Theme 1: Metals and Non-metals

Prior Knowledge

It is recommended that you revise the following topics before you start working on these questions.

- Physical properties of metals and non-metals
- Chemical properties of metals and non-metals, reaction of an acid and base, weak/strong acids and bases, ignition temperature requirement for combustion
- Reactivity series, displacement reactions

Metals & Non-metals

Every element in the periodic table can be classified either as a metal or a non-metal. As you get familiar with the periodic table, you can simply look at it and tell which elements are metals and which are non-metals. Simplistically, we define those elements to be metals that are towards the left-hand columns of the periodic table, whereas non-metals populate the right-hand columns. What's the difference? As you dig deeper, you find that metals are those elements that are happy to donate electrons, whereas non-metals are eager to capture electrons, or at best share them! This makes chemistry a fascinating subject of give and take, and some sharing, which results in the formation of every single molecule and/ or compound known to us. Isn't it marvellous? A particle with a weak negative charge and virtually no mass is able to determine how different elements react with each other and form ALL the substances known to us.

Case Study A - Properties of Metals, Non-metals and their Oxides

Let us look at the effect of this difference in the affinity for electrons on the physical and chemical properties of the two types of elements. To look at the difference in their chemical properties, we will compare the oxides of metals and non-metals.

Question 1

Depending on the properties, metallic or non-metallic elements have different applications. Identify the objects from the list below which can be manufactured using either. Place compounds of non-metals, like hydrocarbons (materials like wood and plastic) or silicate (soil/sand), in the same category as non-metals while answering this question. Also assume that cost does not influence the decision.

1. Swings in playground
2. Spatula (used for serving/stirring food)
3. Furniture body
4. Cap (the lens on top) of an LED - see Fig. 1.1
5. Luggage handles

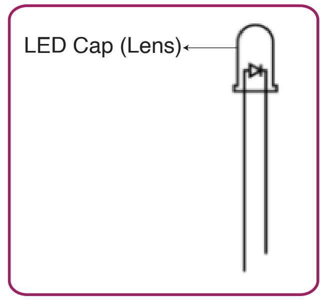


Fig. 1.1, Cap of an LED

a. All	b. All except 4	Answer
c. 2, 3, 5	d. 2, 3, 4, 5	

Question 2

A lab received samples of oxides of 4 different elements. Let us label the elements as E1, E2, E3 and E4. Water based solutions were prepared from these oxides. The chemical properties of the 4 oxides were not known, and hence a few tests were conducted using the solutions.

Turmeric happens to be a natural acid-base indicator as it changes its colour to vermilion (deep orangish-red) when exposed to a base. In an acidic environment, it remains yellow. When vermilion prepared by mixing turmeric with a base is exposed to an acid, its colour changes back to yellow. If the solution is basic, the colour of vermilion remains unchanged. With a neutral solution, neither turmeric nor vermilion changes colour.

Given below are the colours of the solutions after adding turmeric and vermilion respetively. For simplicity of representation, each solution is being referred to using the name of the element whose oxide was used to prepare the solution.

Solution	Colour after adding turmeric	Colour after adding vermilion
E1	yellow	yellow
E2	yellow	vermilion
E3	vermilion	vermilion
E4	vermilion	vermilion

Table 1.1, Solution colour

An observation table (like Table 1.1) may have entries of different types - {yellow, vermilion}, {vermilion, vermilion}, etc. What does an entry {yellow, vermilion} tell you about the pH of the solution? Write your answer in the box given below.

Answer

Question 3

Is there any colour combination which is not possible? Justify your answer with appropriate arguments. Write your answer in the box given below.

Answer

Question 4

Some solutions were now mixed with each other. Which reaction(s) can we predict, for sure, will produce water as one of its products?

a. E1 & E2	b. E2 & E3
c. E3 & E4	d. E4 & E1

Answer

Case Study B - Burning Metals

While burning firecrackers, we experience fire with multiple colours. One of the ways to achieve this is by mixing different metal powders while manufacturing the crackers. For instance, copper burns with a bright green colour and magnesium with a bright white colour. Let us dig deeper into this simple but enjoyable experiment with burning magnesium which can be easily performed in a lab or even at home.

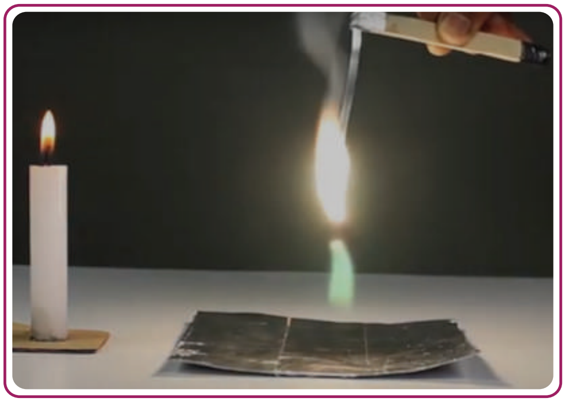


Fig. 1.2, Burning magnesium strip

Question 5

The lab that experimented with the oxides above explored the burning of magnesium. The group burnt a 10 cm long magnesium strip by placing it in a candle flame and recorded the time taken for the strip to catch fire as well as to burn fully. Later the strip was burnt by exposing it to another magnesium strip, which was already burning, and the two time values were recorded.

	Exposed to a candle flame			Exposed to a burning magnesium strip		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Time to catch fire (s)	14	12	15	2	1	2
Time to burn full strip (s)	8	7	9	8	8	7

Table 1.2, Time values

According to you, which of the following is the root cause of the behaviour seen in the first row of the observations above? Note that we often have one cause leading to an effect which causes another effect and so on. Root cause refers to the first cause.

a. The candle flame has less oxygen supply compared to the magnesium flame.

b. The rate at which a candle flame transfers heat is less than the rate at which it is transferred from the magnesium flame.

c. Temperature of the candle flame is lower than that of the magnesium flame.

d. As the candle wick burns, it produces CO_2, which keeps extinguishing the magnesium and hence it takes longer to catch fire.

Answer

Question 6

The lab conducted one more experiment to correlate the type of heat source and the time taken to catch fire. This time, magnesium strips were burnt by exposing some to an oil lamp's flame and others to a bunsen burner's flame. The average time to catch fire through an oil lamp was 13.5 seconds whereas that with a bunsen burner was 3.8 seconds. The people at the lab concluded that it would always take a longer time to catch fire from a wick based heat source.

Do you think the experiment would help them explain the behaviour seen in the first row of the observation table 1.2? Would you suggest any changes/additions to their experiment for them to find the root cause?

a. Yes; to find the root cause they should add water to the ashes produced by burning and verify that it is alkaline.

b. Yes; to find the root cause they should collect data from the other wick-based heat sources (like a spirit lamp) before concluding. Two data points are not sufficient.

c. No since there is nothing common between the heat sources used in the second experiment and those used in the first one; they should use one heat source where the fuel is a solid (like matchstick) as in the case of a candle (wax) and another where the fuel is a liquid (like oil).

d. No since changing the heat source is irrelevant; they should instead vary the length of the strip and observe the impact on the time taken to catch fire when exposed to a candle vs burning magnesium strip.

Answer

Question 7

When magnesium is burnt, it forms magnesium oxide (MgO). There are no other products of this reaction. The lab conducted another experiment where they placed three magnesium strips in one pan of a beam balance and balanced it by placing appropriate weight in the other pan. They then burnt these three strips, collected the ashes and placed them back to the beam balance and checked if the two pans were still balanced. What do you think they are trying to validate through their experiment?

a. Mass is conserved in any chemical reaction

b. Burning of magnesium is a combination reaction where the mass of the product will be greater than that of the reactants

c. When an object undergoes combustion, it loses mass

d. Magnesium oxide is basic

Answer

Case Study C - Reactivity Series

Not all metals react with oxygen, water or acids in the same manner. A displacement reaction helps to know which metal is more reactive among any two given metals. If metal X displaces metal Y from its solution then we conclude that X is more reactive than Y. Eg: if we add lead (Pb) to copper chloride ($CuCl_2$) solution, we get lead chloride ($PbCl_2$) solution, with precipitates of copper metal. Based on several such displacement reactions, a list of metals is developed in their decreasing order of reactivity, which is called the reactivity series.

Our lab received 4 different metals along with three metal salts. Each salt belonged to the sulphate group. The team at the lab named the metals M1, M2, M3 and M4. The salts belonged to M1, M3 and M4.

Question 8

Metal M3 is placed in an M4 salt solution. It is left undisturbed for sufficient time for the chemical reaction, if any, to happen.

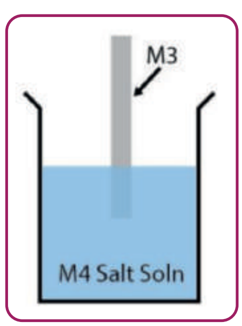


Fig. 1.3, Metal M3 placed in M4 salt solution to infer reactivity

The colour of metal and colour of solution is observed before and after reaction and tabulated as shown in Table 1.3.

Colour of metal (M3)		Colour of solution	
Before	**After**	**Before**	**After**
Silver	Silver	Blue	Blue

Table 1.3, Metal placed in salt solution

Which out of the options A to D can be inferred based on the observations in Table 1.3?

A. Metal M3 is more reactive than M4

B. Metal M4 is more reactive than M3

C. M3 is silver coloured

D. M3 salt solution has blue colour

a. A and C	b. B and C	Answer
c. C and D	d. D and A	

Question 9

The same experiment is repeated by placing metal M1 in M4 salt solution.

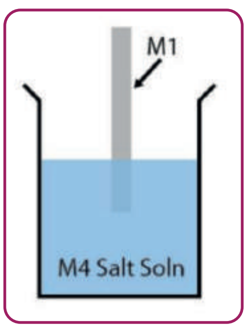


Fig. 1.4, Metal M1 placed in M4 salt solution to infer reactivity

Colour of metal (M1)		Colour of solution	
Before	**After**	**Before**	**After**
Silver	Part dipped in solution is coated with brown solid	Blue	Colourless

Table 1.4, Another metal placed in salt solution

Infer the colour of metal M4 and the salt solution of M1 based on the results tabulated in Table 1.4 and write your answer in the space provided.

Answer

Question 10

Now the metal M4 is placed in the colourless M3 salt solution. What will be the colour of the solution after the reaction (if any)?

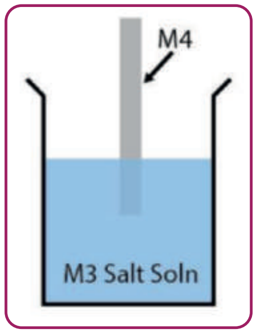


Fig. 1.5, Metal M4 placed in M3 salt solution to infer reactivity

Answer

Question 11

Table 1.6 shows the results of the experiment where metal M2 is placed in M1 salt solution.

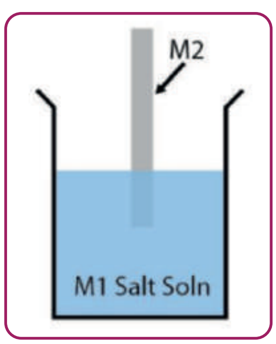


Fig. 1.6, Metal M2 placed in M1 salt solution to infer reactivity

Colour of metal (M2)		Colour of solution	
Before	**After**	**Before**	**After**
Grey	Part dipped in solution is coated with silver coloured crystals	Colourless	Colourless

Table 1.5, M2 placed in M1 salt solution

Combining the results tabulated in Table 1.3 to 1.5, infer the reactivity of metals M1 to M4 and place them in decreasing order of reactivity in the blanks below.

_______________ > _______________ > _______________ > _______________

Case Study D - Symbiotic Relationship

Symbiosis exhibits a win-win for two different living organisms. It is one of the extraordinary designs of nature which cannot be easily reproduced by humans but may get destroyed due to human activities. One of the examples is the impact on marine life known as Coral Bleaching.

Coral reefs, also known as the rainforests of the sea, occupy less than 1% of the ocean's floor space but are home to more than $1/4^{th}$ of the marine species. Corals are green in colour because they host the algae called *zooxanthellae*. Corals provide CO_2 and waste products that zooxanthellae use for photosynthesis and in return, provide oxygen and organic products of photosynthesis. The coral uses these compounds to synthesise calcium carbonate (limestone) which it uses to construct its skeleton - the coral reefs. The sybiotic relationship between corals and zooxanthellae can exist in a narrow band of environmental conditions which are getting disturbed due to multiple factors. Under negative environmental conditions, the corals consume or expel the zooxanthellae which give it the white colour which is called coral bleaching.

Question 12

The factors leading to coral bleaching include extreme water temperatures in the ocean, excessive fishing, changes in salinity, oil spilling, ocean acidification, etc. The graphs in Fig. 1.7 show a possible correlation between CO_2 levels in the atmosphere and the pH level of oceans. These graphs have been sourced from NOAA Pacific Environmental Laboratory (PMEL).

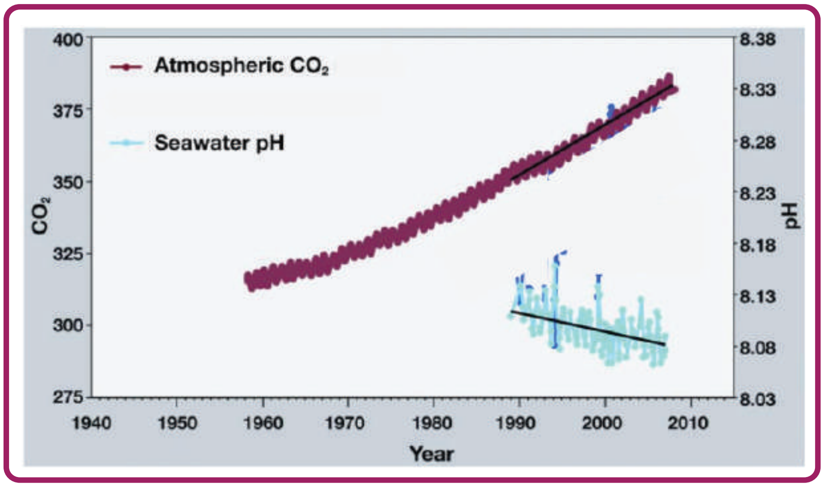


Fig 1.7, Graph correlating atmospheric CO_2 levels and pH level of oceans; via NOAA Pacific Marine Environmental Laboratory (PMEL), USA; graph edited to highlight relevant information

If a pH strip is dipped in a water sample collected from the ocean, which of the following colours is it most likely to show? Refer to the pH colour scale given in Fig. 1.8.

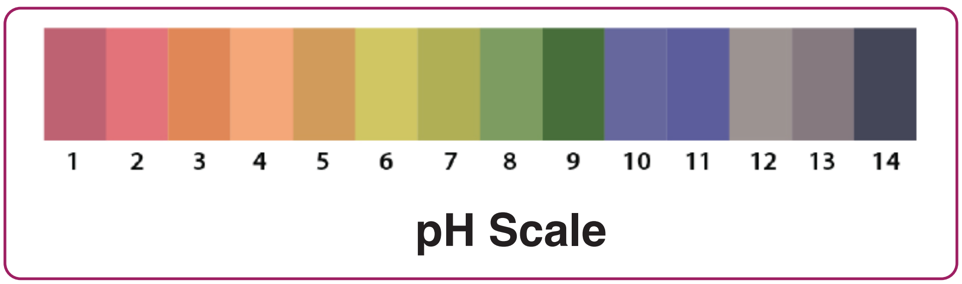


Fig. 1.8, pH colour scale

a. 

b. 

c. 

d. 

Answer

Question 13

The people at our lab were skeptical about the correlation drawn between the two data sets because of two reasons:

1. Carbonic acid is a weak acid.
2. Is the rate at which CO_2 would dissolve in water to form carbonic acid, high enough if water is just exposed to air?

Pursuing question number 2, they conducted an experiment where they placed 5 litres of distilled water in a wide mouth (3 feet diameter) container, exposed to open air and measured the pH after 24 hours for 2 weeks.

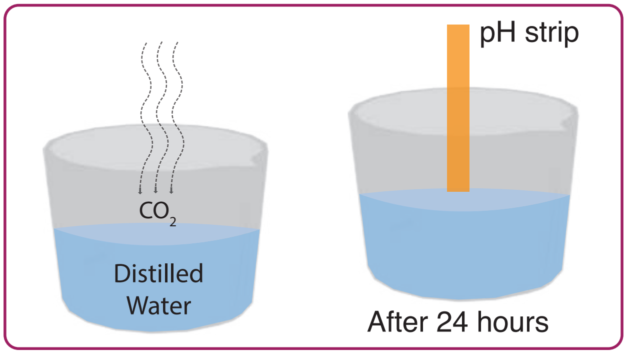


Fig. 1.9, Experiment setup to test impact of CO_2 on pH of water

Suggest changes to their experiment setup and process to make the experiment results more accurate and relevant for the question on which they are researching. You may select one or more than one from the following list.

a. Vary the geographic locations where the container is placed, especially to cover the geographic conditions under which coral reefs grow, and observe the pH of water every 24 hours for 2 weeks. Quantity of water and container size remain unchanged.

b. Vary the geographic conditions and at the same time, also vary the quantity of water to understand the impact on the concentration of the acid.

c. Add salt to match the salinity of water with that of the ocean and observe the solubility of salt in the water.

d. Repeat the same experiment at different times of the year to correlate the CO_2 levels in air with the water pH.

e. Blow CO_2 externally.

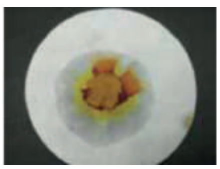
Answer

Exploration Pathway

To explore this theme in an experiential manner you may work on the following hands-on activities:

Matter - Electrical Conductivity

Electrical conductivity is the measure of the amount of electrical current a material can carry. A conductor is a material which allows current to flow through it easily whereas an insulator is a material which does not allow the flow of current through it. In this TACtivity, we will set up a circuit using AA cells and an LED, to test the electrical conductivity of different materials used in our daily life.



Acids-Bases - Turmeric Indicator

There are many wonderful natural acid-base indicators. One such ubiquitous food item in Indian households is turmeric powder. The dazzling yellow of turmeric turns a deep red when exposed to a basic/alkaline substance. However, it remains yellow if the test sample is neutral or acidic. The deep red powder created by exposing turmeric to a basic substance is nothing but vermilion, which is now your natural acid indicator, as it will turn back to yellow (turmeric) when exposed to an acidic solution, but will remain a deep red when exposed to a basic or neutral substance. Enjoy testing various household items, edible and non-edible, for their acidity or alkalinity!

Reaction - Magnesium and Oxygen

Most metals burn in oxygen, provided there's a high enough ignition temperature, with spectacularly coloured - often unique - flames to produce metal oxides, a classic chemical reaction. Here - using your own DIY Tweezers - we burn ribbons of magnesium, which happens to have a relatively low ignition temperature, and so possible to achieve with a candle flame. Enjoy the dazzling flames and test the "ash" that forms. Is there a difference between the mass of the initial ribbon and the ash it forms?

Reaction -Metal Reactivity Series

The ability of a metal to react with other chemicals is an important property of the metal and is called its Reactivity. In this TACtivity we take three metals - Copper, Iron and Magnesium - with different reactivities and test their behaviour by placing them in copper sulphate solution.

DIY Respirometer

Chemical reactions often create a change in colour. Here, we use a classic acid-base indicator to make a simple "respirometer", which can be used to estimate your metabolic rate as you blow into a solution of slaked lime.