Quantitative Analysis

Quantitative analysis techniques are used to determine the abundances of elements and compounds in chemical samples.

The following figure shows some units that are used to describe the abundance of elements and molecules in chemical samples. The figure shows that abundances can be expressed as mass and concentration values or mole and percentage composition numbers.



The analytical balance or scale is used by almost all analytical chemists to determine the masses of different chemical substances. Most analytical balances are incredibly precise machines, and they usually show mass values to the nearest 0.1, 0.01, or even 0.001 milligrams (mg).

Quantitative analysis techniques can help chemists to determine the amount of a substance in a chemical sample and to determine how much desirable chemical product will be produced during a chemical reaction.

There are many ways to analyze the content and composition of a chemical sample. The following table summarizes some of the most important tests for analyzing chemical samples.

Name of Test	How it Works	Purpose	Example of Its Use
Volumetric analysis	The amount of a substance is determined by measuring its volume or by measuring the volume of a second substance that reacts with it.	To determine the unknown concentration of a known reactant	To identify the concentration of contaminants in acid rain or wastewater
Gravimetric analysis	Various methods can be used to quantify an analyte based on its mass.	To quantify the amount of an analyte in a chemical substance	To determine the content of a cation in a sulfate salt
Combustion analysis	An unknown pure compound is reacted with oxygen, and the combustion products are measured.	To determine the empirical formula and abundance of a pure organic compound	To determine the quantity of nitrogen in animal feed
Flame test	A Bunsen burner flame changes color in the presence of certain ions.	To determine the identity of a metal element	To test whether sodium is present in a soil sample
Gas test	Various chemical tests can be performed to determine the identity of an unknown gas.	To confirm the presence or absence of gaseous chemical elements and compounds	To determine if a sample contains carbon dioxide gas by bubbling it through limewater
Precipitation reactions	Two soluble salts are reacted in a solution, and an insoluble product forms.	To identify the presence of a compound, or part of a compound, based on its ability to form a conspicuous insoluble product	To identify the presence of a halide in a salt

Mathematics can be applied to determine the uncertainty associated with measured chemical values. Statistical methods show that measured values are more accurate if more measurements are made of any one chemical quantity. Chemists usually do not make one measurement of some unknown chemical quantity. Chemists repeatedly measure the same chemical quantity to determine a more accurate average value. Comparisons can also be made with reference data to ensure that a chemical quantity was measured accurately.

Example 3: Determining If Chemical Tests Are Quantitative or Qualitative Tests

A chemist finds an unlabeled salt solution and attempts to determine its composition and properties.

1. The chemist adds a few drops of $AgNO_3$ to a sample of the salt solution to see if a precipitate forms, indicating the presence of a halide group. Is this a qualitative or a quantitative test?
   A. Qualitative
   B. Quantitative
2. The chemist finds that a precipitate is formed upon the addition of $AgNO_3$. They filter, dry, and weigh the precipitate and use it to determine the mass of the salt in the solution. Is this a qualitative or a quantitative test?
   A. Quantitative
   B. Qualitative

Answer

Part 1

$AgNO_3$ can be added to a sample to confirm the presence or absence of a halide ion. No measurement is being made, and no quantity is being defined. The test is not a quantitative test. The correct answer is a qualitative test. We can use these statements to determine that option A is the correct answer for this question.

Part 2

This is a quantitative test, because a measurement is being made. We can use this statement to determine that option A is the correct answer for this question.

Example 4: Understanding the Difference between Qualitative and Quantitative Analysis

Chemical analysis can be split into two types: qualitative and quantitative. Which statement best describes the difference between them?

A. Qualitative analysis aims to identify the composition of a substance, whereas quantitative analysis aims to determine the mass, percentage composition, or concentration of a substance.

B. Qualitative analysis can be used to identify the cation in a compound, whereas quantitative analysis can be used to identify the anion in a compound.

C. Qualitative analysis is used when the sample is a solid, whereas quantitative analysis is used when the sample is an aqueous solution.

D. Qualitative analysis aims to identify the chemical properties of a substance, whereas quantitative analysis aims to identify the physical properties.

E. Qualitative analysis aims to determine the mass, percentage composition, or concentration of a substance, whereas quantitative analysis aims to identify the composition of a substance.

Answer

Qualitative analysis is the identification of the constituent substance or substances (elements, ions, compounds, or the functional groups in an organic compound) in a sample, while quantitative analysis is the determination of the amount or quantity of each constituent present in a sample. Statement A, "qualitative analysis aims to identify the composition of a substance, whereas quantitative analysis aims to determine the mass, percentage composition, or concentration of a substance," is correct.

Key Points

- The analyte is the substance in the sample that is being investigated.
- A sample is a small and easy-to-handle quantity of a bulk material. Samples have the same physical and chemical properties as the source material.
- Pure samples have a set of unique chemical and physical properties that distinguishes them from other substances.
- Chemical analysis is carried out in many fields including the medical field, agriculture, the food industry, environmental studies, and engineering.
- Qualitative analysis methods are used to confirm the presence or absence of a substance in a chemical sample.

- Quantitative analysis techniques are used to determine the abundance of elements and compounds in chemical samples.