

Verification of Lambert-Beer's Law and Determination of Concentration using Colorimeter

| Object

To test the validity of Lambert-Beer's law and determine the concentration of unknown solution colorimetrically.

Principle

When light of a suitable wavelength passes through a coloured solution, a part of the incident light is absorbed by the solution. According to Lambert-Beer's law, the absorbance of a solution is directly proportional to its concentration when the path length, wavelength, temperature and other experimental conditions are kept constant.

$$A = \epsilon lc$$

where A is the absorbance, ϵ is the molar absorptivity, l is the path length of the cell and C is the concentration of the solution.

The absorbance is related to the intensity of incident and transmitted light by:

$$A = \log_{10} \left(\frac{I_0}{I} \right)$$

where I_0 is the intensity of incident light and I is the intensity of transmitted light.

For a fixed path length and wavelength:

$$A \propto c$$

Thus, a plot of absorbance against concentration gives a straight line when Lambert-Beer's law is valid over the concentration range studied. The concentration of the unknown solution can be determined directly from the calibration graph using its measured absorbance.

Chemicals Required

- Potassium permanganate ($KMnO_4$)
- Distilled water
- Unknown potassium permanganate solution

Apparatus Required

- Photoelectric colorimeter
- Suitable cuvettes
- Volumetric flasks
- Pipettes
- Beakers
- Measuring cylinder
- Wash bottle

Preparation of Standard Solutions

A $0.001\ M$ stock solution of potassium permanganate was used to prepare standard solutions having concentrations from $0.0001\ M$ to $0.0006\ M$ by suitable dilution with distilled water. The final volume of each standard solution was kept at 10 mL.

S. No.	Required Concentration of $KMnO_4$ (M)	Volume of 0.001 M Stock Solution (mL)	Final Volume (mL)	Distilled Water (mL)
1	0.0001	1	10	9
2	0.0002	2	10	8
3	0.0003	3	10	7
4	0.0004	4	10	6

S. No.	Required Concentration of KMnO_4 (M)	Volume of 0.001 M Stock Solution (mL)	Final Volume (mL)	Distilled Water (mL)
5	0.0005	5	10	5
6	0.0006	6	10	4

Procedure

A. Determination of Maximum Absorption Wavelength

The colorimeter was switched on and allowed to warm up properly. A suitable concentration of potassium permanganate solution was taken for the determination of the maximum absorption wavelength. Distilled water was used as the blank. The cuvette was cleaned and rinsed first with distilled water and then with a small quantity of the potassium permanganate solution.

The blank was placed in the colorimeter and the instrument was adjusted to zero absorbance or 100% transmittance according to the operating procedure of the instrument. The absorbance of the potassium permanganate solution was measured at different available wavelengths or filter settings. The corresponding wavelength and absorbance values were recorded.

A graph was plotted between wavelength on the X-axis and absorbance on the Y-axis. The wavelength corresponding to the maximum absorbance was determined from the graph and was taken as the

working wavelength, λ_{max} , for further measurements.

B. Measurement of Standard Solutions

The standard potassium permanganate solutions of concentrations 0.00001 M to 0.00006 M were taken one by one. The cuvette was rinsed with the respective standard solution and then filled with it. The outside surface of the cuvette was wiped carefully before placing it in the colorimeter.

The absorbance of each standard solution was measured at the selected λ_{max} . The absorbance values were recorded in the observation table. A calibration graph was then plotted between concentration of potassium permanganate and absorbance.

C. Measurement of Unknown Solution

The unknown potassium permanganate solution was taken in a clean cuvette after rinsing the cuvette with a small quantity of the unknown solution. The cuvette was filled with the unknown solution and

its outside surface was wiped carefully.

The absorbance of the unknown solution was measured at the same $\lambda_{\max}$ and under the same experimental conditions as those used for the standard solutions. The absorbance was recorded in the same observation table. The concentration of the unknown solution was determined directly from the calibration graph.

Observations

A. Determination of $\lambda_{\max}$

S. No.	Wavelength (nm)	Absorbance
1		
2		
3		
4		
5		
6		
7		

From the graph, the wavelength corresponding to maximum absorbance was found to be

$\lambda_{\max} = \underline{\hspace{2cm}}$ nm.

B. Absorbance of Standard and Unknown Solutions

S. No.	Concentration of KMnO_4 (M)	Absorbance
1	0.0001	
2	0.0002	
3	0.0003	
4	0.0004	
5	0.0005	

S. No.	Concentration of KMnO_4 (M)	Absorbance
6	0.0006	
7	Unknown	

Calculations

A. Calculation for Preparation of Standard Solutions

The standard solutions were prepared using the dilution equation:

$$C_1 V_1 = C_2 V_2$$

where C_1 is the concentration of the stock solution, V_1 is the volume of stock solution taken, C_2 is the required concentration and V_2 is the final volume of the solution.

For example, for the preparation of 0.0001 M KMnO_4 solution from 0.001 M stock solution:

$$V_1 = \frac{C_2 V_2}{C_1}$$

$$V_1 = \frac{0.0001 \times 10}{0.001} = 1.0\text{ mL}$$

Therefore, 1 mL of 0.001 M stock solution was diluted to 10 mL with distilled water.

B. Determination of $\lambda_{\max}$

The absorbance values obtained at different wavelengths were plotted against the corresponding wavelengths. The wavelength at which maximum absorbance was obtained was taken as the

$\lambda_{\max}$ of the potassium permanganate solution.

$$\lambda_{\max} = \text{wavelength corresponding to maximum absorbance}$$

C. Verification of Lambert-Beer's Law

The absorbance values obtained for the standard potassium permanganate solutions were plotted against their corresponding concentrations at the selected $\lambda_{\max}$. According to Lambert-

Beer's law:

$$A = \epsilon l c$$

Since the wavelength and path length were kept constant:

$$A \propto c$$

Therefore, a straight-line relationship between absorbance and concentration confirmed the validity of Lambert-Beer's law over the investigated concentration range.

D. Determination of Concentration of Unknown Solution

The absorbance of the unknown solution was measured at the selected $\lambda_{\max}$. The measured absorbance of the unknown solution was marked on the Y-axis of the calibration graph. A horizontal line was drawn from this point to intersect the calibration curve. From the point of intersection, a vertical line was drawn towards the X-axis. The concentration corresponding to this point was directly obtained from the X-axis.

Thus, the concentration of the unknown solution was determined directly from the calibration graph without using any separate calculation formula.

Graphs

Graph 1: Determination of $\lambda_{\max}$

A graph was plotted between wavelength (nm) on the X-axis and absorbance on the Y-axis. The wavelength corresponding to the maximum absorbance was taken as $\lambda_{\max}$.

Graph 2: Verification of Lambert-Beer's Law

A graph was plotted between concentration of KMnO_4 solution on the X-axis and absorbance on the Y-axis at the selected $\lambda_{\max}$. A straight-line relationship was obtained for the standard solutions. The absorbance of the unknown solution was then used to determine its concentration directly from this calibration graph.

Result

The maximum absorption wavelength of potassium permanganate solution was determined from the absorbance versus wavelength graph and was found to be _____ nm. Lambert-Beer's law was found to be valid for the investigated concentration range of potassium permanganate solution. The concentration of the unknown solution was determined colorimetrically from the calibration graph and was found to be _____ M.

Precautions

1. The colorimeter was allowed to warm up properly before taking measurements.
2. Distilled water was used as the blank.
3. The cuvette was cleaned and rinsed properly before use.
4. The outside surface of the cuvette was wiped clean before placing it in the instrument.
5. Air bubbles were avoided inside the cuvette.
6. The cuvette was placed in the same orientation for all measurements.
7. The same path length and selected $\lambda_{\max}$ were used for all standard and unknown solutions.
8. The standard solutions were prepared accurately by suitable dilution of the stock solution.
9. All absorbance measurements were taken under identical experimental conditions.
10. The solutions were kept within the suitable linear working range of the colorimeter.