Lesson 2: Colorimetry

*Read through the lesson notes. You can write them out, print them or save them.

*Once you have tried to understand the lesson answer the questions that follow and self-evaluate your work by checking the answers.

Learning Intentions

-Learn how to set up a colorimetric analysis.

-Learn about the applications of colorimetry in an analytical laboratory.

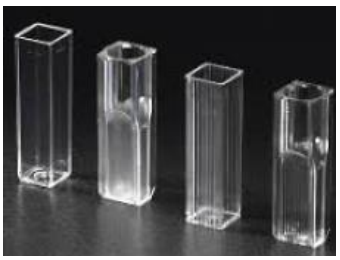
Background

Colorimetry uses the relationship between colour intensity of a solution and the concentration of the coloured species present. It is a useful technique as it determines the concentration of coloured compounds in solutions.

A solution will be coloured if it absorbs some, but not all, parts of the white light passing through it. Those parts that are not absorbed are transmitted through the solution and combine to give the colour we see. For example, if a solution absorbs the blue part of white light then the light that is transmitted appears yellow (complementary colour). While the colour of a solution depends on the colour of light it absorbs, the intensity of its colour depends on the concentration of the solution: the more concentrated the solution, the darker its colour, i.e. the more light it absorbs.

A colorimeter or spectrophotometer can be used to determine the concentrations of coloured substances in solution.

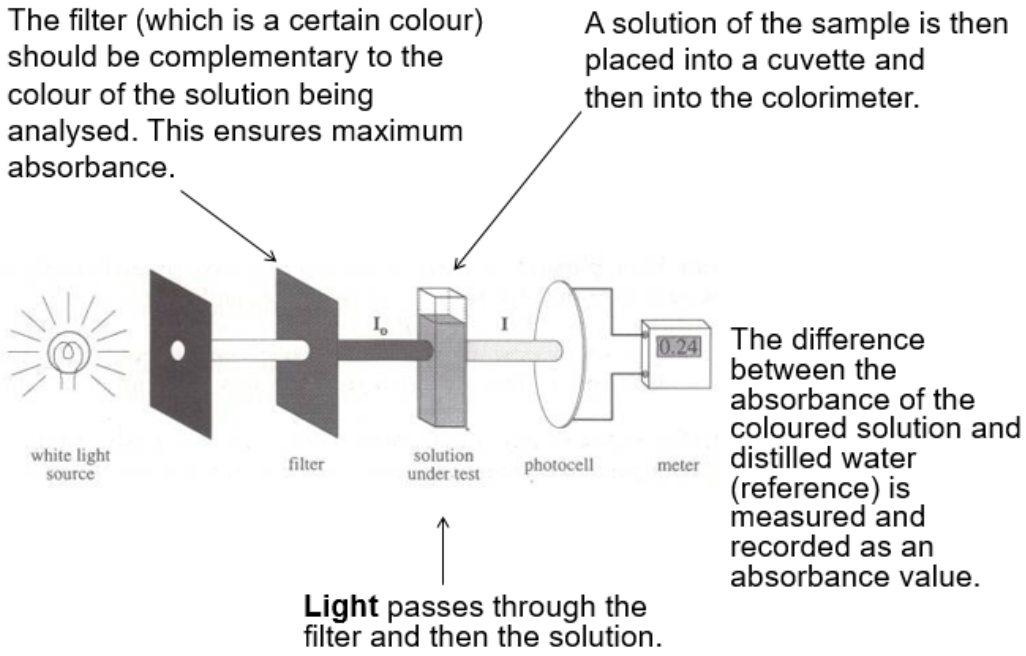
Cuvettes are small Perspex holders where the coloured samples are placed. One side is clear which faces the light source on the colorimeter. The other side of the cuvette is ribbed and this is used to pick up and place down.



Simple laboratory colorimeter prepared for analysing a series of coloured solutions.

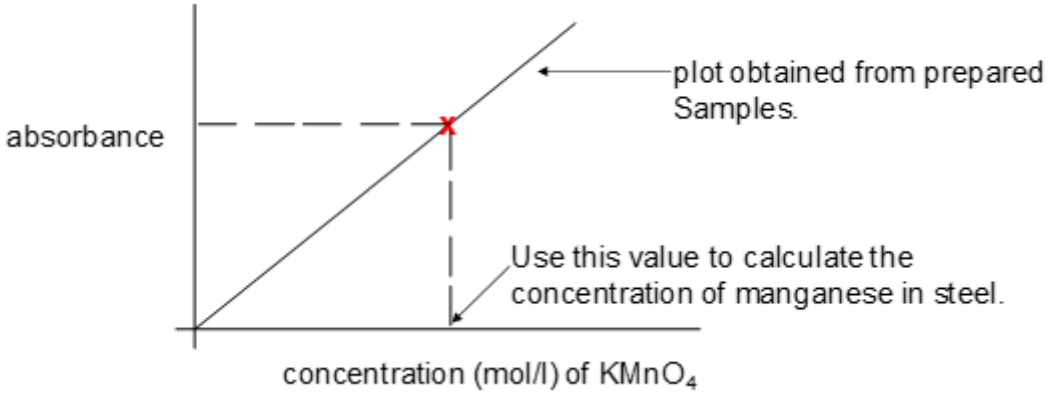
The colorimeter consists of a light source, coloured filter, light detector and recorder. Before any sample can be analysed, a reference or blank sample (normally distilled water) is analysed by the colorimeter. This should give a value of zero.

The colorimeter works in the following way:



For any colorimetric analysis, it is important to prepare a calibration graph. This is achieved by carefully preparing several samples from a standard solution (solution of known concentration). This is done by serial dilution. The absorbance of each of these samples is measured by the colorimeter. It is important that a wide range of concentrations from the serial dilutions are obtained as this will ensure covering the concentration of the unknown sample.

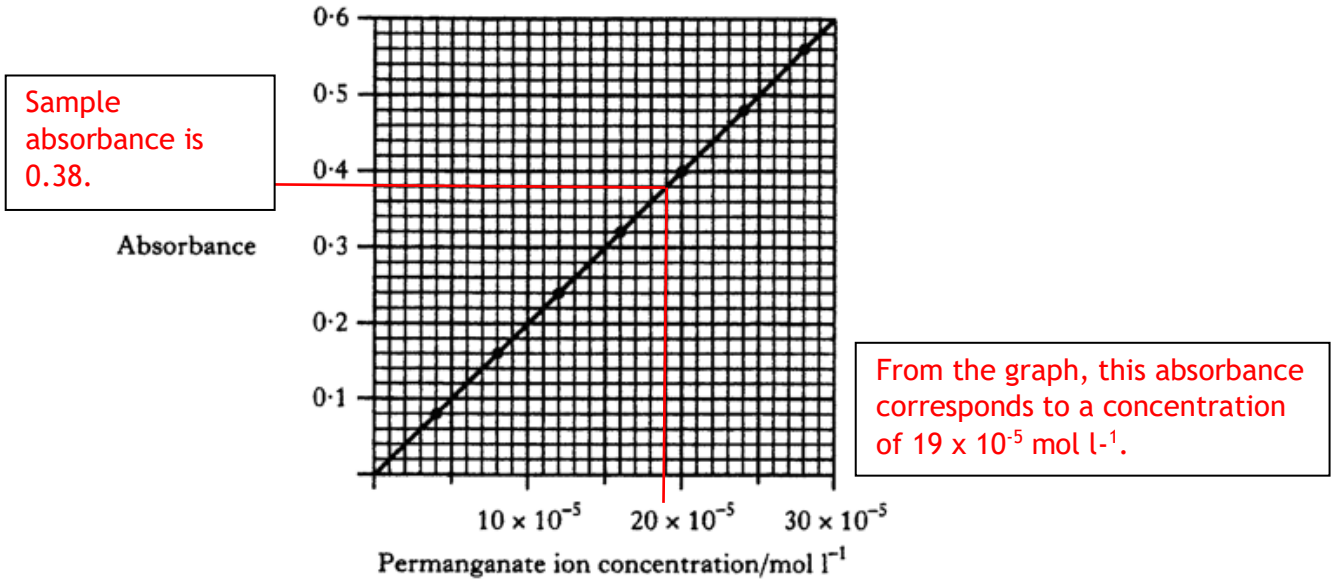
The concentration of the coloured species being tested must lie in the straight line section of the calibration graph e.g. determination of manganese in steel.



Worked Example

In a determination, the manganese in 0.302g of a piece of steel was oxidised to permanganate ions and the solution made up to 50cm^3 in a volumetric flask. The absorbance of the solution was measured as 0.38.

Use this information and the calibration graph below to calculate the percentage of manganese in the sample of steel.



n = c x v

n = (19 x 10^{-5}) x 0.05 (volume of volumetric flask)

n = 9.5 x 10^{-6} moles

Mass of manganese = n x GFM

Mass of manganese = 9.5 x 10^{-6} x 54.9

Mass of manganese = 5.22 x 10^{-4}g

$$\% \text{ manganese in steel sample} = \frac{5.22 \times 10^{-4}}{0.302} \times 100$$

% manganese in steel sample = 0.17%

→ Watch the clip on Youtube, https://www.youtube.com/watch?v=yrXZXGbg9KI

→ https://drive.google.com/file/d/1o1sHVGlnwGtYy5jsifgpFMKAC6dsFeJ-/view?usp=sharing

→ Read Scholar Heriot-Watt/ Researching Chemistry Section 6.1.

→ Read Bright Red Advanced Higher Textbook Page 88 and 89.

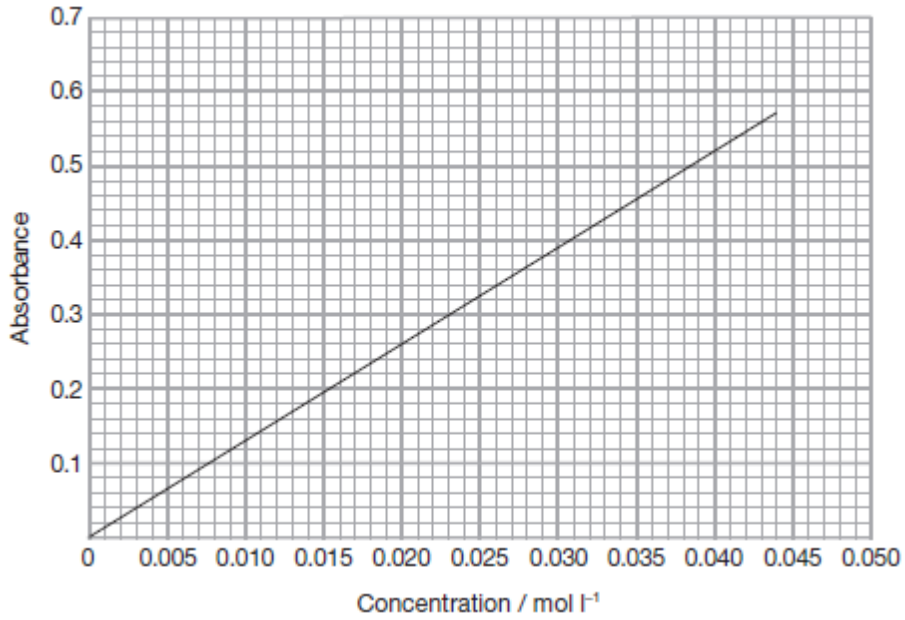
→ Answer the questions from Sheet 4.2 and check the answers when you have completed them.

4.2 Colorimetry

1. A steel nail weighing 0.847 g was analysed to estimate the percentage by mass of manganese present. The nail was first dissolved in acid to convert all the manganese to Mn^{2+} ions. The solution was then treated with a strong oxidising agent to convert the Mn^{2+} ions to permanganate ions, MnO_4^-. The entire solution was made up to 100 cm^3 in a standard flask using distilled water.

Firstly, the colorimeter was set up with a green filter and a blank sample to act as a reference. The second step was to obtain a calibration graph, shown below, from a standard solution of potassium permanganate.

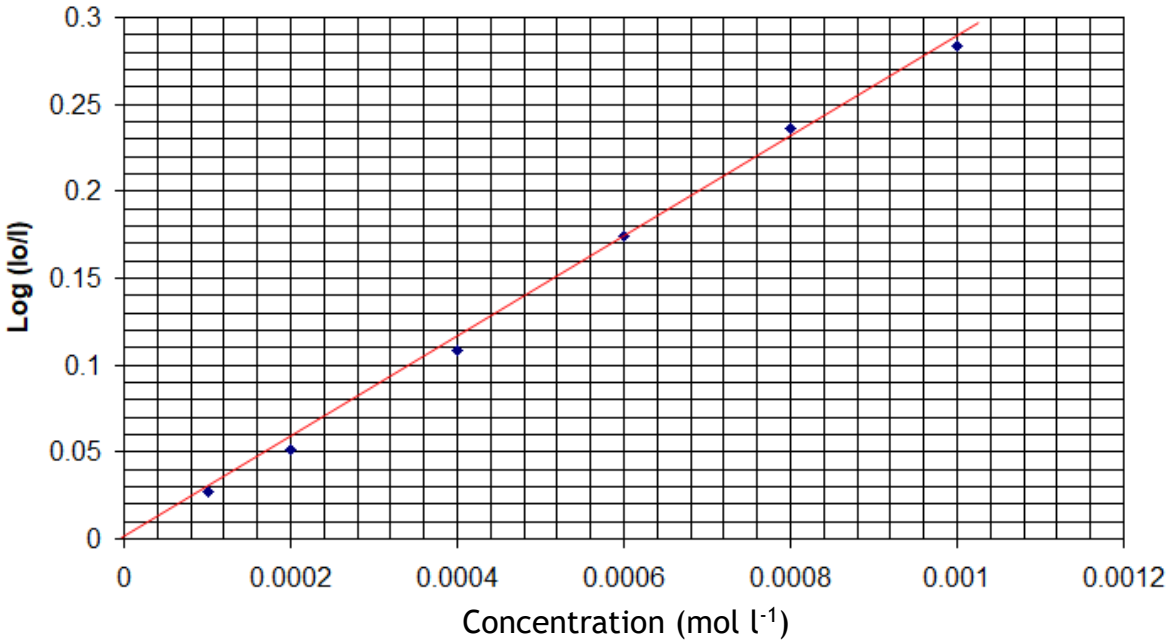
Finally, a sample of the permanganate solution obtained from treating the nail was analysed in the colorimeter and found to have an absorbance of 0.44.



a) Write the ion–electron equation for the oxidation of the manganese metal to manganese (II) ions.
b) Write the ion–electron equation for the oxidation of manganese (II) ions to permanganate ions. (Refer to the Data Book.)
c) Explain how the blank sample was set up to reference the colorimeter.
d) Explain why a green filter was chosen for this analysis.
e) Describe fully the procedure required to obtain results that would allow a calibration graph to be drawn.
f) From the calibration graph, obtain the concentration of the permanganate solution.
g) Calculate the mass of manganese in the nail.
h) Calculate the percentage, by mass, of manganese in the nail.

2. A sample of tea weighing 1.135 g was analysed to estimate the percentage by mass of iron present. The tea is roasted in a crucible and then reacted with nitric acid to produce iron (iii) nitrate. This is added to a 50 cm^3 standard flask and made up to the mark using distilled water.

Calibration graph made from a standard solution of Fe^{3+} ions.



A sample of the Fe^{3+} solution was analysed in the colorimeter and found to have an absorbance of 0.15.

a) Calculate the mass of iron, in mg, in the sample of tea.
b) Calculate the percentage mass of iron in the sample of tea.
c) A different brand of tea was found to contain 2.128 mg of iron. What absorbance value would be obtained when this tea sample undergoes the same procedure as above?

3. Small amounts of manganese are added to the aluminium used for drinks cans to improve their corrosion resistance. The technique of colorimetry can be used to determine the quantity of manganese in these alloys and involves converting the manganese to permanganate ions, MnO_4^-.

a) Describe how the technique of colorimetry can be used to determine the concentration of permanganate ions.

b) During colorimetric analysis, 0·35 g of an aluminium alloy was dissolved in nitric acid. The manganese in the resulting solution was oxidised and the solution was made up to 250 cm^3.

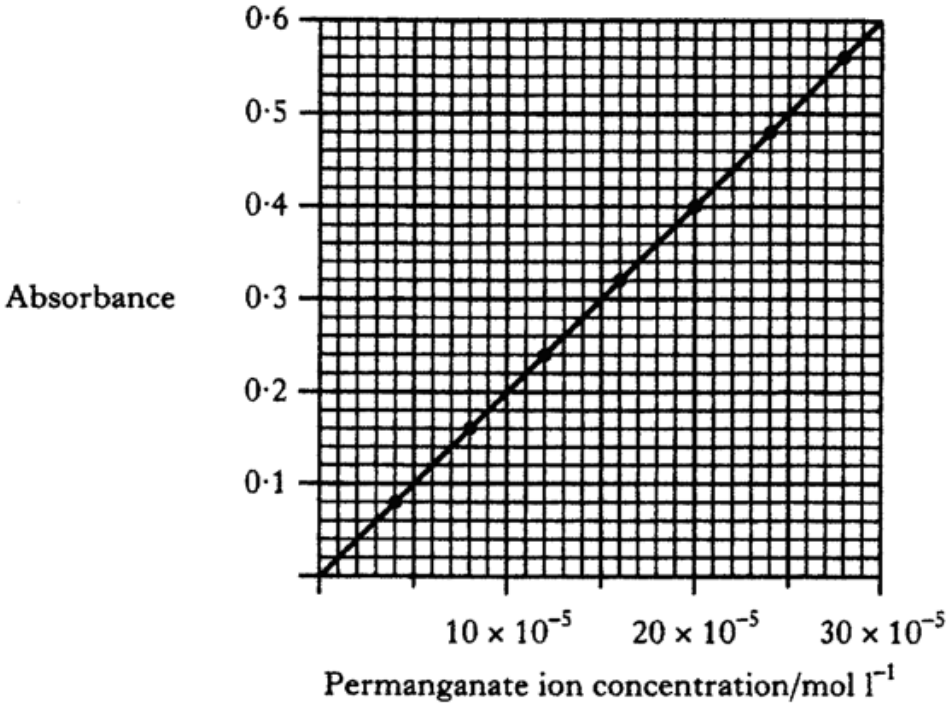
The concentration of this solution was found to be $4{\cdot}25 \times 10^{-4}\ mol\ l^{-1}$.

Calculate the percentage, by mass, of manganese in the alloy.

4.

In a determination, the manganese in 0·214 g of steel was oxidised to permanganate ions and the solution made up to 100 cm^3 in a standard flask. The absorbance of the solution was measured as 0·22.

Use this information and the following calibration graph to calculate the percentage of manganese in this sample of steel.



5. EXTENSION WORK: For this question you will need graph paper or alternatively you can try to draw the graph using excel or a similar software.

A pupil set out to determine the percentage by mass of manganese in a steel paper clip by using colorimetry. The first task the pupil carried out was to prepare a calibration graph using a standard solution of potassium permanganate.

Table used to draw calibration graph.

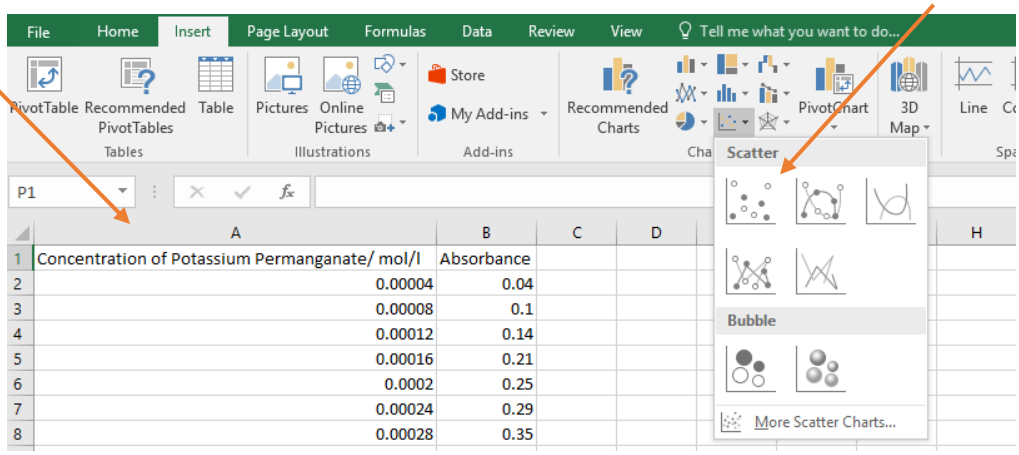
Concentration of permanganate/ mol l^{-1}	Absorbance
0.00004	0.04
0.00008	0.10
0.00012	0.14
0.00016	0.21
0.00020	0.25
0.00024	0.29
0.00028	0.35

Once the pupil had obtained the calibration graph, they analysed a 0.198g sample of paper clip by oxidising it to permanganate ions and diluting it with distilled water to 100cm^3 in a volumetric flask. When the pupil analysed the sample using the colorimeter, they obtained an absorbance value of 0.18.

a) Use the table above to draw the calibration graph. The screenshot below shows you briefly how to draw a graph using excel.

Make a table as shown on the left.

Use a scatter graph to plot the points.



b) Use the calibration graph that you have drawn and the pupils' absorbance value of the sample to calculate the percentage by mass of manganese in the sample of paper clip.

c) Outline the main steps that the pupil would need to consider when setting up the colorimeter for their experiment.