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From Balancing Redox Reactions to Determining Change of Oxidation Numbers

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From Balancing Redox Reactions to Determining Change of Oxidation Numbers

By Pong Kau Yuen and Cheng Man Diana Lau

Redox reaction is a core concept in teaching and learning chemistry. This article explores a new method for balancing organic redox reactions that requires the balancing of both atoms and charges. The H^+ , O , H_2O , and e^- are used as balanced vehicles in two half reactions. A non-oxidation number approach can be applied to both molecular and ionic equations. The article also provides standard operating procedures and examples. The number of transferred electrons is first determined by balancing a

half redox reaction; consequently, the change of oxidation numbers can be calculated. The mathematical equation of $Te^- = n \Delta ON$ is established, and the change of oxidation numbers (ΔON) can be counted by the number of transferred electrons (Te^-) and the number of atoms with oxidation numbers change (n). By using this mathematical equation as a new approach, students can conveniently calculate the change of mean oxidation numbers for an assigned atom in a half redox reaction.

Redox reaction is a core concept in teaching and learning chemistry (Goodstein, 1970). The oxidation number method has been widely used for balancing redox reactions, and the determination of the oxidation number is a required step in the process (Herndon, 1997; Chang & Goldsby, 2013; Tro, 2014; Generalic & Vladislavic, 2018). However, the act of balancing organic redox reactions often poses problems for students (Lockwood, 1961; Jensen, 2009). In this article, we discuss a new method, the proton method, that can be applied to both molecular and ionic chemical equations. The method can be used for not only balancing redox equations but also determining the number of transferred electrons and the change of oxidation numbers.

Proton method: Procedures for balancing half reactions

This section shows how the proton method is used to balance both atoms and charges. H^+ , O , H_2O , and e^- are used as vehicles in two half reactions.

Step 1. Balance atoms.

- Step 1.1. Balance all other atoms except H and O.
- Step 1.2. Balance hydrogen atoms with H^+ .
- Step 1.3. Balance oxygen atoms with O .
- Step 1.4. Add two H^+ atoms for each O atom.
- Step 1.5. Convert two H^+ and one O to one H_2O molecule.

Step 2. Balance charges.

- Step 2.1. Count the number of charges on both sides.

- Step 2.2. Add electrons to make charges on both sides equivalent.

Step 3. Convert H^+ to OH^- (optional step when working in a basic medium).

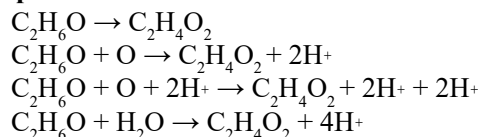
- Step 3.1. Add one OH^- for each H^+ .
- Step 3.2. Convert one OH^- and one H^+ to one H_2O molecule.
- Step 3.3. Simplify an overall equation.

Examples for balancing molecular half reactions

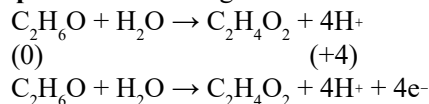
Example 1

Convert the equation $CH_3CH_2OH \rightarrow CH_3COOH$ to $C_2H_6O \rightarrow C_2H_4O_2$.

Step 1. Balance atoms.



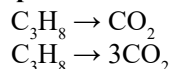
Step 2. Balance charges.

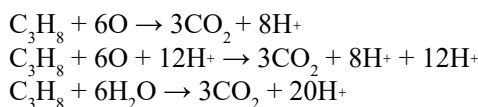


Example 2

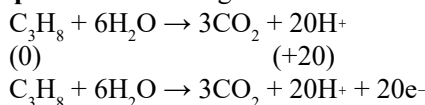
Convert the equation $CH_3CH_2CH_3 \rightarrow CO_2$ to $C_3H_8 \rightarrow CO_2$.

Step 1. Balance atoms.





Step 2. Balance charges.

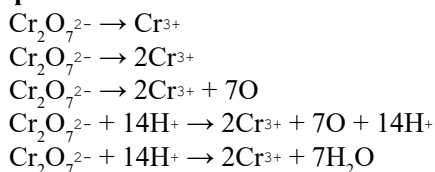


Examples for balancing ionic half reactions

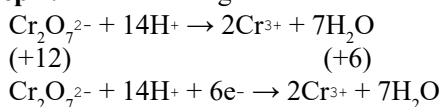
Example 3

Given an ionic equation $\text{Cr}_2\text{O}_7^{2-} \rightarrow \text{Cr}^{3+}$ (in acidic medium):

Step 1. Balance atoms.



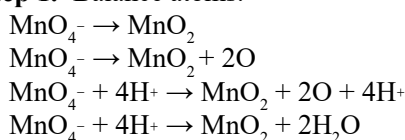
Step 2. Balance charges.



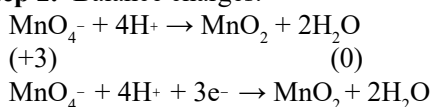
Example 4

Given an ionic equation $\text{MnO}_4^- \rightarrow \text{MnO}_2$ (in basic medium):

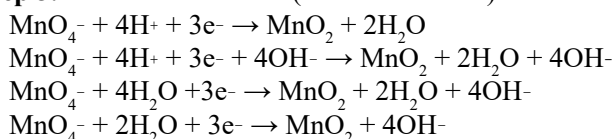
Step 1. Balance atoms.



Step 2. Balance charges.



Step 3. Convert H^+ to OH^- (in basic medium).



Determination of Te^- in a balanced half redox reaction

First, one needs to balance atoms and charges, then the number of transferred electrons can be determined accordingly. In Example 1, the reaction of $\text{C}_2\text{H}_6\text{O} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_4\text{O}_2 + 4\text{H}^+ + 4\text{e}^-$, a loss of four electrons identifies an oxidation reaction. In Example 3, the reaction of $\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$, a gain of six elec-

trons identifies a reduction reaction. An oxidation reaction can be represented by $\text{Te}^- > 0$ (positive value), and a reduction reaction can be represented by $\text{Te}^- < 0$ (negative value). These half-reaction examples are quantified and defined in Table 1.

TABLE 1

Quantifying and defining half redox reactions.

Example of half redox reaction	Te^-	Electrons	Type
$\text{C}_2\text{H}_6\text{O} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_4\text{O}_2 + 4\text{H}^+ + 4\text{e}^-$	+4	loss	oxidation
$\text{C}_3\text{H}_8 + 6\text{H}_2\text{O} \rightarrow 3\text{CO}_2 + 20\text{H}^+ + 20\text{e}^-$	+20	loss	oxidation
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	-6	gain	reduction
$\text{MnO}_4^- + 2\text{H}_2\text{O} + 3\text{e}^- \rightarrow \text{MnO}_2 + 4\text{OH}^-$	-3	gain	reduction

Relationship among Te^- , n , and ΔON in balanced half redox reactions

Based on Examples 1 through 4, the values of Te^- , n , and ΔON are shown in Table 2. In Table 2, Te^- , n , and ΔON

TABLE 2

Quantifying Te^- , n , and ΔON in half redox reactions.

Example of half redox reaction	Atom with oxidation numbers change	Te^-	n	ΔON
$\text{C}_2\text{H}_6\text{O} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_4\text{O}_2 + 4\text{H}^+ + 4\text{e}^-$	C	+4	2	+2
$\text{C}_3\text{H}_8 + 6\text{H}_2\text{O} \rightarrow 3\text{CO}_2 + 20\text{H}^+ + 20\text{e}^-$	C	+20	3	$+\frac{20}{3}$
$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^+ + 6\text{e}^- \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}$	Cr	-6	2	-3
$\text{MnO}_4^- + 2\text{H}_2\text{O} + 3\text{e}^- \rightarrow \text{MnO}_2 + 4\text{OH}^-$	Mn	-3	1	-3

denote the number of transferred electrons, the number of atoms with oxidation number change, and the change of mean oxidation numbers, respectively. ΔON can be counted by the difference between the oxidation number of an atom on the product side (ON_f) and the oxidation number of an atom on the reactant side (ON_i), and it is demonstrated by $\Delta\text{ON} = \text{ON}_f - \text{ON}_i$. An oxidation reaction can be represented by $\Delta\text{ON} > 0$ (positive value), and a reduction reaction can be represented by $\Delta\text{ON} < 0$ (negative value).

In a balanced half reaction, the relationship among Te^- , n , and ΔON can be deduced, and the mathematical equation is shown as follows:

$$\text{Te}^- = n \Delta\text{ON}$$

Proton method: Procedures for balancing overall redox reactions

An overall number of transferred electrons is counted by the least common multiple (LCM) of two half redox reactions. The procedures for balancing an overall reaction are as follows:

Step 1. Divide into two half reactions.

Step 2. Balance all atoms in two half reactions.

Step 3. Balance charges of two half reactions by adding electrons.

Step 4. Make electrons of two half reactions equivalent.

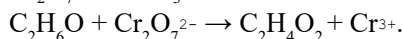
Step 5. Combine and simplify two half reactions.

Step 6. Convert H^+ to OH^- (optional step when working in basic medium).

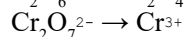
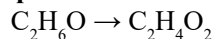
Examples for balancing overall redox reactions

Example 5

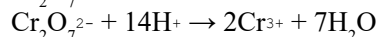
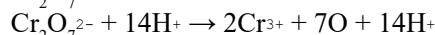
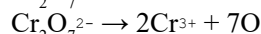
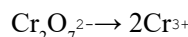
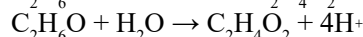
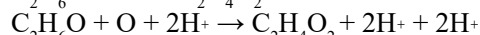
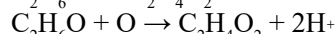
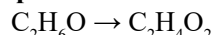
Convert the ionic chemical equation $CH_3CH_2OH + Cr_2O_7^{2-} \rightarrow CH_3COOH + Cr^{3+}$ (in acidic medium) to



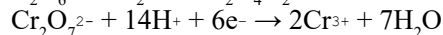
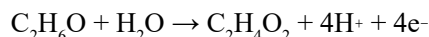
Step 1. Divide into two half reactions:



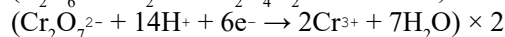
Step 2. Balance all atoms in two half reactions.



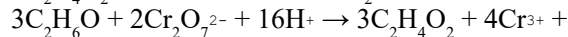
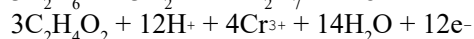
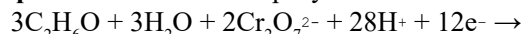
Step 3. Balance charges of two half reactions by adding electrons.



Step 4. Make electrons of two half reactions equivalent (LCM = 12).



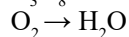
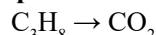
Step 5. Combine and simplify two half reactions.



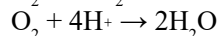
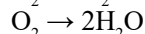
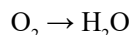
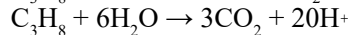
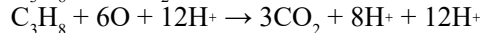
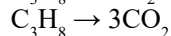
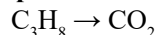
Example 6

Convert molecular chemical equation $CH_3CH_2CH_3 + O_2 \rightarrow CO_2 + H_2O$ to $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$.

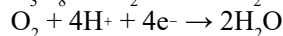
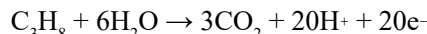
Step 1. Divide into two half reactions.



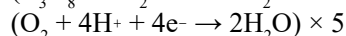
Step 2. Balance all atoms in two half reactions.



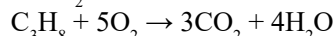
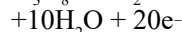
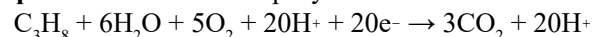
Step 3. Balance charges of two half reactions by adding electrons.



Step 4. Make electrons of the two half reactions equivalent (LCM = 20).



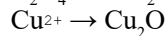
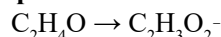
Step 5. Combine and simplify two half reactions.



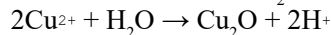
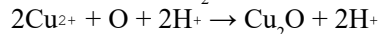
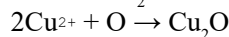
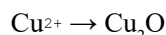
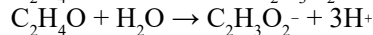
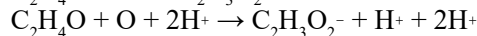
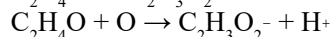
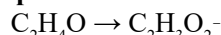
Example 7

Convert ionic chemical equation $CH_3CHO + Cu^{2+} \rightarrow CH_3COO^- + Cu_2O$ (in basic medium) to $C_2H_4O + Cu^{2+} \rightarrow C_2H_3O_2^- + Cu_2O$.

Step 1. Divide into two half reactions.

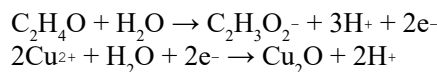


Step 2. Balance all atoms in two half reactions.

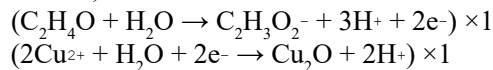


From Balancing Redox Reactions to Determining Change of Oxidation Numbers

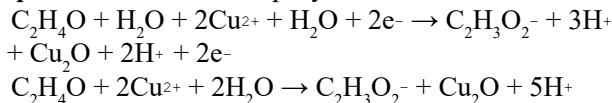
Step 3. Add electrons to balance charges of half reactions.



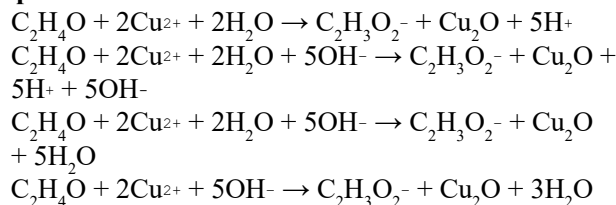
Step 4. Make electrons of two half reactions equivalent (LCM = 2).



Step 5. Combine and simplify into two half reactions.



Step 6. Convert H^+ to OH^- .

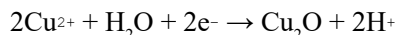


Calculation of ΔON in balanced half redox reactions

By using the oxidation method, the oxidation numbers of atoms are first assigned, then the change of oxidation numbers and the number of transferred electrons are counted, and finally the given equation is balanced. The proton method works in a reverse direction. By balancing an equation, the number of transferred electrons can be determined first, then the change of oxidation numbers can be calculated. Here are two half reactions from Example 7 that demonstrate calculations:

Example 7a

Given the balanced half redox reaction: Reduction



$$n_{\text{Cu}} = 2; \text{Te}^- = -2$$

$$\Delta\text{ON} = \frac{\text{Te}^-}{n}$$

$$\Delta\text{ON}_{\text{Cu}} = \frac{-2}{2} = -1$$

In $2\text{Cu}^{2+} + \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{Cu}_2\text{O} + 2\text{H}^+$, there are two copper atoms gaining two electrons in the half reduction reaction. The change of mean copper oxidation numbers ($\Delta\text{ON}_{\text{Cu}}$) from Cu^{2+} (ON_i) to Cu_2O (ON_f) equals -1 .

Example 7b

Given the balanced half redox reaction: Oxidation



$$n_{\text{C}} = 2; \text{Te}^- = +2$$

$$\Delta\text{ON} = \frac{\text{Te}^-}{n}$$

$$\Delta\text{ON}_{\text{C}} = \frac{+2}{2} = +1$$

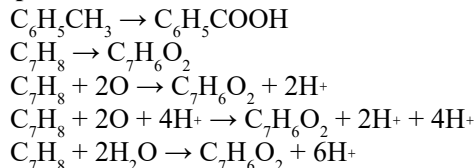
In the balanced half equation of $\text{C}_2\text{H}_4\text{O} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_3\text{O}_2^- + 3\text{H}^+ + 2\text{e}^-$, two carbon atoms carry the oxidation numbers change and lose two electrons. The calculated change of mean carbon oxidation numbers ($\Delta\text{ON}_{\text{C}}$) equals $+1$.

Example 8

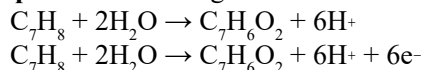
Determine the change of mean carbon oxidation numbers ($\Delta\text{ON}_{\text{C}}$) for a redox couple of $\text{C}_6\text{H}_5\text{CH}_3$ and $\text{C}_6\text{H}_5\text{COOH}$.

Solution

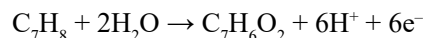
Step 1. Balance atoms.



Step 2. Balance charges.



Step 3. Determine change of mean carbon oxidation numbers.



$$n_{\text{C}} = 7; \text{Te}^- = +6$$

$$\Delta\text{ON} = \frac{\text{Te}^-}{n}$$

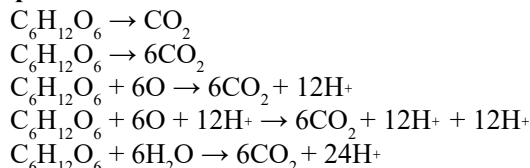
$$\Delta\text{ON}_{\text{C}} = \frac{+6}{7} = +\frac{6}{7}$$

Example 9

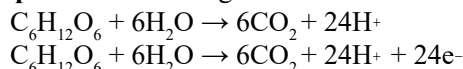
Given a half redox reaction $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow \text{CO}_2$, determine the change of mean carbon oxidation numbers ($\Delta\text{ON}_{\text{C}}$).

Solution

Step 1. Balance atoms.

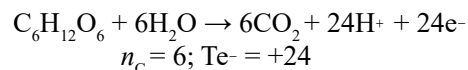


Step 2. Balance charges.



From Balancing Redox Reactions to Determining Change of Oxidation Numbers

Step 3. Determine change of mean carbon oxidation numbers.



$$\Delta\text{ON} = \frac{\text{Te}^-}{n}$$

$$\Delta\text{ON}_{\text{C}} = \frac{+24}{6} = +4$$

Conclusion

By using a non-oxidation number approach, the proton method can be used to balance atoms and charges in redox reactions for both molecular and ionic chemical equations. Regarding a balanced half redox equation, the mathematic equation of $\text{Te}^- = n \Delta\text{ON}$ is established. This offers a new approach to count the change of mean oxidation numbers for an assigned atom in a balanced half reaction.

References

- Chang, R., & Goldsby, K. A. (2013). *Chemistry* (11th ed). McGraw-Hill International.
- Generalic, E., & Vladislavic, N. (2018). Aggregate redox species method: An improved oxidation number change method for balancing redox equations. *Chemistry Journal*, 4(3), 43–49. <http://www.aiscience.org/journal/cj>
- Goodstein, M. P. (1970). Interpretation of oxidation-reduction. *Journal of Chemical Education*, 47(6), 452–457. <https://doi.org/10.1021/ed047p452>
- Herndon, W. C. (1997). On balancing chemical equations: Past and present. A critical review and annotated bibliography. *Journal of Chemical Education*, 74(11), 1359–1362. <https://doi.org/10.1021/ed074p1359>
- Jensen, W. B. (2009). Balancing redox equations. *Journal of Chemical Education*, 86(6), 681–682. <https://doi.org/10.1021/ed086p681>
- Karen, P., McArdle, P., & Takats, J. (2014). Toward a comprehensive definition of oxidation state (IUPAC Technical Report). *Pure and Applied Chemistry*, 86(6), 1017–1081. <https://doi.org/10.1515/ci-2014-0523>
- Karen, P., McArdle, P., & Takats, J. (2016). Comprehensive definition of oxidation state (IUPAC Recommendations 2016). *Pure and Applied Chemistry*, 88(8), 831–839. <https://doi.org/10.1515/pac-2015-1204>
- Lockwood, K. L. (1961). Redox revisited. *Journal of Chemical Education*, 38(6), 326–329. <https://doi.org/10.1021/ed038p326>
- Tro, N. J. (2014). *Chemistry—A molecular approach* (3rd ed.).

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