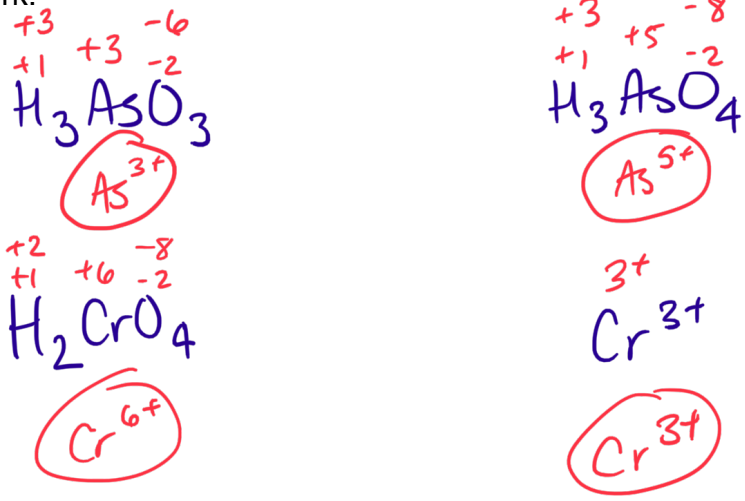
CHEM 1032 – Spring 2023 - Challenge Question 8 - key

How does redox help us remove toxic compounds?

Depending on its oxidation state, chromium is either a toxic compound (*google Erin Brockovich*) or a possibly essential nutrient. Analyze the reaction below to see if mixing H_2CrO_4 with arsenic is a beneficial reaction.

$$H_3AsO_3\ (aq) + H_2CrO_4\ (aq) \leftrightarrows H_3AsO_4\ (aq) + Cr^{3+}$$

A. First, identify the oxidation state of As and Cr in the products and reactants. Show your work.



B. Which compound is being reduced? Which compound is being oxidized? Which compound is the reducing agent? Which compound is the oxidizing agent? Explain your answer.

$As^{3+} \longrightarrow As^{5+}$ Because As^{3+} is gaining positive charge As is losing electrons. Therefore it is being oxidized. Compounds which are oxidized are reducing agents because they are transferring electrons away.

$Cr^{6+} \longrightarrow Cr^{3+}$ Because Cr^{6+} is losing positive charge Cr is gaining electrons. Therefore it is being reduced. Compounds which are reduced are oxidizing agents because they pull electrons away from other compounds.

C. Balance the redox reaction in acidic conditions. Clearly show all of your work.

$H_3AsO_3 + H_2CrO_4 \rightleftharpoons H_3AsO_4 + Cr^{3+}$

$3(H_2O + H_3AsO_3 \rightarrow H_3AsO_4 + 2H^+ + 2e^-)$

$3H_2O + 3H_3AsO_3 \rightarrow 3H_3AsO_4 + 6H^+ + 6e^-$

$2(3e^- + 6H^+ + H_2CrO_4 \rightarrow Cr^{3+} + 4H_2O)$

$6e^- + 12H^+ + 2H_2CrO_4 \rightarrow 2Cr^{3+} + 8H_2O$

$6H^+ + 3H_3AsO_3 + 2H_2CrO_4 \rightarrow 3H_3AsO_4 + 2Cr^{3+} + 5H_2O$

	R	P
H	19	19
As	3	3
Cr	2	2
O	17	17

	R	P
Charge	+6	+6 ✓

D. The relevant half reactions are shown below. Calculate the value of $E°_{cell}$. Is the reaction spontaneous or nonspontaneous? Explain.

$H_3AsO_4 + 2\ H^+ + 2e^- \leftrightarrows H_3AsO_3 + H_2O$	E° 0.575 V
$H_2CrO_4 + 6\ H^+ + 3\ e^- \leftrightarrows Cr^{3+} + 4\ H_2O$	E° 2.36 V

As^{3+} is being oxidized → Anode

Cr^{6+} is being reduced → cathode

$E°_{cell} = E_{cath} - E_{anode} = 2.36\ V - 0.575\ V$

$= 1.785\ V$

The reaction is spontaneous because the voltage is positive, so electrons are favored to move from As to Cr.

E. Chromium (VI) is a toxic species. Using specific information from Parts A, B, C, and D determine if the reaction shown above is beneficial in making chromium less toxic. Explain. Is arsenic a good choice for the reaction? Explain.

Based on Part A, the reaction is written as Cr^{6+} turning into Cr^{3+}, which we identified in Part B as being reduction. In Part C we were able to balance the redox reaction in acidic conditions so it does seem viable. In Part D we calculated the $E°_{cell}$ as +1.785 V, which indicates a spontaneous reaction at standard conditions. Taken together the reaction should in fact convert toxic Cr^{6+} into a nontoxic version of chromium.

BUT Arsenic is toxic! So while it works to make chromium less toxic, there's not much we can do about the arsenic, so a different reducing agent would be a better choice.

This challenge question was inspired by the research article below:

Coupled Redox Transformation of Chromate and Arsenite on Ferrihydrite
Cerkez, E., et al. Environmental Science and Technology, 49, 5

https://pubs.acs.org/doi/full/10.1021/es505666w