

**Topic: Comparing Measured and Labelled Iron(II) Content in  
Over-the-Counter Iron Tablets by Permanganate Titration**

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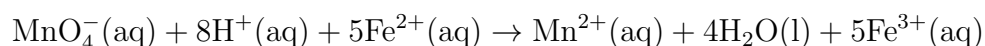
# 1 Introduction

Iron is an essential mineral for oxygen transport via haemoglobin in red blood cells. Insufficient intake contributes to anaemia, affecting 40% of children aged 6–59 months and 30% of women worldwide (World Health Organization, 2025). As a student interested in pharmacology and medicine, and someone who has been affected by iron deficiency, I became curious about label claims and the actual iron(II) content of over-the-counter iron tablets. Ensuring reliable dosing is crucial for clinicians, as over- or under-administration may harm patients (Nguyen and Tadi, 2023). This investigation, therefore, connects widely used supplements with analytical chemistry.

## 2 Background Information

Most iron supplements provide iron in the ferrous ( $\text{Fe}^{2+}$ ) form, for instance, ferrous sulfate, ferrous fumarate, or ferrous gluconate. These salts vary in their mass proportions of elemental iron, and supplement labels typically report iron content differently (NIH, 2023). However, each brand used in this investigation listed elemental iron. Because labels are the basis for dosing decisions, comparing measured iron(II) content to label claims offers a meaningful way to evaluate product claim accuracy using chemistry.

To determine the true  $\text{Fe}^{2+}$  content, this investigation used a redox titration with potassium permanganate ( $\text{KMnO}_4$ ) in an acidic solution. In strongly acidic conditions, permanganate ions ( $\text{MnO}_4^-$ ) act as a powerful oxidising agent and are reduced to  $\text{Mn}^{2+}$ , while  $\text{Fe}^{2+}$  is oxidised to  $\text{Fe}^{3+}$ . The balanced ionic equation is:



The moles of  $\text{Fe}^{2+}$  in the sample can therefore be determined directly from the titre volume and the standardised  $\text{KMnO}_4$  concentration (Mendham et al., 2000). An advantage of  $\text{KMnO}_4$  titration is that  $\text{MnO}_4^-$  is self-indicating due to its deep purple colour. The endpoint is identified when a faint, permanent pale pink colour persists after mixing, indicating a slight excess of  $\text{MnO}_4^-$  ions beyond the stoichiometric equivalence point (Pearson Education, 2015). However, iron tablets contain excipients and sometimes additional active ingredients that may not dissolve completely or react with oxidants, a consideration discussed later.

### 2.1 Choice of Acid: Sulfuric Acid

An acidic medium is required because the reduction of  $\text{MnO}_4^-$  to  $\text{Mn}^{2+}$  consumes  $\text{H}^+$  ions; without sufficient acid, permanganate is instead reduced to  $\text{MnO}_2$ , a brown precipitate that obscures the endpoint and alters the stoichiometry from 5:1 to 3:1  $\text{Fe}^{2+}:\text{MnO}_4^-$  (Mendham

et al., 2000). Dilute sulfuric acid was selected because it does not react with permanganate under titration conditions (Harvey, 2000). Hydrochloric acid is unsuitable because  $\text{Cl}^-$  can be oxidised by  $\text{MnO}_4^-$  ( $E^\circ = +1.51 \text{ V}$  vs.  $+1.36 \text{ V}$  for  $\text{Cl}_2/\text{Cl}^-$ ), consuming additional titrant and inflating the calculated iron content. Nitric acid is also avoided because the nitrate ion is itself an oxidising agent in acidic conditions, which could independently oxidise  $\text{Fe}^{2+}$  before the titration begins (Mendham et al., 2000).

## 2.2 Research Question

To what extent do the actual Fe(II) contents of Boots, H&B, Tesco Health, Wellbeing, and Morrisons tablets (determined by  $\text{KMnO}_4$  titration) match the 20 mg and 14 mg claims?

## 2.3 Variables

**Dependent Variable:** Mass of Fe(II) per tablet determined by  $\text{KMnO}_4$  redox titration.

**Independent Variable:** Brand of iron supplement (Boots Iron, Holland & Barrett Iron & Vitamin C, Tesco Health Iron, Tesco Wellbeing Iron, and Morrisons Iron).

**Controlled Variables:** The same standardised  $\text{KMnO}_4$  solution ( $0.002 \pm 0.0001 \text{ mol dm}^{-3}$ ) was used for all titrations to ensure a consistent titrant concentration. All brands were dissolved in the same volume of  $\text{H}_2\text{SO}_4$  ( $1 \text{ mol dm}^{-3}$ ) and made up to  $250.0 \text{ cm}^3$  in a volumetric flask, keeping the dilution factor constant. A  $25.00 \text{ cm}^3$  aliquot was pipetted for every trial. The same analytical balance, burette, and volumetric glassware were used throughout, and all titrations were performed at ambient room temperature ( $\sim 22^\circ \text{C}$ ).

# 3 Main Experiment

## 3.1 Methodology

Five tablets from each brand were prepared for analysis: Boots Iron (14 mg Fe), Holland & Barrett Iron & Vitamin C (20 mg Fe), Tesco Health Iron (14 mg Fe), Tesco Wellbeing Iron (14 mg Fe), and Morrisons Iron (14 mg Fe). Each set of five tablets was weighed on an analytical balance ( $\pm 0.001 \text{ g}$ ) and ground to a fine powder using a mortar and pestle to maximise surface area and aid dissolution. The powder was transferred to a  $250.0 \text{ cm}^3$  volumetric flask using a wash bottle, and approximately  $125 \text{ cm}^3$  of dilute  $\text{H}_2\text{SO}_4$  ( $1 \text{ mol dm}^{-3}$ ), measured using a  $100 \text{ cm}^3$  measuring cylinder, was added. The mixture was swirled until the sample had dissolved as far as practicable, then filtered through filter paper into a clean flask to prevent insoluble and coloured residues from obscuring the endpoint. Filtration was applied consistently to all brands. The flask was then filled to the  $250.0 \text{ cm}^3$  mark with deionised water (also rinsing the filter to make sure as little residue leftover) and inverted several times to homogenise.

A  $25.00\text{ cm}^3$  aliquot was pipetted (volumetric pipette,  $\pm 0.06\text{ cm}^3$ ) into a conical flask placed on a white tile. Standardised  $\text{KMnO}_4$  ( $0.002 \pm 0.0001\text{ mol dm}^{-3}$ ), provided by the school laboratory with the stated uncertainty reflecting the manufacturer's tolerance, was added dropwise from a  $50.0\text{ cm}^3$  burette ( $\pm 0.05\text{ cm}^3$  per reading) until the first persistent pale pink colour appeared. Initial and final burette readings were recorded.

Each titration was repeated until at least three concordant values were obtained, defined as titres agreeing within  $0.10\text{ cm}^3$ . This concordance window was chosen because it represents the smallest burette scale division. Trials outside this range were recorded but excluded from the mean. All glassware was rinsed before use, and volume measurements were read at eye level to minimise parallax error.

### 3.2 Apparatus

Table 1: Equipment, tolerances, and justification for selection.

| Apparatus                   | Specification         | Uncertainty                    | Purpose / Variable Controlled                                                |
|-----------------------------|-----------------------|--------------------------------|------------------------------------------------------------------------------|
| Burette + stand/clamp       | 50.0 cm <sup>3</sup>  | ±0.05 cm <sup>3</sup> /reading | Deliver titrant KMnO <sub>4</sub>                                            |
| Volumetric pipette + filler | 25.00 cm <sup>3</sup> | ±0.06 cm <sup>3</sup>          | Transfer a precise aliquot                                                   |
| Volumetric flask            | 250.0 cm <sup>3</sup> | ±0.20 cm <sup>3</sup>          | Prepare stock solution; defines dilution factor                              |
| Measuring cylinder          | 100 cm <sup>3</sup>   | ±0.5 cm <sup>3</sup>           | Measure approximate H <sub>2</sub> SO <sub>4</sub> (not in calculation)      |
| Analytical balance          | 0.001 g readability   | ±0.001 g                       | Weigh tablets                                                                |
| Conical flask               | 250 cm <sup>3</sup>   | N/A                            | Reaction vessel                                                              |
| Mortar and pestle           | —                     | —                              | Crush tablets to increase surface area                                       |
| Funnel + filter paper       | —                     | —                              | Remove insoluble excipients                                                  |
| Wash bottle                 | —                     | —                              | Rinse flask walls for quantitative transfer                                  |
| White tile                  | —                     | —                              | Improves visibility of the faint pink MnO <sub>4</sub> <sup>-</sup> endpoint |
| PPE (goggles, coat, gloves) | —                     | —                              | Safety when handling acid and oxidisers                                      |

### 3.3 Safety Considerations

Table 2: Hazard assessment based on CLEAPSS HazCards and precautions taken.

| Hazard                                                | Risk Assessment (CLEAPSS Reference)                                                                                                             | Precautions Taken                                                                                                                 |
|-------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
| Sulfuric acid (1 mol dm <sup>-3</sup> )               | CLEAPSS HazCard 98a: At 1 mol dm <sup>-3</sup> , classified as an irritant; risk of skin and eye irritation from this corrosive reagent.        | Safety goggles, a lab coat, and nitrile gloves are worn throughout. Acid kept in labelled containers; spills cleaned immediately. |
| Potassium permanganate (~0.002 mol dm <sup>-3</sup> ) | CLEAPSS HazCard 81: Solid is harmful and oxidising; at 0.002 mol dm <sup>-3</sup> the solution is low hazard but still causes visible staining. | PPE was worn throughout. Burette filled via funnel below eye level. Containers labelled and closed when not in use.               |

## 4 Data Analysis

### 4.1 Data Processing

For each brand, the mean concordant KMnO<sub>4</sub> titre volume (dm<sup>3</sup>) was used to determine the amount of Fe<sup>2+</sup> present. Since 1 mol of KMnO<sub>4</sub> oxidises 5 mol of Fe<sup>2+</sup>, the moles of Fe<sup>2+</sup> in the 25.00 cm<sup>3</sup> aliquot were calculated as:

$$n(\text{Fe}^{2+})_{\text{aliquot}} = 5 \times c(\text{KMnO}_4) \times V(\text{KMnO}_4)$$

where  $c(\text{KMnO}_4)$  is the standardised concentration (mol dm<sup>-3</sup>) and  $V(\text{KMnO}_4)$  is the mean titre volume (dm<sup>3</sup>). Because the aliquot represents 25.00 cm<sup>3</sup> of a 250.0 cm<sup>3</sup> stock solution, the total moles of Fe<sup>2+</sup> dissolved from five tablets are:

$$n(\text{Fe}^{2+})_{\text{total}} = n(\text{Fe}^{2+})_{\text{aliquot}} \times \left( \frac{250.0}{25.00} \right) = n(\text{Fe}^{2+})_{\text{aliquot}} \times 10$$

The total mass of elemental iron was then calculated by multiplying by the molar mass of iron ( $M_{\text{Fe}} = 55.845 \text{ g mol}^{-1}$ ) and converting to milligrams. Finally, dividing by five gives the mass of Fe per tablet:

$$m(\text{Fe}) \text{ per tablet} = \frac{n(\text{Fe}^{2+})_{\text{total}} \times M_{\text{Fe}} \times 1000}{5} \quad (\text{in mg})$$

The percentage of label claim was calculated as:

$$\% \text{ of claim} = \left( \frac{\text{measured mass}}{\text{label claim}} \right) \times 100$$

All results are reported with significant figures consistent with the titre precision ( $\pm 0.10 \text{ cm}^3$ ).

## 4.2 Uncertainty Propagation

Uncertainties were propagated by summing the percentage uncertainties of each measured quantity that enters the stoichiometric calculation. The key instrumental tolerances are listed in Table 3.

Table 3: Absolute uncertainties for each measurement entering the calculation.

| Measurement                             | Apparatus                                                                   | Absolute Uncertainty                                   |
|-----------------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------|
| Mass of 5 tablets                       | Analytical balance ( $\pm 0.001 \text{ g}$ )                                | $\pm 0.001 \text{ g}$                                  |
| Aliquot volume ( $25.00 \text{ cm}^3$ ) | Volumetric pipette                                                          | $\pm 0.06 \text{ cm}^3$ ( $\pm 0.00006 \text{ dm}^3$ ) |
| Flask volume ( $250.0 \text{ cm}^3$ )   | Volumetric flask                                                            | $\pm 0.20 \text{ cm}^3$ ( $\pm 0.00020 \text{ dm}^3$ ) |
| Titre volume (derived)                  | $50.0 \text{ cm}^3$ burette, 2 readings $\times$<br>$\pm 0.05 \text{ cm}^3$ | $\pm 0.10 \text{ cm}^3$ ( $\pm 0.0001 \text{ dm}^3$ )  |
| $\text{KMnO}_4$ concentration           | Standardised solution<br>(manufacturer's tolerance)                         | $\pm 0.0001 \text{ mol dm}^{-3}$                       |

Each absolute uncertainty was converted to a percentage of its measured value:

$$\%u = \left( \frac{\text{absolute uncertainty}}{\text{measured value}} \right) \times 100$$

The total percentage uncertainty was obtained by summing all five component uncertainties:

$$\%u(\text{total}) = \%u(c) + \%u(V_{\text{titre}}) + \%u(V_{\text{aliquot}}) + \%u(V_{\text{flask}}) + \%u(\text{mass})$$

This total was then applied to the computed Fe mass (mg) to give an absolute uncertainty for each trial.

### Worked Example (Boots, Trial 2)

Using the concordant titre volume of 15.1 cm<sup>3</sup> (0.0151 dm<sup>3</sup>):

$$\%u(V_{\text{titre}}) = \left( \frac{0.0001 \text{ dm}^3}{0.0151 \text{ dm}^3} \right) \times 100 = 0.662\%$$

$$\%u(V_{\text{aliquot}}) = \left( \frac{0.00006 \text{ dm}^3}{0.02500 \text{ dm}^3} \right) \times 100 = 0.240\%$$

$$\%u(V_{\text{flask}}) = \left( \frac{0.00020 \text{ dm}^3}{0.25000 \text{ dm}^3} \right) \times 100 = 0.080\%$$

$$\%u(c_{\text{KMnO}_4}) = \left( \frac{0.0001}{0.002} \right) \times 100 = 5.000\%$$

$$\%u(\text{mass}) = \left( \frac{0.001 \text{ g}}{1.266 \text{ g}} \right) \times 100 = 0.079\%$$

$$\%u(\text{total}) = 0.662 + 0.240 + 0.080 + 5.000 + 0.079 = 6.06\%$$

$$m(\text{Fe}) = \frac{5 \times 0.002 \times 0.0151 \times 10 \times 55.845 \times 1000}{5} = 16.87 \text{ mg}$$

$$\text{Absolute uncertainty} = 6.06\% \times 16.87 \text{ mg} = \pm 1.0 \text{ mg}$$

## 4.3 Results

Several trials were identified as non-concordant and excluded. Boots Trial 1 (6.81 mg) was approximately one-third of the concordant values, consistent with incomplete dissolution. Morrisons Trial 1 (15.64 mg) fell outside the concordance window of Trials 2–4. Tesco Health Trial 1, H and B Trial 3, and Wellbeing Trial 2 were likewise excluded. All outliers are marked in the raw data.

Table 4: Table 4: Raw and processed data for all brands, with percentage of label claim and propagated uncertainty.

| Brand                   | Trial | Mass 5 pills (g) | V KMnO <sub>4</sub> (dm <sup>3</sup> ) | Mass Fe (mg/pill) | Label (mg) | % of claim | Unc. ( $\pm$ mg) |
|-------------------------|-------|------------------|----------------------------------------|-------------------|------------|------------|------------------|
| Boots Iron (not used)   | 1     | 1.266            | 0.0061                                 | 6.81              | 14         | 48.66      | 0.5              |
| Boots Iron              | 2     | 1.266            | 0.0151                                 | 16.87             | 14         | 120.47     | 1.0              |
| Boots Iron              | 3     | 1.266            | 0.0152                                 | 16.98             | 14         | 121.26     | 1.0              |
| Boots Iron              | 4     | 1.266            | 0.0151                                 | 16.87             | 14         | 120.47     | 1.0              |
| H and B                 | 1     | 2.221            | 0.0237                                 | 26.47             | 20         | 132.35     | 1.5              |
| H and B                 | 2     | 2.221            | 0.0237                                 | 26.47             | 20         | 132.35     | 1.5              |
| H and B (not used)      | 3     | 2.221            | 0.0233                                 | 26.02             | 20         | 130.12     | 1.5              |
| H and B                 | 4     | 2.221            | 0.0236                                 | 26.36             | 20         | 131.79     | 1.5              |
| Tesco Health (not used) | 1     | 1.397            | 0.0148                                 | 16.53             | 14         | 118.07     | 1.0              |
| Tesco Health            | 2     | 1.397            | 0.0145                                 | 16.20             | 14         | 115.68     | 1.0              |
| Tesco Health            | 3     | 1.397            | 0.0144                                 | 16.08             | 14         | 114.88     | 1.0              |
| Tesco Health            | 4     | 1.397            | 0.0144                                 | 16.08             | 14         | 114.88     | 1.0              |
| Wellbeing               | 1     | 1.321            | 0.0132                                 | 14.74             | 14         | 105.31     | 0.9              |
| Wellbeing (not used)    | 2     | 1.321            | 0.0134                                 | 14.97             | 14         | 106.90     | 0.9              |
| Wellbeing               | 3     | 1.321            | 0.0132                                 | 14.74             | 14         | 105.31     | 0.9              |
| Wellbeing               | 4     | 1.321            | 0.0131                                 | 14.63             | 14         | 104.51     | 0.9              |
| Morrisons (not used)    | 1     | 1.37             | 0.0140                                 | 15.64             | 14         | 111.69     | 1.0              |
| Morrisons               | 2     | 1.37             | 0.0137                                 | 15.30             | 14         | 109.30     | 0.9              |
| Morrisons               | 3     | 1.37             | 0.0137                                 | 15.30             | 14         | 109.30     | 0.9              |
| Morrisons               | 4     | 1.37             | 0.0138                                 | 15.41             | 14         | 110.09     | 0.9              |

Figure 1: Mean percentage of iron(II) relative to label claims for each brand. Error bars represent propagated uncertainty (converted to % of label claim). The red line at 100% indicates exact agreement with label claim.

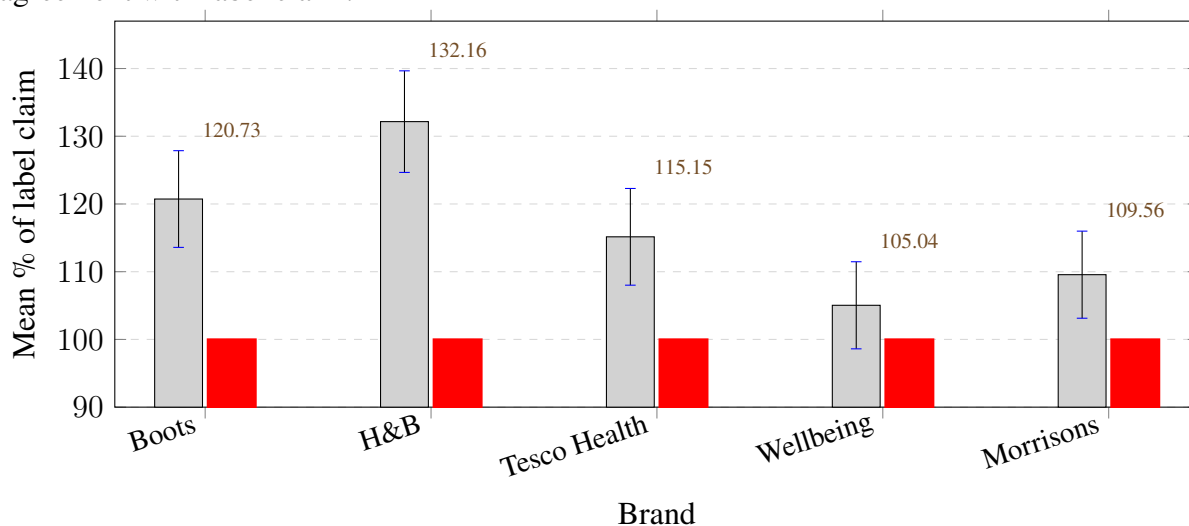
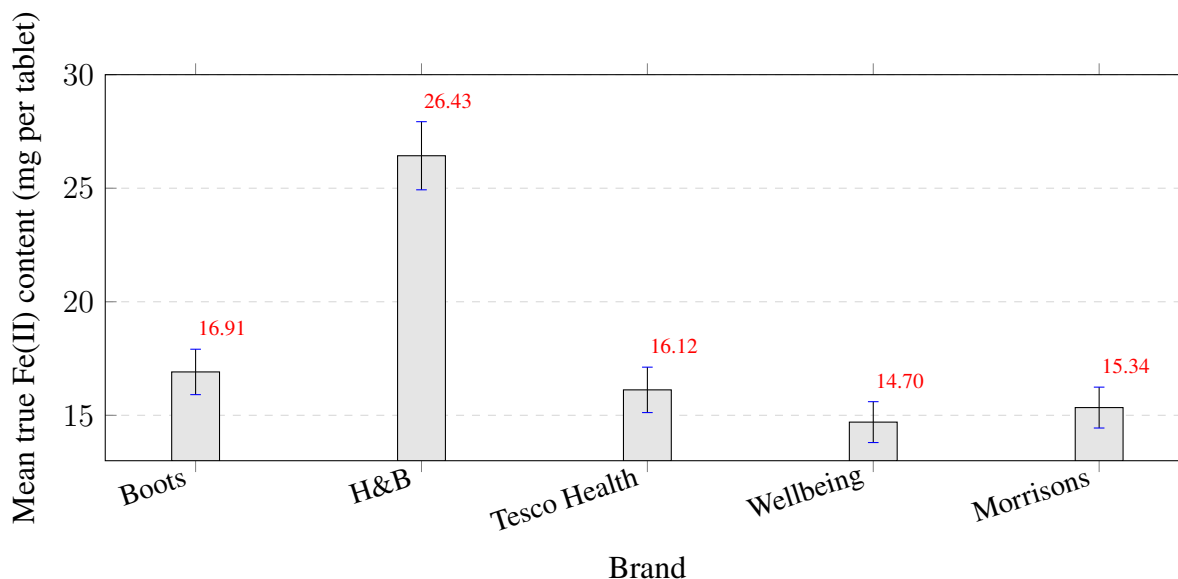


Figure 2: Mean true content of Fe(II) in mg per tablet by brand. Error bars represent propagated uncertainty calculated using the method described in the Uncertainty Propagation section.



The  $\text{KMnO}_4$  concentration uncertainty (5.00%) dominates in terms of uncertainty. The error bars reflect instrumental precision, thus it is important to note that systematic errors such as excipient co-oxidation are not captured.

#### 4.4 Sources of Error

Iron supplement tablets contain excipients (inactive ingredients) such as binders, coatings, colourants, and sometimes additional active ingredients (e.g., vitamin C). Reducing excipients (e.g., ascorbic acid in H&B tablets) can be oxidised by  $\text{MnO}_4^-$ , increasing the titre and causing the measured  $\text{Fe}^{2+}$  to appear higher than the true value. Coloured excipients (e.g., iron oxide colourants in Tesco Health) may obscure the endpoint, leading to systematic overshooting. Insoluble excipients require filtration, which risks losing dissolved  $\text{Fe}^{2+}$  adsorbed onto the filter paper or trapped in residue, causing a negative bias. The “first persistent pale pink” endpoint is also a qualitative judgement, introducing small random error.

These factors mean that the  $\text{KMnO}_4$  titration, while effective for measuring total reducing capacity, does not exclusively measure  $\text{Fe}^{2+}$  unless interfering species are controlled for (Quiñones et al., 2024); however, examining the formulations of the tested brands, only H&B lists a known reducing agent (ascorbic acid) as an active ingredient, supported by both the literature and the results of this investigation.

## 4.5 Note on Statistical Analysis

Because only three concordant titrations were performed on the same pooled stock solution, repeat-based statistical measures reflect analytical precision rather than inter-tablet variability. Propagated instrumental uncertainty and chemical evaluation of systematic error were therefore more informative than formal hypothesis testing.

## 5 Conclusion

### 5.1 Discussion

All five brands produced a mean Fe(II) mass per tablet exceeding the label claim (14 mg for Boots, Tesco Health, Wellbeing, and Morrisons; 20 mg for H&B). The mean concordant values were: Boots 16.9 mg, H&B 26.4 mg, Tesco Health 16.1 mg, Wellbeing 14.7 mg, and Morrisons 15.3 mg. Expressed as percentages of the label claim, these correspond to approximately 121% (Boots), 132% (H&B), 115% (Tesco Health), 105% (Wellbeing), and 109% (Morrisons).

The magnitude of deviation varies considerably. Wellbeing tablets showed the smallest deviation at  $+5.0 \pm 6.4\%$ , falling within the range of typical industry overages (Andrews et al., 2017). Tesco Health ( $+15.1 \pm 7.1\%$ ) and Morrisons ( $+9.6 \pm 6.4\%$ ) are similarly modest. Boots ( $+20.7 \pm 7.1\%$ ) and H&B ( $+32.2 \pm 7.5\%$ ) show larger deviations, warranting further chemical analysis.

Key qualitative observations support the quantitative findings. The H&B tablets produced an off-white solution, distinct from other brands. Tesco Health produced an orange solution from iron oxide colourants, making endpoint detection harder.



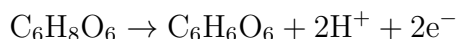
(a) H&B tablets in acidic solution (off-white before titration).



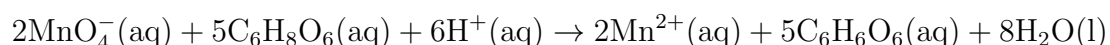
(b) Tesco Health tablets in acidic solution (orange-colored).

Figure 3: Student images of tablet solutions before addition of  $\text{KMnO}_4$  titrant.

The most significant excipient interference comes from the H&B tablets, which list ascorbic acid (vitamin C,  $C_6H_8O_6$ ) as an active ingredient. Ascorbic acid is a reducing agent; its oxidation half-equation is (Babatunde, 2008):



In acidic solution, permanganate oxidises ascorbic acid with a 2:5 stoichiometric ratio (Babatunde, 2008):



Any ascorbic acid present would consume additional  $KMnO_4$  alongside  $Fe^{2+}$ , inflating the apparent titre. Without a blank excipient titration, it is not possible to isolate the iron-only signal from the H&B data. The off-white appearance of the H&B solution is consistent with dissolved ascorbic acid, supporting this interpretation.

The Tesco Health tablets contain iron oxide colouring agents, producing an orange solution that obscures the colourless-to-pink endpoint transition, increasing the likelihood of overshooting. Wellbeing tablets showed the smallest deviation (+5%), consistent with the absence of additional reducing agents in their formulation.

## 5.2 Comparison with Literature

Published analytical studies of commercial iron supplements using similar redox titration methods have reported iron contents ranging from 82% to 106% of label claims (Balarabe and Folashade, 2019). A large-scale USDA study found that measured mineral content in supplements routinely exceeded label claims by 1.5–13%, and up to 25% for some nutrients, reflecting standard industry overage practices (Andrews et al., 2017). The results for Wellbeing (+5%), Morrisons (+9%), Tesco Health (+15%), and Boots (+21%) fall within or near this expected range. However, H&B (+33%) exceeds typical literature values, consistent with co-oxidation of ascorbic acid, inflating the result rather than a genuine 33% overfill.

## 5.3 Answering the Research Question

The measured Fe(II) contents of all five brands exceeded their label claims: Boots ( $16.9 \pm 1.0$  mg vs. 14 mg), H&B ( $26.4 \pm 1.5$  mg vs. 20 mg), Tesco Health ( $16.1 \pm 1.0$  mg vs. 14 mg), Wellbeing ( $14.7 \pm 0.9$  mg vs. 14 mg), and Morrisons ( $15.3 \pm 0.9$  mg vs. 14 mg).

For Wellbeing, the label claim of 14 mg falls within the uncertainty range ( $14.7 \pm 0.9$  mg gives 13.8–15.6 mg), meaning the deviation is not statistically significant and is consistent with the

label. For Morrisons, 14 mg falls just within the lower bound of  $15.3 \pm 0.9$  mg (14.4–16.2 mg), so the deviation is marginal. For Tesco Health, 14 mg falls outside the range of  $16.1 \pm 1.0$  mg (15.1–17.1 mg), indicating a genuine excess consistent with standard pharmaceutical overages. For Boots, 14 mg falls well outside  $16.9 \pm 1.0$  mg (15.9–17.9 mg), confirming a significant overage. For H&B, 20 mg falls well outside  $26.4 \pm 1.5$  mg (24.9–27.9 mg); however, the ascorbic acid co-oxidation identified in the evaluation section accounts for much of this deviation, so the true Fe(II) content is likely closer to the label claim than the measured value suggests.

Since this investigation measured total oxidisable species rather than  $\text{Fe}^{2+}$  alone, the most significant systematic bias is the co-oxidation of ascorbic acid in H&B tablets (Babatunde, 2008), which inflates the measured titre and accounts for much of the +33% deviation. Additional controls, particularly a blank excipient titration, would be required to confirm whether the remaining brands genuinely over-formulate by the measured amounts. Brands without interfering excipients, such as Wellbeing (+5%) and Morrisons (+9%), show deviations consistent with standard pharmaceutical overages (Andrews et al., 2017).

## 6 Evaluation

The  $\text{KMnO}_4$  redox titration successfully differentiated between brands with high reproducibility. The self-indicating endpoint and low-uncertainty volumetric glassware ensured acceptable instrumental uncertainties relative to measured values. However, the method measures total oxidisable species rather than  $\text{Fe}^{2+}$  alone, systematically overestimating iron content when other reducing agents are present.

### 6.1 Limitations

Listed in order of estimated impact:

1. **Co-oxidation of reducing excipients:** Ascorbic acid in the H&B tablets is oxidised by  $\text{MnO}_4^-$  alongside  $\text{Fe}^{2+}$ , inflating the titre. Each H&B tablet contains 80 mg of ascorbic acid ( $\text{C}_6\text{H}_8\text{O}_6$ ,  $M = 176.12 \text{ g mol}^{-1}$ ). Five tablets provide  $400 \text{ mg} = 0.00227 \text{ mol}$  ascorbic acid. From the balanced equation ( $2 \text{ mol MnO}_4^- : 5 \text{ mol C}_6\text{H}_8\text{O}_6$ ), this would consume  $\left(\frac{2}{5}\right) \times 0.00227 = 0.000909 \text{ mol KMnO}_4$ . In a  $25.00 \text{ cm}^3$  aliquot ( $\frac{1}{10}$  of the  $250.0 \text{ cm}^3$  solution), this corresponds to  $0.000909 \text{ mol}$ , equivalent to  $45.5 \text{ cm}^3$  of  $0.002 \text{ mol dm}^{-3} \text{ KMnO}_4$ , exceeding the actual titre of  $23.7 \text{ cm}^3$ . This suggests that the ascorbic acid did not fully dissolve or survive into the titration solution, possibly due to oxidation during dissolution or removal during filtration. Nevertheless, even partial dissolution would account for a substantial titre increase, confirming that the +33% deviation for H&B cannot be attributed to iron(II) content alone.

2. **Endpoint overshooting:** Coloured solutions (e.g., Tesco Health's orange) make the pale pink endpoint harder to detect, causing the operator to add slightly more  $\text{KMnO}_4$  than required. Even  $0.1\text{--}0.2\text{ cm}^3$  of overshoot would increase the calculated iron by approximately  $0.1\text{--}0.2\text{ mg}$  per trial, a small but consistent positive bias across all brands.
3. **Incomplete dissolution and filtration losses:** Some tablet material did not dissolve fully, and filtration was used to obtain a clear solution. Any  $\text{Fe}^{2+}$  trapped in undissolved residue or retained on the filter paper would be lost from the analysis, producing a negative bias. Since the results are high, this loss was evidently smaller than the positive biases described above, but it introduces an unquantified level of uncertainty.
4. **Pooling of five tablets:** Dissolving five tablets together means that the measured mean represents the batch average, not individual tablet content. With only  $n = 3$  concordant titrations on the same solution, inter-tablet variability is not captured.

## 6.2 Suggested Improvements

1. **Control titration for excipients:** A solution of the listed excipients (without iron) at equivalent concentrations could be titrated with  $\text{KMnO}_4$ . Subtracting the blank titre would correct for co-oxidation, isolating the  $\text{Fe}^{2+}$  signal (Mendham et al., 2000).
2. **Instrumental endpoint detection:** Replacing visual endpoint detection with a colorimeter or spectrophotometer (measuring absorbance at  $\sim 530\text{--}550\text{ nm}$ ) would remove subjective judgment, particularly for coloured solutions such as Tesco Health and H&B (Barde, 2024).
3. **Individual tablet analysis:** Titrating tablets individually captures inter-tablet variability and gives a more meaningful standard deviation that can be used for hypothesis testing ( $n = 5$  per brand, rather than 3 titrations of one pooled solution), could not be done due to time constraints in this investigation.
4. **Lower uncertainty for standardized solution:** using solution with lower manufacturer uncertainty would reduce the dominant uncertainty term in the stoichiometric calculation, so the propagated percentage uncertainty on  $\text{Fe(II)}$  per tablet would be smaller.

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