📚 B. Pharmacy 1st Semester - Pharmaceutical Analysis Notes

UNIT – 4

🔄 REDOX TITRATIONS

📋 Points to be covered in this topic

→ **INTRODUCTION** 🌞
→ **OXIDATION NUMBER OR OXIDATION STATE** 🔢
→ **BALANCING SIMPLE REDOX REACTIONS** ⚖️
→ **THEORY OF REDOX TITRATIONS** 🧪
→ **REDOX INDICATORS** 🎨
→ **IODIMETRY AND IODOMETRY** 💜
→ **BROMATOMETRY** 🔴
→ **DICHROMETRY** 🟡
→ **TITRATION WITH POTASSIUM IODATE** 🍊

🌞 INTRODUCTION

🔬 Concept of oxidation and reduction

In titrimetric analysis, we determine the quantity of pure component based on measurement of volume of standard solution that reacts completely with the analyte. This measurement of standard solution can be accomplished through different reactions, and when the reaction involved in this measurement is an oxidation-reduction reaction, that method is called **"oxidation reduction titration"** or **"Redox titration."**

In Redox titration, oxidation and reduction reactions occur simultaneously, making it a powerful analytical technique for quantitative analysis.

⬆️ Oxidation

Oxidation can be defined in several ways:

- **Classical definition**: Combination of the substance with oxygen is termed as oxidation
- **Modern definition**: Loss of electron(s) is known as oxidation
- When an atom loses electrons, its positive valency increases and negative valency decreases
- **General representation**: $Fe^{2+} \rightarrow Fe^{3+} + e^{-}$
- **Result**: Increase in oxidation number

⬇️ Reduction

Reduction is the opposite process of oxidation:

- **Classical definition**: Removal of oxygen from substance
- **Modern definition**: Gain of electrons
- When an atom gains electrons, its positive valency decreases and negative valency increases
- **General representation**: $Fe^{3+} + e^{-} \rightarrow Fe^{2+}$
- **Result**: Decrease in oxidation number

🔄 Redox reactions

Redox reactions are characterized by the simultaneous occurrence of oxidation and reduction processes. In any redox reaction, if one atom or species is undergoing oxidation, there will always be a second atom or species undergoing reduction. This fundamental principle ensures that when there is an atom that donates electrons, there is always an atom that accepts electrons, facilitating electron transfer from one atom to another.

🔢 OXIDATION NUMBER OR OXIDATION STATE (OS)

Oxidation number is defined as a positive, zero, or negative integer that represents the hypothetical charge an atom would have if all bonds were completely ionic. A positive oxidation state reflects the loss of electrons, while a negative oxidation state reflects the gain of electrons in the atom.

📏 Rules for Assigning Oxidation State:

1. **Sum Rule**: The sum of the oxidation numbers of all atoms in a molecule or ion must be equal in sign and value to the charge on the molecule or ion.

2. **Neutral Elements**: All atoms in their elemental state have an oxidation number of 0. Elements such as O_2, S_8, P_4, etc., are neutral substances containing atoms of only one element.

3. **Binary Compounds Rule**: In binary compounds (consisting of only two different elements), the element with greater electronegativity is assigned a negative oxidation state equal to its charge as a simple monoatomic ion.

📊 Common Oxidation States Table

Element	Common Oxidation States	Notes
Hydrogen (H)	+1, -1	+1 in most compounds, -1 in hydrides
Oxygen (O)	-2, -1, 0	-2 in most compounds, -1 in peroxides
Alkali metals (Li, Na, K)	+1	Always +1 in compounds
Alkaline earth metals (Mg, Ca, Ba)	+2	Always +2 in compounds
Halogens (F, Cl, Br, I)	-1, +1, +3, +5, +7	Variable depending on compound

⚖️ BALANCING SIMPLE REDOX REACTIONS

Simple redox reactions are balanced using a systematic stepwise approach. The process involves identifying the oxidation and reduction half-reactions and ensuring that both mass and charge are balanced.

🔄 Step-by-Step Balancing Process:

Step 1: Identify and separate the oxidation and reduction half-reactions from the overall equation.

Step 2: Balance each half-reaction individually for both atoms and charges by adding electrons to the appropriate side.

Step 3: Make the number of electrons equal in both half-reactions by multiplying by appropriate coefficients.

Step 4: Add the balanced half-reactions together and cancel out the electrons.

Step 5: Verify that both atoms and charges are balanced in the final equation.

This systematic approach ensures that the fundamental laws of conservation of mass and charge are maintained throughout the balancing process.

🧪 THEORY OF REDOX TITRATIONS

🔬 Electrochemical Cell Setup

Redox titrations utilize highly selective electrolytic cells consisting of two different types of electrodes:

Indicator Electrode

- Consists of a noble metal that serves as the center of electron transfer from the bulk solution to the external circuit
- **Platinum (Pt) electrode** is commonly used due to its inert nature and excellent conductivity
- Responds to changes in the relative concentrations of oxidized and reduced species in solution

Reference Electrode

- Provides a stable, constant potential against which the indicator electrode potential can be measured

- **Standard Hydrogen Electrode (SHE)** and **Standard Calomel Electrode (SCE)** are commonly used
- **Saturated Calomel Reference Electrode** half-reaction provides reliable reference potential

⚡ Nernst Equation Application

The relationship between concentration and electrode potential is governed by the Nernst equation:

$$E = E° - (RT/nF) \ln(a\_red/a\_ox)$$

Where:

- **E_red**: Half-cell reduction potential at the temperature of interest
- **E°_red**: Standard half-cell reduction potential
- **R**: Universal gas constant ($8.314 \ J \cdot K^{-1} \cdot mol^{-1}$)
- **T**: Absolute temperature
- **a**: Chemical activity (a_red for reductant, a_ox for oxidant)
- **F**: Faraday constant ($9.648 \times 10^4 \ C \cdot mol^{-1}$)
- **z**: Number of moles of electrons transferred

🎨 REDOX INDICATORS

A redox indicator must produce a sudden change in electrode potential in the vicinity of the equivalence point during a redox titration. This is achieved when the indicator itself is redox active, capable of undergoing reversible oxidation or reduction processes.

🌈 Types of Indicators

🔴 Self Indicators

Self indicators are titrants that are so strongly colored that after the equivalence point, a single drop imparts a definite color at the end-point.

Characteristics:

- **Potassium permanganate**: Provides pink coloration
- **Ceric sulphate**: Shows pale yellow color
- **Iodine**: Exhibits brown coloration
- **Disadvantage**: Slight over-titration always occurs due to color intensity

🔵 External Indicators

External indicators are based on visible reactions of the titrated substances with suitable reagents, marking the end-point by failure to elicit the expected reaction.

Application: Used when the analyte or titrant undergoes a characteristic reaction with an external reagent that changes or disappears at the equivalence point.

🟢 Internal or Redox Indicators

These are substances that exhibit different colors in their oxidized and reduced forms through reversible reactions.

Characteristics:

- Most redox indicators are dyes

- Reduced forms are typically colorless

- The reaction is completely reversible

- Color change is sharp and easily detectable

📊 Common Redox Indicators Table

S.No.	Indicator	Oxidized State	Reduced State
1	Nitro ferroin	Pale-Blue	Red
2	Ferroin	Pale-Blue	Red
3	n-phenyl anthranilic acid	Purple-Red	Colourless
4	Diphenylamine	Violet	Colourless
5	Diphenylamine Sulphonic acid	Red-violet	Colourless
6	Starch-Iodine	Blue	Colourless
7	Methylene Blue	Blue	Colourless

📈 Potentiometric Method

The potentiometric method is a physico-chemical approach that can be applied when:

- Suitable visual indicators are not available

- Visual indicator methods fail or have limited accuracy

- Solutions are highly colored or very dilute

- High precision is required

This method measures the electrode potential throughout the titration, providing accurate determination of the equivalence point through

potential change curves.

💜 IODIMETRY AND IODOMETRY

Iodine-based titrations are among the most important and widely used redox titrations in pharmaceutical analysis. These methods can be conveniently and accurately performed using standard thiosulphate solution.

🔍 Types of Iodine Titrations

🟣 Iodimetry

In iodimetric determinations, a **standard iodine solution** is used as the titrant.

Principle:

- Iodine (I_2) acts as a weak oxidant
- Can be reduced by various reductants
- Common reducing agents include Stannous Chloride ($SnCl_2$) and Sodium thiosulphate ($Na_2S_2O_3$)
- These reductants react rapidly and completely with I_2

Procedure:

1. Take a known volume of reductant solution in a glass-stoppered conical flask (iodine flask)
2. Add 1 ml starch solution or sodium starch glycolate as indicator

3. Gradually add standard iodine solution from burette while swirling frequently

4. End-point detection: Blue color changes to colorless

5. **Reaction**: $I_2 + e^- \rightarrow 2I^-$ (Blue color disappears)

● Iodometry

In iodometric determinations, the **liberated iodine** during a chemical reaction is titrated.

Principle:

- Strong oxidants like $CuSO_4$, $K_2Cr_2O_7$, and $KMnO_4$ are treated with excess KI in acidic medium
- Iodide ions are oxidized to iodine: $\mathbf{2I^- - 2e^- \rightarrow I_2}$
- The liberated iodine is equivalent to the amount of oxidant present
- **Key relationship**: $2CuSO_4 \equiv 2Cu^{2+} \equiv I_2$

Procedure:

1. Add large excess of KI solution to the oxidant in acidic medium

2. Iodine is liberated proportional to the oxidant concentration

3. Titrate the liberated iodine with standard thiosulphate solution

4. **Final reaction**: $I_2 + 2Na_2S_2O_3 \rightarrow Na_2S_4O_6 + 2NaI$

Applications:

- Determination of copper compounds
- Analysis of dichromate solutions

- Estimation of permanganate content

🔴 BROMATOMETRY

Bromatometry involves the use of **potassium bromate (KBrO₃)** as a strong oxidizing agent in acidic solution for quantitative analysis.

⚡ Principle and Mechanism

Primary Reaction: $BrO_3^- + 5Br^- + 6H^+ \rightarrow 3Br_2 + 3H_2O$

The oxidizing capacity is determined by the Br_2/Br^- system with a standard electrode potential of **$E_0 = +1.08$ V**.

🧪 Experimental Conditions

Preparation of Standard Solution:

- Recrystallized potassium bromate can be used to prepare standard solutions of precisely known concentration
- The solution remains stable over extended periods
- **Hydrochloric acid** is used to maintain the required acidic pH

Indicator System:

- **Methyl orange** is the commonly used indicator
- Shows irreversible color change from **red to colorless**
- Provides sharp end-point detection

📋 Applications

Bromatometry is extensively used for the determination of:

- **Azophenol compounds**
- **Antimony** content in samples
- **Arsenic** concentrations
- **Iodide** ions in solution

Advantages:

- High precision and accuracy
- Stable standard solutions
- Sharp end-point detection
- Wide range of applications

🟠 DICHROMETRY

Dichrometry utilizes **potassium dichromate ($K_2Cr_2O_7$)** as a strong oxidizing agent in highly acidic solutions for quantitative redox analysis.

⚡ Fundamental Reaction

$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O$ (E_0 = +1.36 V)

The high standard electrode potential makes dichromate an excellent oxidizing agent for various analytical applications.

🌞 Advantages over $KMnO_4$

Superior Stability:

- Stable and precise standard solutions can be prepared directly from pure potassium dichromate salt

- No standardization against primary standards required
- Solutions remain stable for extended periods

Chemical Compatibility:

- **Not sensitive to chloride ions**, unlike permanganate
- Can be used in the presence of hydrochloric acid
- Broader applicability in various chemical environments

🎨 Indicator System

Diphenylamine Indicator:

- Commonly used indicator in dichrometry
- **Color change**: Colorless to dark blue at the end-point
- Provides sharp and easily detectable end-point
- Highly sensitive to potential changes

📋 Primary Applications

Iron(II) Determination:

- Most common application of dichrometry
- Quantitative analysis of ferrous salts
- High precision in iron content determination
- Suitable for pharmaceutical and industrial samples

Other Applications:

- Analysis of organic compounds containing reducible groups

- Determination of alcohol content in pharmaceutical preparations
- Quality control in chemical manufacturing

🍊 TITRATION WITH POTASSIUM IODATE

This method is specifically designed for determining **vitamin C concentration** in solutions through redox titration using potassium iodate in the presence of potassium iodide.

🧬 Biochemical Significance

Vitamin C (Ascorbic Acid):

- More properly called **ascorbic acid**
- Essential antioxidant required by the human body
- Plays crucial role in collagen synthesis and immune function
- Easily oxidized, making it suitable for redox analysis

🔬 Reaction Mechanism

Step 1 - Iodine Generation: When iodate ions (IO_3^-) are added to an acidic solution containing iodide ions (I^-), an oxidation-reduction reaction occurs:

Reduction half-reaction: $IO_3^- + 6H^+ + 5e^- \rightarrow \frac{1}{2}I_2 + 3H_2O$ **Oxidation half-reaction**: $2I^- \rightarrow I_2 + 2e^-$

Overall reaction: $IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$

Step 2 - Ascorbic Acid Oxidation: The iodine formed oxidizes ascorbic acid to dehydroascorbic acid while being reduced to iodide ions:

Ascorbic acid + I$_2$ → 2I$^-$ + Dehydroascorbic acid

🎯 End-Point Detection

Starch Indicator Mechanism:

- Iodine formed is immediately reduced to iodide as long as ascorbic acid is present
- Once all ascorbic acid has been oxidized, excess iodine reacts with starch indicator
- Forms characteristic **blue-black starch-iodine complex**
- This color change marks the **end-point of the titration**

📊 Applications and Advantages

Application	Sample Type	Advantages
Pharmaceutical Analysis	Vitamin C tablets	High precision and accuracy
Food Industry	Fresh fruit juices	More reliable than direct iodine titration
Quality Control	Packaged fruit juices	Stable potassium iodate solutions
Nutritional Assessment	Solid fruits and vegetables	Primary standard reliability

Method Advantages:

- **Enhanced Reliability**: More reliable than direct iodine titration methods

- **Primary Standard**: Potassium iodate solution is more stable than iodine as a primary standard

- **Wide Applicability**: Suitable for various sample types and concentrations

- **Cost-Effective**: Simple procedure with readily available reagents

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📚 COMMON OXIDANTS AND REDUCTANTS

🔼 Oxidizing Agents

- **Potassium permanganate** ($KMnO_4$)

- **Potassium dichromate** ($K_2Cr_2O_7$)

- **Potassium iodate** (KIO_3)

- **Potassium bromate** ($KBrO_3$)

- **Ceric sulphate** $[Ce(SO_4)_2]$

- **Iodine** (I_2)

- **Lead dioxide** (PbO_2)

- **Potassium Periodate** (KIO_4)

🔽 Reducing Agents

- **Ferrous sulphate** ($FeSO_4$)

- **Sodium thiosulphate** ($Na_2S_2O_3$)

- **Stannous chloride** ($SnCl_2$)

- **Oxalic acid** ($H_2C_2O_4$)

- **Titanous sulphate** $[Ti_2(SO_4)_3]$

- **Sodium arsenite** ($NaAsO_2$)

☀️ Primary Standards

The following compounds can be used as **primary standards** for direct preparation of standard solutions:

- Potassium iodate (KIO_3)

- Potassium bromate ($KBrO_3$)

- Potassium dichromate ($K_2Cr_2O_7$)

- Potassium bi-iodate

- Iodine (I_2)

- Arsenious oxide (As_2O_3)

- Sodium oxalate ($Na_2C_2O_4$)

These primary standards eliminate the need for standardization procedures, providing direct and accurate concentration determination for analytical applications.

📖 Summary

Redox titrations represent a fundamental and versatile analytical technique in pharmaceutical analysis. The various methods - **Cerimetry, Iodimetry, Iodometry, Bromatometry, Dichrometry,** and **Potassium Iodate titrations** - each offer unique advantages for specific analytical applications. Understanding the principles of oxidation-reduction reactions, proper indicator selection, and end-point detection is crucial for

accurate quantitative analysis in pharmaceutical quality control and research applications.

The choice of specific redox titration method depends on factors such as the nature of the analyte, required precision, sample matrix, and availability of suitable indicators. Each method provides reliable, cost-effective, and accurate determination of various pharmaceutical compounds and active ingredients.