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Teaching Redox as a Chinese Buffet

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I have taught Wetland Ecology 25 times - 15 as an Adjunct Associate Professor at the University of Michigan and UM-Dearborn while I worked at the USGS-Great Lakes Science Center in Ann Arbor and 10 in my new life in academia as the Empire Innovation Professor of Wetland Science at SUNY--The College at Brockport in my native western New York State. Surprisingly, my favorite lecture of all time is on oxidation-reduction, or redox. Here is the story behind that strange outcome and an overview of the lecture.

In my first year at Michigan, I presented a somewhat straightforward lecture on redox from the Mitsch and Gosselink textbook (first edition) that followed the reading assignment. I thought it was going well until I saw the need to pose this question, "When I say 'ion,' does everyone know what I mean?" Four students in the class of 40+ informed me that they did not, which was reasonable because they were landscape architecture grad students taking the course because they had interests in design work for wetland restorations and had no chemistry background.

I am not sure how I managed to finish the lecture, but I knew that a new approach was needed for the following year that could reach students with limited understanding of chemistry. I like to use analogies during lectures, and it dawned on me that I could make an analogy with a Chinese buffet. I truly enjoy Chinese buffets, so imagine me giving the following lecture with exaggerated hand gestures and voice intonations as I move through Powerpoint slides (●) and get into the buffet analogy (*with accompanying spoken explanations and asides*).

- REDOX (OXidation-REDuction) *sounds better than OXRED*.
- As organic matter decomposes, it is oxidized (a process that emits electrons). Something has to be reduced (accept the electrons) *or maybe lightning would discharge from the sediment*.
- During oxidation, a chemical loses electrons (e.g., Fe^{+2} → $Fe^{+3} + e^-$). *That Fe^{+3} ferric ion is the reddish brown color that you see on your old car when the paint is gone and the iron is exposed to the air and oxidation.*

FIGURE 1. Diagram showing decrease of organic substrate by oxidation and release of electrons through time, accompanied by sequential reduction of oxygen, nitrate, manganese (manganous), iron (ferrous), sulfate, and carbon dioxide. (Source: copyrighted image from Mitsch and Gosselink 2015, derived from Reddy and DeLaune 2008; permission received from John Wiley & Sons;)

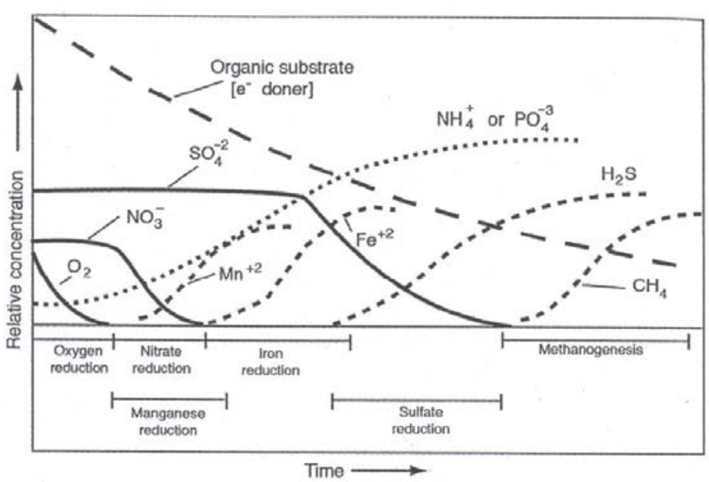
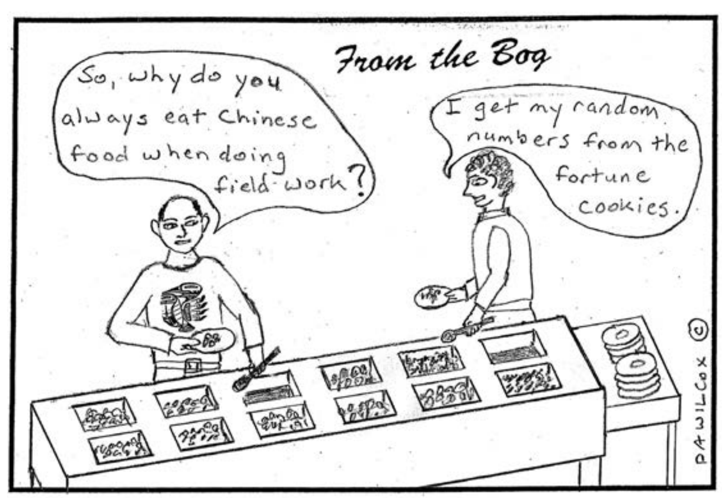


FIGURE 2. Chinese buffet (D.A.Wilcox: From the Bog).



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- During reduction, a chemical gains electrons (e.g., $Fe^{+3} + e^{-} \rightarrow Fe^{+2}$).
- Eh = redox potential, or the proportion of oxidized to reduced components. It is a measure of electron availability or pressure of electrons. Eh is given in units of mV (electron availability measured on a hydrogen scale).
- When in an oxidized environment, a lot of electrons are available, so Eh is high. As reduction occurs, electrons are taken up and Eh goes down.
- See Figure 1. *This can be a confusing diagram. Did any of you figure out what it means from your reading assignment? Within five to ten minutes, you will understand it completely.*
- See Figure 2. *I am going to teach redox as if we were at a Chinese buffet, and I love Chinese buffets!*
- It is the end of the evening; all entrees are available but in limited quantities, and they will not make any more because they do not want to throw food away.
- Look again at Figure 1. *It has concentrations of various components on the Y-axis and time on the X-axis. As you can see, as the organic substrate is oxidized over time, it decreases in concentration and serves as an electron donor (spelled with an o).* The analogy to redox is that the depletion of organic substrate is actually loss of stomach space, and stomach space is valuable at a Chinese buffet.
- My Objective:
  - Stomach space is limited, so use it wisely.
  - EAT NO RICE or anything with little taste that can use up stomach space.
  - There is competition with others for limited quantities of the tastiest food.
  - Eat favorite food until it is all gone (Hunan beef) and do not let anyone else eat it. I then pick a student and use a basketball move to box them out.
  - When gone, move to second favorite (there really is none) and eat the sesame chicken until it is nearly all gone.
  - Then move to the third favorite (Szechwan chicken), fourth favorite (Mongolian beef), etc.
  - See Table 1, noting chemical reactions, and refer to Figure 1.
  - *Hunan beef is oxygen (O_2).*
  - *Sesame chicken is nitrate (NO_3^-).*
  - *Szechwan chicken is manganese (Note that Figure 1 shows the increase in reduced manganous (Mn^{+2}) ion, rather than the original oxidized manganic (Mn^{+4}) ion to avoid a messy graph – same for the remaining chemicals).*
  - *Mongolian beef is oxidized ferric (Fe^{+3}) ion.*
  - *Kung Pao chicken is sulfate (SO_4^{-2}).*
  - *Hunan bean curd is carbon dioxide (CO_2).*
- See Figure 3. *When carbon dioxide is the electron acceptor, the end product is methane, a process known as methanogenesis.*

TABLE 1. Order of food eaten at Chinese buffet and corresponding reduction reactions.

Hunan beef	$O_2 \rightarrow H_2O$
Sesame chicken	$NO_3^- \rightarrow N_2$
Szechwan chicken	$Mn^{+4} \rightarrow Mn^{+2}$
Mongolian beef	$Fe^{+3} \rightarrow Fe^{+2}$
Kung Pao chicken	$SO_4^{-2} \rightarrow HS^-$
Hunan beef curd	$CO_2 \rightarrow CH_4$

FIGURE 3. Methanogensis (D.A. Wilcox: From the Bog).

• See Figure 4. *Derived from the text (Mitsch and Gosselink), here are the full chemical reactions for oxidation and reduction.*

Figure 4. Chemical equations showing oxidation of organic substrate and sequential reduction of oxygen, nitrate, manganese (manganous), iron (ferrous), sulfate, and carbon dioxide. (Source: Mitsch and Gosselink 2015; permission received from John Wiley & Sons)

Oxidation of organic substrate:

$$[CH_2O]n + nH_2O \rightarrow nCO_2 + 4ne^- + 4nH^+$$

Reduction transformations:

$$O_2 + 4e^- \rightarrow 2H_2O$$

$$2NO_3 + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$$

$$MnO_2 + 2e^- + 4H^+ \rightarrow Mn^{++} + 2H_2O$$

$$Fe(OH)_3 + e^- + 3H^+ \rightarrow Fe^{++} + 3H_2O$$

$$SO_4^{=} + 8e^- + 9H^+ \rightarrow HS^- + 4H_2O$$

$$CO_2 + 8e^- + 8H^+ \rightarrow CH_4 + 5H_2O$$

• See Table 2. *More simply, from the text, here are the electron acceptors in order, showing oxidized and reduced forms, along with the Eh ranges in mV.*

Table 2. Oxidized and reduced forms of several elements and approximate redox potentials for transformation. (Source: Copyrighted image from Mitsch and Gosselink 2015; permission received from John Wiley & Sons)

Element	Oxidized Form	Reduced Form	Approximate Redox Potential for Transformation (mV)
Nitrogen	NO_3^- (nitrate)	N_2O, N_2, NH_4^+	250
Manganese	Mn^{4+} (manganic)	Mn^{2+} (manganous)	225
Iron	Fe^{3+} (ferric)	Fe^{2+} (ferrous)	+100 to −100
Sulfur	$SO_4^{=}$ (sulfate)	$S^{=}$ (sulfide)	−100 to −200
Carbon	CO_2 (carbon dioxide)	CH_4 (methane)	Below −200

• Look again at Figure 1. *This diagram now makes sense. It shows organic substrate being oxidized (emitting electrons) and the succession of electron acceptors/end products. That is redox.* ■

REFERENCES

Mitsch, W.J. and J.G. Gosselink. 2015. Wetlands. Fifth edition. John Wiley & Sons, Hoboken, New Jersey, USA.