Demonstrating the Chemistry Behind Why the Statue of Liberty is Green
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Rapid Formation of Copper Patinas: A Simple Chemical Demonstration of Why the Statue of Liberty Is Green

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Cuprite: $\text{Cu}_2\text{O}$

Copper: Cu

Tenorite: CuO

Atacamite?: $\text{Cu}_2(\text{OH})_3\text{Cl}$

Azurite?: $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$
THE NEW COLOSSUS.

NOT LIKE THE BRAZEN GIANT OF GREEK FAME,
WITH CONQUERING LIMBS ASTRIDE FROM LAND TO LAND;
HERE AT OUR SEA-WASHED, SUNSET GATES SHALL STAND
A MIGHTY WOMAN WITH A TORCH, WHOSE FLAME
IS THE IMPRISONED LIGHTNING, AND HER NAME
MOTHER OF EXILES, FROM HER BEACON-HAND
GLOWS WORLD-WIDE WELCOME: HER MILD EYES COMMAND
THE AIR-BRIDGED HARBOR THAT TWIN CITIES FRAME.
"KEEP ANCIENT LANDS, YOUR STORIED POMP!"
GRIES SHE
WITH SILENT LIPS. "GIVE ME YOUR TIRED, YOUR
POOR;
YOUR RUDDLED MASSES YEARNING TO BREATHE FREE.
THE WRETCHED REFUSE OF YOUR TEEMING SHORE.
SEND THESE: THE HOMELESS, TEMPEST-VOST TO ME.
I LIFT MY LAMP BESIDE THE GOLDEN DOOR!"

THIS TABLET, WITH HER SONNET TO THE EARTHOLI STATUE
OF LIBERTY ENGRAVED UPON IT, IS PLACED UPON THESE WALLS
IN LOVING MEMORY OF
EMMA LAZARUS
BORN IN NEW YORK CITY, JULY 22, 1849
DIED NOVEMBER 19TH, 1887.
Formation of cuprite:

$$2 \text{Cu(s)} + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{Cu}_2\text{O(s)}$$
Cuprite reacts with a variety of atmospheric compounds:

\[ 4 \text{Cu}_2\text{O}(s) + 2 \text{SO}_2(g) + 3 \text{O}_2(g) + 6 \text{H}_2\text{O}(l) \rightarrow 2 \text{Cu}_4(\text{SO}_4)(\text{OH})_6(s) \]  
(brochantite)

\[ 6 \text{Cu}_2\text{O}(s) + 4 \text{SO}_2(g) + 5 \text{O}_2(g) + 8 \text{H}_2\text{O}(l) \rightarrow 4 \text{Cu}_3(\text{SO}_4)(\text{OH})_4(s) \]  
(antlerite)

\[ 2 \text{Cu}_2\text{O}(s) + 2 \text{Cl}^-(aq) + \text{O}_2(g) + 4 \text{H}_2\text{O}(l) \rightarrow 2 \text{Cu}_2(\text{OH})_3\text{Cl}(s) + 2 \text{OH}^-(aq) \]  
(atacamite)

\[ 6 \text{Cu}_2\text{O}(s) + 8 \text{CO}_2(g) + 3 \text{O}_2(g) + 4 \text{H}_2\text{O}(l) \rightarrow 4 \text{Cu}_3(\text{CO}_3)_2(\text{OH})_2(s) \]  
(azurite)
Demonstration of tenorite and cuprite formation

$$2 \text{Cu(s)} + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{Cu}_2\text{O(s)} \text{ AND Cu(s)} + \text{O}_2(\text{g}) \rightarrow \text{CuO(s)}$$
Demonstration of rapid patina formation

Rapid Formation of a Copper Patina

https://youtu.be/nng3E1ZyiRg
The electrochemical process can be viewed as:

\[ 2 \text{H}_2\text{O}(l) + 2 \text{e}^- \rightarrow \text{H}_2(g) + 2 \text{OH}^-(aq) \quad E^0 = -0.83 \text{ V} \]

\[ \text{Cu}^{2+}(aq) + 2 \text{e}^- \rightarrow \text{Cu}(s) \quad E^0 = +0.34 \text{ V} \]

\[ 2 \text{H}_2\text{O}(l) + \text{Cu}(s) \rightarrow \text{Cu}^{2+}(aq) + \text{H}_2(g) + 2 \text{OH}^-(aq) \quad E^0 = -1.17 \text{ V} \]
Further experimentation:  
Reaction with peroxide

\[2 \text{Cu}^{2+}(aq) + \text{HO}_2^-(aq) + \text{OH}^-(aq) \rightarrow 2 \text{Cu}^+(aq) + \text{O}_2(g) + \text{H}_2\text{O}(l)\]

\[\text{Cu}^{2+}(aq) + e^- \rightarrow \text{Cu}^+(aq) \quad E^0 = +0.15 \text{ V}\]

\[\text{O}_2(g) + \text{H}_2\text{O}(l) + 2e^- \rightarrow \text{HO}_2^-(aq) + \text{OH}^-(aq) \quad E^0 = -0.07 \text{ V}\]

\[2 \text{Cu}^{2+}(aq) + \text{HO}_2^-(aq) + \text{OH}^-(aq) \rightarrow 2 \text{Cu}^+(aq) + \text{O}_2(g) + \text{H}_2\text{O}(l) \quad E^0 = +0.08 \text{ V}\]
Further experimentation: Reaction with ammonia

\[ \text{Cu}^{2+}(aq) + 4 \text{NH}_3(aq) \rightarrow \text{Cu(NH}_3)_4^{2+}(aq) \]
Further experimentation:
Colorful copper campfire chemistry

penny → NH₃/NaCl → patina
Connections to the Curriculum

- Elements vs. compounds
- Metals vs. ions
- Elements that form multiple charges (Cu\(^+\)/Cu\(^{2+}\))
- Environmental chemistry & climate change
- Chemistry of the atmosphere
- Electrochemistry
- Chemical reactions & chemical reactivity
- Flame tests
- Social studies connections
- Exploratory learning
Where can I learn more?

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Chemical Education Xchange

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cuprite    copper    tenorite    cuprite    atacamite?    azurite?

Cu₂O    Cu    CuO    Cu₂O    Cu₂(OH)₃Cl    Cu₃(CO₃)₂(OH)₂