Question 1: (a) $MnO_4^-{}_{(aq)} + 8H^+{}_{(aq)} + 5Fe^{2+}{}_{(aq)} ==> Mn^{2+}{}_{(aq)} + 5Fe^{3+}{}_{(aq)} + 4H_2O_{(l)}$
(b) (i) mol MnO_4^- = 0.02 x 24.3 / 1000 = 0.000486, mol Fe^{2+} = 5 x 0.000486 (1 : 5 in equation) = 0.00243 in 20 cm^3, so scaling up to 1 dm^3, the **molarity of Fe^{2+}** = 0.00243 x 1000 / 20 = **0.122 mol dm^{-3}**.
(ii) The end point is the **first faint permanent pink** due to a trace excess of $KMnO_4$.
(c) mol MnO_4^- = 0.02 x 25.45 / 1000 = 0.000509, mol Fe = 5 x 0.000509 = 0.002545,
mass Fe = 0.002545 x 55.9 = 0.1423 g,
total Fe in wire = 0.1423 x 10 = 1.423 g ($^1/_{10}$th of the made up solution used in titration),
so **% Fe** = 1.423 x 100 / 1.51 = **94.2 %**
(d) The choice of acid is fully discussed in **Ex 6.4 of Advanced Redox Chemistry Part 2**.

Question 2:(a) $2S_2O_3^{2-}{}_{(aq)} + I_{2(aq)} ==> S_4O_6^{2-}{}_{(aq)} + 2I^-{}_{(aq)}$
(b) mol $S_2O_3^{2-}$ = 0.012 x 23.5 / 1000 = 0.000282, mole iodine as I_2 = mol $S_2O_3^{2-}$ / 2 (1 : 2 in equation) = 0.000141,
mass of iodine = 0.000141 x 126.9 x 2 = **0.0358 g**
(c) mol $S_2O_3^{2-}$ = 0.095 x 26.5 / 1000 = 0.002518,
mol of iodine = mole 'thio' / 2 = 0.002518 / 2 = 0.001259 in 25 cm^3,
scaling up to 1 dm^3 gives 0.001259 x 1000 /25 = **0.0504 mol dm^{-3} of molecular iodine I_2**.
mass concentration of I_2 = 0.0504 x 2 x 126.9 = **12.8 g dm^{-3} of iodine**

Question 3: (a) (i) $Sn^{2+}{}_{(aq)} + 2Fe^{3+}{}_{(aq)} ==> Sn^{4+}{}_{(aq)} + 2Fe^{2+}{}_{(aq)}$
(ii) $Cr_2O_7^{2-}{}_{(aq)} + 14H^+{}_{(aq)} + 6Fe^{2+}{}_{(aq)} ==> 2Cr^{3+}{}_{(aq)} + 6Fe^{3+}{}_{(aq)} + 7H_2O_{(l)}$
(b) for a 25cm^3 aliquot titrated, mol $Cr_2O_7^{2-}$ = 0.02 x 26.4 / 1000 = 0.000528,
mol Fe^{2+} titrated = 6 x $Cr_2O_7^{2-}$ = 0.003168 (1 : 6 in equation),
mol Fe_2O_3 = mol Fe / 2 = 0.003168 / 2 = 0.001584,
$Mr(Fe_2O_3)$ = 159.8, mass Fe_2O_3 = 0.001584 x 159.8 = 0.2531 g.
Total mass of Fe_2O_3 = 0.2531 x 10 ($^1/_{10}$th titrated) = 2.531 g. **% Fe_2O_3** = 2.531 x 100 / 2.83 **= 89.4%**
(c) Potassium manganate(VII) isn't used for this titration because it is strong enough to oxidise chloride ions (from the hydrochloric acid) to form chlorine, giving a completely false titration.

Question 4: mol Fe^{2+} = 0.1 x 25 / 1000 = 0.0025,
mol MnO_4^- = mol Fe^{2+} / 5 (from equation 1 : 5) = 0.0005 in 24.15 cm^3,
scaling up to 1 dm^3, **molarity of MnO_4^-** = 0.0005 x 1000 / 24.15 = **0.0207 mol dm^{-3}**.

Question 5: mol $Cr_2O_7^{2-}$ = 0.02 x 21.25 / 1000 = 0.000425,
mol of Fe salt = mol Fe^{2+} titrated = 6 x $Cr_2O_7^{2-}$ = 6 x 0.000425 = 0.00255,
BUT only $^1/_{10}$th of Fe^{2+} salt used in titration,
so 1 g of $FeSO_4.(NH_4)_2S0_4$.$x$$H_2O$ is equal to 0.00255 mol.
Scaling up to 1 mol gives a molar mass for the salt in g mol^{-1} of 1 x 1 /0.00255 = 392.2.
So the formula mass for $FeSO_4.(NH_4)_2S0_4.$$x$$H_2O$ is 392.2.
Now the formula mass of $FeSO_4.(NH_4)_2S0_4$ = 284.1, this leaves 392.2 - 284.1 = 108.1 mass units.
$M_r(H_2O)$ = 18, so 108.1 / 18 = 6.005 mol of water, so **x = 6 in the salt formula,** $FeSO_4.(NH_4)_2S0_4.$**6**H_2O.

Question 6: (a) $2MnO_4^-{}_{(aq)} + 16H^+{}_{(aq)} + 5C_2O_4^{2-}{}_{(aq)} ==> 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)} + 10CO_{2(g)}$
or $2MnO_4^-{}_{(aq)} + 6H^+{}_{(aq)} + 5H_2C_2O_{4(aq)} ==> 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)} + 10CO_{2(g)}$
(b) $M_r(H_2C_2O_4.2H_2O)$ = 126.0,
total mol $H_2C_2O_4.2H_2O$ (or $C_2O_4^{2-}$) = 1.52 / 126 = 0.01206,
but mol of $C_2O_4^{2-}$ in titration = 0.001206 ($^1/_{10}$th used, 25 of 250 cm^3),
mol MnO_4^- = mol of $C_2O_4^{2-}$ / 2.5 (2:5 or 1:2.5 ratio),

mol MnO_4^- = 0.001206 / 2.5 = 0.0004824 (in 24.55 cm^3),
scaling up to 1 dm^3 the **molarity of MnO$_4^-$** = 0.0004824 x 1000 / 24.55 = **0.0196 mol dm^{-3}**.
$M_r(KMnO_4)$ = 158, so in terms of mass **concentration** = 0.0196 x 158 = **3.1 g dm^{-3}**

Question 7: mol $KHC_2O_4.H_2C_2O_4.2H_2O$ (M_r = 254.1) = 0.15 / 254.1 = 0.0005903,
ratio of tetroxalate to manganate(VII) is 2:2.5 or 1:1.25 (note equiv of 2 $C_2O_4^{2-}$ in salt),
so mol MnO_4^- in titration = 0.0005903 / 1.25 = 0.0004723 in 23.2 cm^3,
scaling up to 1 dm^3 gives for **[MnO$_4^-$]** = 0.0004723 x 1000 / 23.2 = **0.0204 mol dm^{-3}**.

Question 8: (a) $2MnO_4^-{}_{(aq)} + 6H^+{}_{(aq)} + 5H_2O_{2(aq)} ==> 2Mn^{2+}{}_{(aq)} + 8H_2O_{(l)} + 5O_{2(g)}$
(b) in titration mol MnO_4^- = 0.02 x 20.25 / 1000 = 0.000405,
MnO_4^-:H_2O_2 ratio is 2:5 or 1:2.5, so mol H_2O_2 in titration = 0.000405 x 2.5 = 0.0010125,
scaling up for total mol H_2O_2 in diluted solution (of 1 dm^3 or 1000 cm^3) = 0.0010125 x 1000 / 25 = 0.0405 mol,
but in the original 50 cm^3 solution,
therefore scaling up to 1 dm^3, the **original molarity of H$_2$O$_2$** is 0.0405 x 1000 / 50 = **0.81 mol dm^{-3}**.

Question 9: (a) $Zn_{(s)} + 2Fe^{3+}{}_{(aq)} ==> Zn^{2+}{}_{(aq)} + 2Fe^{2+}{}_{(aq)}$
(b) mol MnO_4^- in titration = 0.01 x 26.5 / 1000 = 0.000265,
mol Fe (Fe^{2+}) = mol MnO_4^- x 5 = 0.001325 in 20 cm^3 of the alum solution,
scaling up gives total mol Fe = 0.001325 x 500 / 20 = 0.033125,
total mass Fe in the 13.2 g of alum = 0.033125 x 55.9 = 1.852,
so **% Fe =** 1.852 x 100 / 13.2 = **14.0%**

Question 10: mol MnO_4^- in titration = 0.05 x 24.5 / 1000 = 0.001225,
ratio MnO_4^-:$Na_2C_2O_4$ is 2:5 or 1:2.5, so mol $Na_2C_2O_4$ titrated = 0.001225 x 2.5 = 0.003063 in 5 cm^3,
scaling up to 1 dm^3, **molarity Na$_2$C$_2$O$_4$** = 0.003063 x 1000 / 5 = **0.613 mol dm^{-3}**
$M_r(Na_2C_2O_4)$ = 134, so **concentration** = 0.613 x 134 = **82.1 g dm^{-3}**

Question 11: mol $KMnO_4$ = 0.01 x 43.85 / 1000 = 0.0004385, mol Fe (Fe^{2+}) = mol $KMnO_4$ x 5,
mol Fe = 0.0004385 x 5 = 0.0021925, so mol $FeSO_4.xH_2O$ is also 0.0021925,
in the titration $^1/_{20}$th of the salt was used ($^{25}/_{500}$), so $^1/_{20}$th of 12.18 g = 0.0021925 mol of the salt = 0.609 g,
scaling up the mass of 1 mole of the salt is 0.609 x 1 / 0.0021925 = 277.8,
so formula mass of $FeSO_4.xH_2O$ is 277.8, now the formula mass of $FeSO_4$ is 152.0,
so the formula mass of xH_2O = 277.8 - 152.0 = 125.8,
$M_r(H_2O)$ = 18, so x = 125.8 / 18 = 6.989,
so **x = 7** and the formula of the salt is **FeSO$_4$.7H$_2$O**, i.e. seven molecules of water of crystallisation.

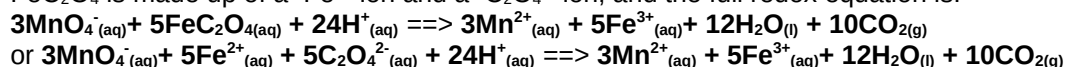**Question 12**: (a) $2MnO_4^-{}_{(aq)} + 6H^+{}_{(aq)} + 5NO_2^-{}_{(aq)} ==> Mn^{2+}{}_{(aq)} + 5NO_3^-{}_{(aq)} + 3H_2O_{(l)}$
(b) mol $KMnO_4$ in titration = 0.025 x 25 / 1000 = 0.000625,
mol ratio MnO_4^-:NO_2^- is 2:5 or 1:2.5, so mol NO_2^- in titration = 0.000625 x 2.5 = 0.0015625 in 24.2 cm^3,
scaling up to 1 dm^3 gives a **molar concentration of NaNO$_2$** of 0.0015625 x 1000 / 24.2 = **0.0646 mol dm^{-3}**
$M_r(NaNO_2)$ = 69, so in terms of mass **concentration** = 0.0646 x 69 = **4.46 g dm^{-3}**

Question 13: $M_r(FeC_2O_4)$ = 143.9, mol FeC_2O_4 in original solution = 2.68 / 143.9 = 0.01862,
scaling down the mol FeC_2O_4 in the titration = 0.01862 x 25 / 500 = 0.000931,
mol $KMnO_4$ in titration = 0.02 x 28.0 / 1000 = 0.00056,
so ratio $KMnO_4$:FeC_2O_4 is 0.00056:0.000931 = giving the 'not so easy to spot' **3:5 the reacting mole ratio**.
FeC_2O_4 is made up of a Fe^{2+} ion and a $C_2O_4^{2-}$ ion, and the full redox equation is:
$3MnO_4^-_{(aq)}$ + $5FeC_2O_{4(aq)}$ + $24H^+_{(aq)}$ ==> $3Mn^{2+}_{(aq)}$ + $5Fe^{3+}_{(aq)}$ + $12H_2O_{(l)}$ + $10CO_{2(g)}$
Or **$3MnO_4^-_{(aq)}$ + $5Fe^{2+}_{(aq)}$ + $5C_2O_4^{2-}_{(aq)}$ + $24H^+_{(aq)}$ ==> $3Mn^{2+}_{(aq)}$ + $5Fe^{3+}_{(aq)}$ + $12H_2O_{(l)}$ + $10CO_{2(g)}$**

Question 14: (a) **$IO_3^-_{(aq)}$ + $5I^-_{(aq)}$ + $6H^+_{(aq)}$ ==> $3I_{2(aq)}$ + $3H_2O_{(l)}$**
(b) mol I^- titrated = 0.100 x 20 / 1000 = 0.002, mole ratio IO_3^-:I^- is 1:5,
so mole IO_3^- reacted = 0.002 / 5 = 0.0004,
so 0.0004 = 0.012 x (volume IO_3^- required) / 1000,
volume IO_3^- required = 0.0004 x 1000 / 0.012 = **33.3 cm³**
(c)(i) mole $S_2O_3^{2-}$ ('thio') = 0.05 x 24.1 / 1000 = 0.001205,
I_2:$S_2O_3^{2-}$ ratio is 1:2 in the titration reaction, so mol I_2 = mole $S_2O_3^{2-}$ / 2 = 0.001205 / 2 = 0.0006025,
now the IO_3^-:I_2 reaction ratio is 1:3,
so mol IO_3^- reacting to give iodine = mole I_2 formed / 3 = 0.0006025 / 3 = 0.000201 in 25 cm³,
so scaling up to 1 dm³ the **molarity of the KIO₃** (IO_3^-) = 0.000201 x 1000 / 25 = **0.00804 mol dm⁻³**,
$M_r(KIO_3)$ = 214.0, so in terms of mass, **concentration** = 0.00804 x 214 = **0.043 g dm⁻³**.
A quicker approach if confident! - ratios from all equations involved are: $2S_2O_3^{2-}$: I_2 : $^1/_3IO_3^-$, means that the overall mole iodate(V) = mole thiosulphate / 6, so you can 'jump' from line '1' to the last 'few' lines. However in exams these days all the stages (i.e. , to , !) are often 'broken down' for you.
(ii) **Starch indicator** is used for the titration, when the last of the iodine reacts with the thiosulphate, the blue colour from the starch-iodine 'complex' is discharged and the solution becomes colourless.

Question 15: (i) mol $KMnO_4$ = 0.02 x 22.5 / 1000 = 0.00045,
mol Fe^{2+} = mol $KMnO_4$ x 5 = 0.00225 in 25 cm³,
scaling up to 1 dm³, **molarity of the original Fe^{2+}** = 0.00225 x 1000 / 25 = **0.090 mol dm⁻³**
(ii) the 2nd titration gives the total concentration of Fe^{2+} + Fe^{3+} because any Fe^{3+} has been reduced to Fe^{2+},
mol $KMnO_4$ = 0.02 x 37.6 / 1000 = 0.000752, total mol Fe^{2+} titrated = mol $KMnO_4$ x 5 = 0.00376 in 25 cm³,
scaling up to 1 dm³, total molarity of Fe^{2+} + Fe^{3+} in original solution = 0.00376 x 1000 / 25 = 0.150 mol dm⁻³,
so using the result from (a) the **Fe^{3+} concentration** = 'Fe' total - Fe^{2+} = 0.150 - 0.090 = **0.060 mol dm⁻³**.

Question 16: you can ignore the 25 cm³ of the solution because you use the same volume in each titration and you can work on the ratio of the moles of 'Fe' out of the (a) and (b) titration calculations.
(a) **mol Fe^{2+}** = 5 x MnO_4^- = 5 x 0.02 x 16.9 / 1000 = **0.00169 mol** = unreacted iron (which dissolved in the acid to form Fe^{2+}).
(b) **mol Fe^{3+}** = $EDTA^{4-}$ = 0.10 x 17.6 / 1000 = **0.00176 mol** = total mol iron in the sample titrated.
(c) calculation (a) gives the relative moles of unreacted iron Fe, as it dissolved to form the titratable Fe^{2+}.
Calculation (b) gives the total of unreacted Fe + the rust i.e. Fe^{3+}, because any Fe^{2+} formed from Fe has been oxidised to Fe^{3+}.
So from the original mixture (in terms of the 25 cm³ sample), mol unreacted Fe = 0.00169,
mol of reacted iron = 0.00176 - 0.00169 = 0.00007.
Therefore the % rusted iron = 0.00007 x 100 / 0.00176 = **3.98 % rusted iron**.

Question 17: (a) $I_{2(aq)} + 2S_2O_3^{2-}{}_{(aq)} ==> S_4O_6^{2-}{}_{(aq)} + 2I^-{}_{(aq)}$

or $I_{2(aq)} + 2Na_2S_2O_{3(aq)} ==> Na_2S_4O_{6(aq)} + 2NaI_{(aq)}$

(b) **Starch indicator** is used, starch gives a blue/black colour with iodine, this colour disappears when the last of the iodine is titrated, so a **blue to colourless** sharp end-point is observed.

(c) mole 'thio' = 0.1 x 17.6/1000 = 0.00176,

mol I_2 = 0.00176 ÷ 2 = 0.00088 in 25 cm^3,

scaling up gives 0.00088 x 1000 ÷ 25 = **0.0352 mol dm^{-3}** for molarity of iodine,

formula mass I_2 = 2 x 127 = 254, so **concentration** = 0.0352 x 254 **= 8.94 g dm^{-3}**

Question 18: (a) $Cr_2O_7^{2-}{}_{(aq)} + 14H^+{}_{(aq)} + 6I^-{}_{(aq)} ==> 2Cr^{3+}{}_{(aq)} + 3I_{2(aq)} + 7H_2O_{(l)}$

(b) $2S_2O_3^{2-}{}_{(aq)} + I_{2(aq)} ==> S_4O_6^{2-}{}_{(aq)} + 2I^-{}_{(aq)}$

(c) **mol 'thio'** = 20 x 0.1/1000 = **0.002**,

therefore from equation (b), **mol iodine** = mol 'thio'/2 = **0.001**

(d) From equation (a) **mol dichromate(VI)** reacting = mol iodine liberated/3 = **0.000333** (3sf)

(e) **M$_r$(K$_2$Cr$_2$O$_7$)** = **294.2**

mass K$_2$Cr$_2$O$_7$ titrated = 0.000333 x 294.2 = **0.0980 g** (3 sf)

(f) Since the aliquot of 25 cm3 is 1/10th of the total solution in the flask, the **total mass** of the **K$_2$Cr$_2$O$_7$ in original sample** dissolved in the flask solution = 10 x 0.0980g = **0.98g**

and the **% purity** of the **K$_2$Cr$_2$O$_7$** = 0.98 x 100/1.01 = **97.0 %** (3 sf)