EXPERIMENT 5

THE MANY OXIDATION STATES OF VANADIUM

CHEMISTRY 134L // SPRING 2020

Intro

Oxidation: Loss of electron(s)

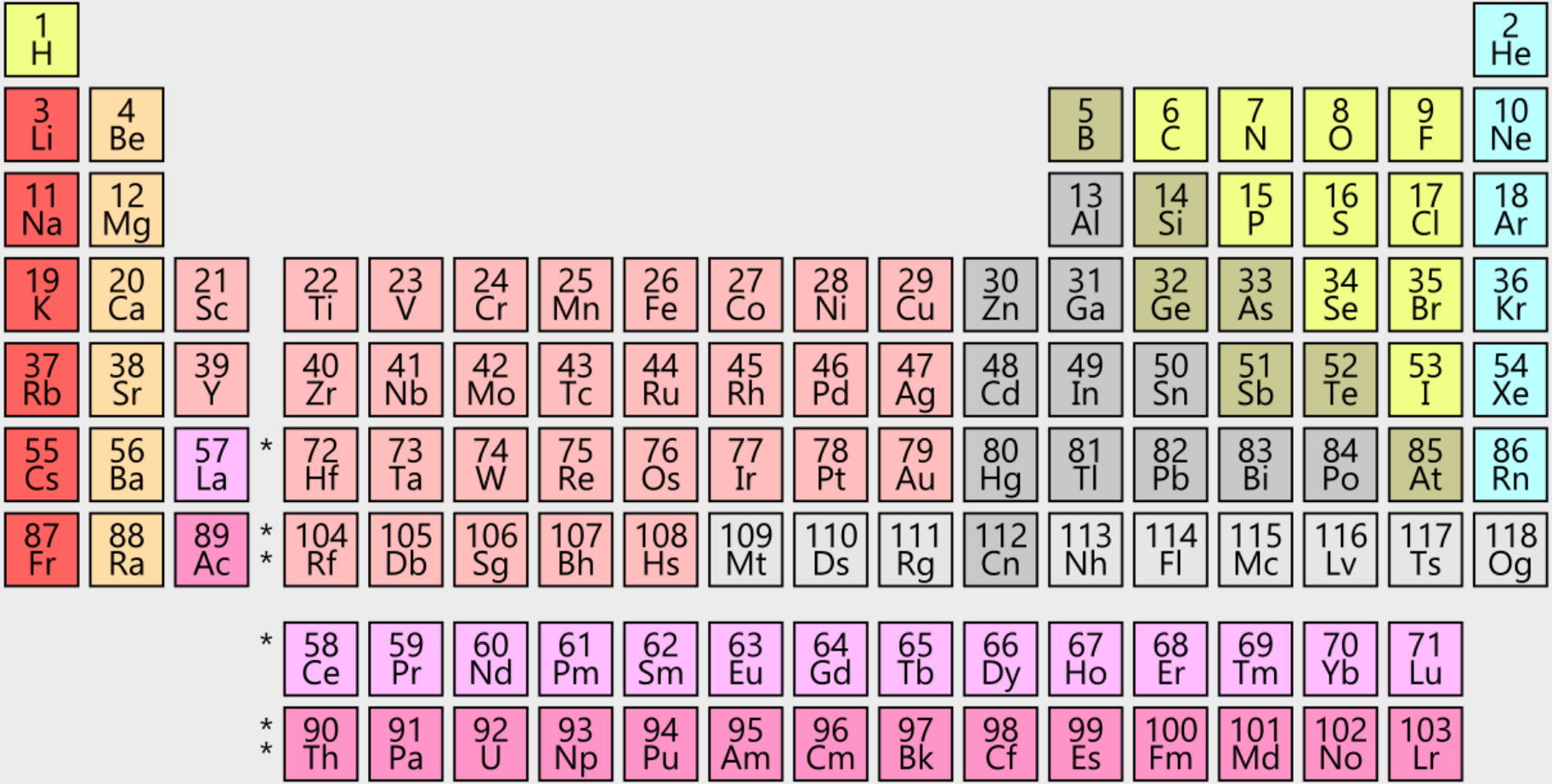
$$Mg \rightarrow Mg^{2+} + 2\,e^-$$

Reduction: Gain of electron(s)

$$2\,H^+ + 2\,e^- \rightarrow H_2$$

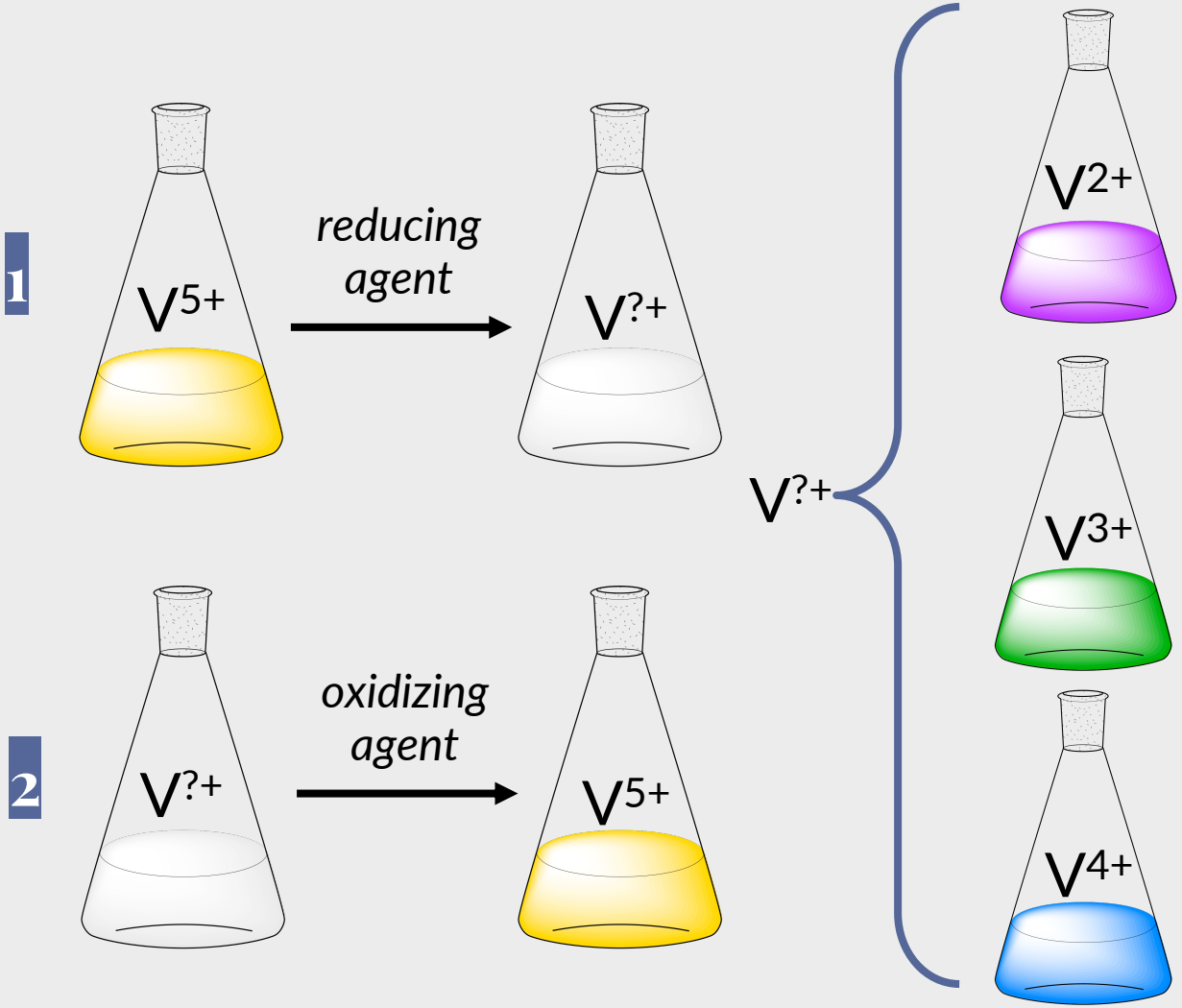
Oxidation Number: Indication of how many electrons (e^-) have been lost or gained by an atom in a chemical species *relative to the neutral atom.*

This is a theoretical/hypothetical number.


1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
57 La
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
89 Ac
104 Rf
105 Db
106 Sg
107 Bh
108 Hs
109 Mt
110 Ds
111 Rg
112 Cn
113 Nh
114 Fl
115 Mc
116 Lv
117 Ts
118 Og
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
90 Th
91 Pa
92 U
93 Np
94 Pu
95 Am
96 Cm
97 Bk
98 Cf
99 Es
100 Fm
101 Md
102 No
103 Lr

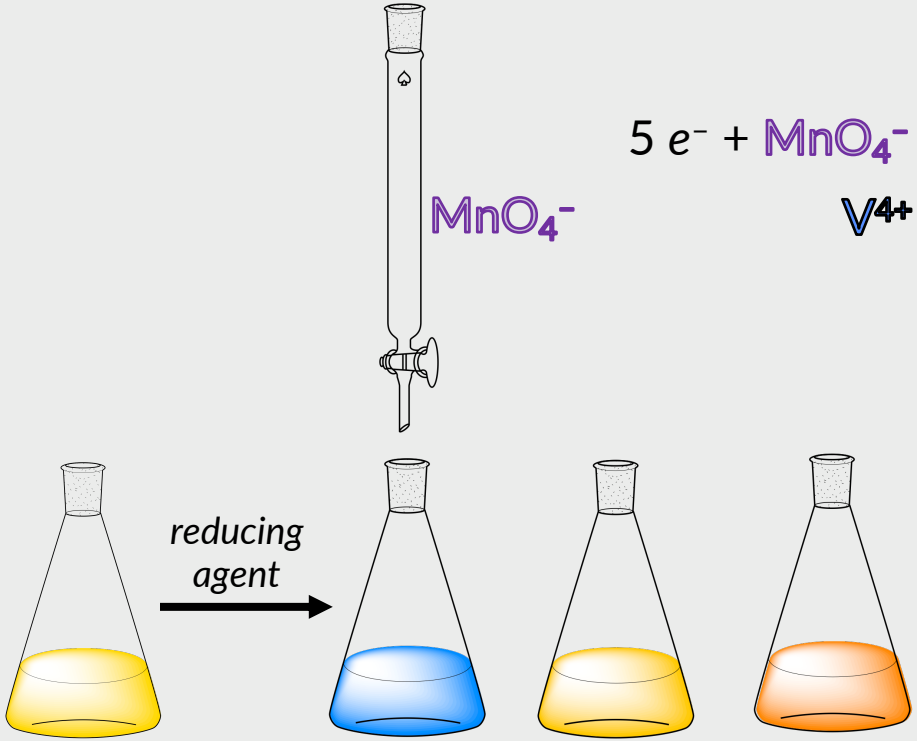
Shades of Vanadium

Overview



Scenario 1

$V^{5+} \rightarrow V^{4+}$



$5\ e^- + MnO_4^- \rightarrow Mn^{2+}$

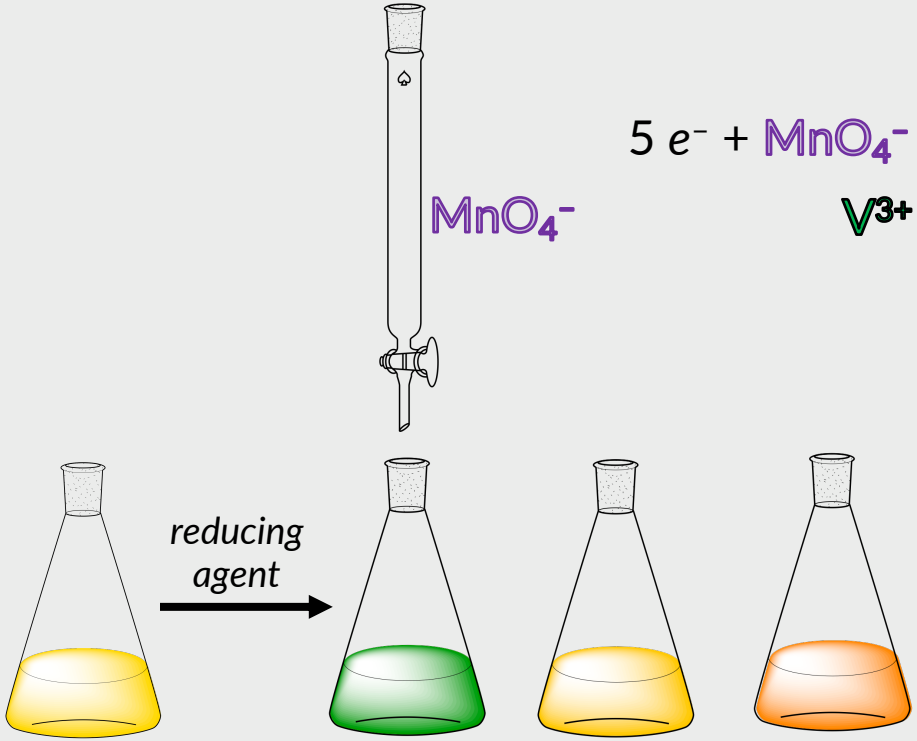
$V^{4+} \rightarrow V^{5+} + 1\ e^-$

$5\ V^{4+} + 1\ MnO_4^- + 8\ H^+ \rightarrow 5\ V^{5+} + 1\ Mn^{2+} + 4\ H_2O$

oxidation

Scenario 2

$V^{5+} \rightarrow V^{3+}$



$5\ e^- + MnO_4^- \rightarrow Mn^{2+}$

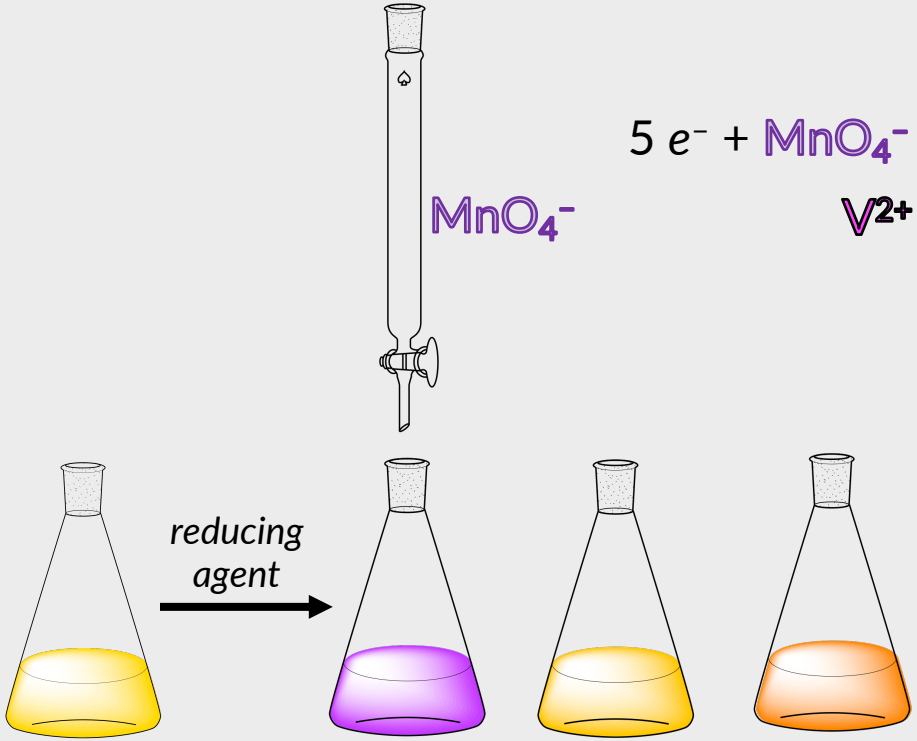
$V^{3+} \rightarrow V^{5+} + 2\ e^-$

$5\ V^{3+} + 2\ MnO_4^- + 16\ H^+ \rightarrow 5\ V^{5+} + 2\ Mn^{2+} + 8\ H_2O$

oxidation

Scenario 3

$V^{5+} \rightarrow V^{2+}$



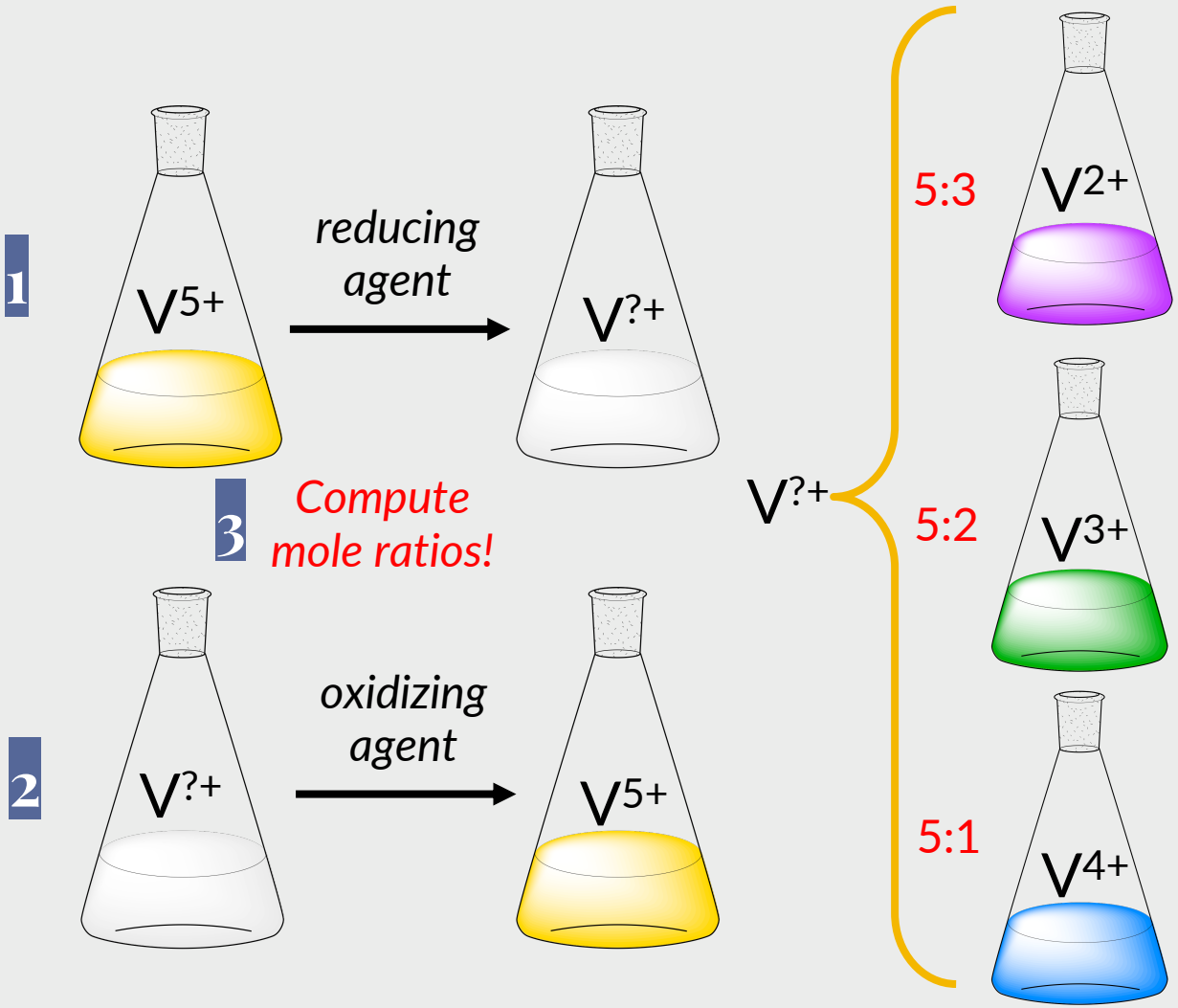
$5\ e^- + MnO_4^- \rightarrow Mn^{2+}$

$V^{2+} \rightarrow V^{5+} + 3\ e^-$

$$\underline{5}\ V^{2+} + \underline{3}\ MnO_4^- + 24\ H^+ \rightarrow 5\ V^{5+} + 3\ Mn^{2+} + 12\ H_2O$$

oxidation

Overview


1
V5+
reducing agent
V?+
3
Compute mole ratios!
2
V?+
oxidizing agent
V5+
V?+
5:3
V2+
5:2
V3+
5:1
V4+

Part 1

SO_2 reduces V^{5+} to V^{X+}

$$SO_2 + 5\ V^{5+} + 2\ H_2O \rightarrow SO_4^{2-} + 2\ V^{X+} + 4\ H^+$$

We can titrate V^{x+} with MnO_4^- to determine the value of X.

Part 2A

Zn reduces V^{5+} to V^{Y+}

$$3\ Zn + 2\ V^{5+} \rightarrow 2\ V^{Y+} + 3\ Zn^{2+}$$

We could titrate V^{Y+} with MnO_4^- to determine the value of Y.

But, instead, we will …

Part 2B

$$1\ \text{part}\ V^{Y+} + 2\ \text{parts}\ V^{5+} \rightarrow 3\ \text{parts}\ V^{Z+}$$

1 mmol *2 mmol* *3 mmol*

Then, we titrate V^{Z+} with MnO_4^- to determine the value of Z.

Part 3A

Zn reduces V^{5+} to V^{Y+}

$$3\ Zn + 2\ V^{5+} \rightarrow 2\ V^{Y+} + 3\ Zn^{2+}$$

↓

We could titrate V^{Y+} with MnO_4^- to determine the value of Y.

But, instead, we will …

Part 3B

2 parts V^{Y+} + 1 part V^{5+} → 3 parts V^{W+}

2 mmol *1 mmol* *3 mmol*

↓

Then, we titrate V^{W+} with MnO_4^- to determine the value of W.

An Example

Balance the following reaction under basic conditions.

$$Fe^{2+}\,(aq) + MnO_4^-\,(aq) \rightarrow Fe^{3+}\,(aq) + MnO_2\,(s)$$

If Fe^{2+} is added as $FeSO_4$ and MnO_4^- as $KMnO_4$, write the complete ionic equation.

1. Assign oxidation states of each element.
2. Separate into reduction and oxidation half-reactions.
3. Balance heavy atoms (atoms that are not O and H).
4. Balance O atoms with H_2O on opposite side.
5. Balance H atoms with H^+ on opposite side.
6. Balance *total charge* with electrons (e^-).
7. Balance electrons by multiplying entire half-reactions.
8. Add the two half-reactions together. Simplify.
9. Neutralize (formation of H_2O) excess H^+ with OH^-.

$$3\,Fe^{2+}\,(aq) + MnO_4^-\,(aq) + 2\,H_2O\,(l) \rightarrow 3\,Fe^{3+}\,(aq) + MnO_2\,(s) + 4\,OH^-\,(aq)$$

$$3\,Fe^{2+}\,(aq) + 3\,SO_4^{2-}\,(aq) + K^+\,(aq) + MnO_4^-\,(aq) + 2\,H_2O\,(l) \rightarrow 3\,Fe^{3+}\,(aq) + 3\,SO_4^{2-}\,(aq) + K^+\,(aq) + MnO_2\,(s) + 4\,OH^-\,(aq)$$

Notes

1. Do Part 1 in the fume hood because SO_2 is toxic.
2. Be careful inserting the rubber hose onto the filter flask.
3. Parts 2 & 3: *Loosely* stopper & swirl for 20 minutes.
4. Minimize interference of O_2 in the air.