Good Practice Report

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Balancing redox equations through zero oxidation number method

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Abstract: Many high school students and first-year undergraduate students find it difficult to balance redox reactions. A method using zero oxidation number to balance redox equations is presented herein. This method may shorten the balancing time and lessen the effort. It is a helpful complement to the traditional oxidation number method and half-reaction method.

Keywords: balancing redox equations; oxidation number; stoichiometry.

For high school students and first year undergraduate students, balancing oxidation-reduction (redox) equations is a good training for understanding gain/loss of electrons and half-reaction in electrochemistry (Andraos, 2016; Herndon, 1997; Jensen, 2009). It could be challenging for balancing organic reactions such as exhaustive oxidations of organic compounds because it might involve different oxidation numbers for same type of atoms or a fractional oxidation number on average. As a special case of Ludwig's unconventional oxidation number method (Ludwig, 1996), a strategy using zero oxidation number to balance some redox equations is presented herein.

When encountering a compound that is hard to assign oxidation number for all atoms in it, we can assign zero oxidation number for them in such redox-active compound in one side (reactant side or product side) of a reaction, in case it is easy to assign oxidation numbers for the molecules in the other side. We use exhaustive oxidation of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$) by KMnO_4 in acidic conditions (Guo, 1997) to illustrate this balancing process. $\uparrow$ denotes the sum of increase of oxidation numbers and $\downarrow$ denotes the sum of decrease of oxidation numbers. Since a redox reaction requires the same amount of gain/loss of electrons, we first find out the increase/decrease of the oxidation numbers, which represents the number of loss/gain of electrons; then we use common multiple to balance the equation with minimum integral coefficients. It should be noted that assigning zero oxidation numbers is solely for the balancing purpose. It by no means suggests the real oxidation numbers for the compound(s) (Karen, 2015).

For the exhaustive oxidation of glucose, no matter what relative oxidation numbers are assigned to C, H, and O in glucose, the net increase of oxidation numbers is always the same, as shown below. Therefore, assigning zero oxidation number for balancing the equation is mathematically relevant. In general, assign C,

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H, and O the oxidation number a, b, and c respectively, then chemically, $6a + 12b + 6c = 0$ (Eq. (1)). A simple calculation can prove that the total change of the oxidation number is not related to the relative oxidation number of C, H, and O in the exhaustive oxidation of glucose (Eq. (2)).

Herein we present several examples to show the convenience of this method in balancing redox reactions (see Supplementary Material for more examples and its scope of application). For example, oxidation of glycerine ($\text{C}_3\text{H}_8\text{O}_3$) by KMnO_4 in basic conditions (Kennedy, 1982) and combustion of an energetic salt (Li et al., 2016) based on furazan derivative and melamine ($\text{C}_9\text{H}_{10}\text{N}_{18}\text{O}_4$) can be balanced without assigning fractional oxidation numbers or solving algebraic equations.

This method can easily find the optimal ratio of two explosive mixtures for larger relative explosive power. For example, the optimal mixture of pentaerythryl tetranitrate (PETN, $\text{C}_5\text{H}_8\text{N}_4\text{O}_{12}$) and glyceryl trinitrate (GTN, $\text{C}_3\text{H}_5\text{N}_3\text{O}_9$) must contain four moles of GTN for every mole of PETN (ten Hoor, 2003).

Unlike combustion (Yuen & Lau, 2021), many oxidations of organic compounds only involve a certain part of the compound. Simply letting the reacting part's oxidation number be zero, we can still use this method to balance the equation. For example, propene oxidation by KMnO_4 gave potassium acetate and carbonate as the oxidation products (Burrell, 1959). During the oxidation, one carbon was oxidized to carboxylate, and the other was transformed into carbonate.

For oxidation of nicotine by CrO_3 (Thomas, 2014), only the atoms in the pyrrolidine ring got oxidized, so the redox could be balanced by assigning zero oxidation number to the side ring.

For a more complicated oxidation of a tetrahydroquinoline compound in basic solution (Klemm, 1996), assigning zero oxidation number to the reacting part will facilitate the balancing process. During the oxidation, four carbons in the tetrahydroquinoline ring got oxidized to carboxylate, one phenyl ring (six carbons) was oxidized to carbonate (see the circled part, the partial formula is $\text{C}_{10}\text{H}_{10}$).

Oxidation of a double complex salt, $[\text{Cr}(\text{H}_2\text{NCONH}_2)_6]_4[\text{Cr}(\text{CN})_6]_3$, by potassium permanganate in acidic conditions (Stout, 1995) can be balanced readily using this method.

For some disproportionation reactions, assigning zero oxidation number for specific compound(s) on one side (but keep at least one compound regular oxidation number on that side, then balancing the equation from the other side) could simplify the balancing process. For example, letting oxidation number of P and I in P_2I_4 be zero and keeping H_2O be normal would facilitate the balancing of the following disproportionation reaction (Giomini, Marrosu, & Cardinali, 1995; Kolb, 1979, 1981).

For the double redox reaction (Tóth, 1997) of ethanol and potassium iodide in water (an electrolysis reaction), letting oxidation number of C, H, and O in both ethanol and water be zero simplifies the balancing process. This way, balancing from the products side only involves the redox between K_2CO_3 and CHI_3 .

This method is also good for balancing redox equations involving Zintl phases (Bohme et al., 2007).

Application of this methodology in balancing organic redox equations was briefly covered in my undergraduate Organic Chemistry-II lecture. Before presenting this method, only a quarter of the class could balance ethanol oxidation by $\text{Na}_2\text{Cr}_2\text{O}_7$ reaction; after explaining this method, about half of the class could balance oxidation of p-picoline to p-picolinic acid equation (for detail, see the Supplementary Material).

In summary, balancing complex redox equations using zero-oxidation number method may shorten the time and lessen the effort. It is a versatile method for balancing many redox reactions, especially disproportionation and double redox reactions. It is a helpful complement to the traditional oxidation number method and half-reaction method.

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