observe what happens then explain:

a) First add the about 2/3 of the pink solution to the colorless solution in the larger vial. Use a glass Pasteur pipette for the transfer of solutions.
The pink solution is cobalt (II) chloride in water.
The colorless solution is sodium phosphate.

b) Now add the remaining 1/3 of the pink solution to the smaller vial containing a (different) colorless solution.
The pink solution is cobalt (II) chloride in water.
The colorless solution is sodium nitrate.

Explain what happens in (a) and in (b).

) When the pink cobalt chloride solution is added to the sodium phosphate solution, a deep ultramarine blue precipitate forms. The precipitate is a new species, most likely the product of cobalt(II) ions plus phosphate ions.

) When the pink cobalt chloride solution is added to the sodium nitrate solution, no precipitate forms; the final solution is still pink. No reaction appears to occur.

Write a balanced equation for the reaction in (a). (s)

\[ \text{2Na}_3\text{PO}_4 + \text{3CoCl}_2 \rightarrow \text{6Na}^+ + \text{6Cl}^- + \text{Co}_3(\text{PO}_4)_2 \text{ (s)} \]

Write the net reaction for (a).

\[ \text{2PO}_4^{3-} + \text{3Co}^{2+} \rightarrow \text{Co}_3(\text{PO}_4)_2 \text{ (s)} \]

The precipitate formed in reaction (a) is a paint pigment, sold as “cobalt violet”. You have probably already deduced its formula as \( \text{Co}_3(\text{PO}_4)_2 \). I found on a website another “recipe” for making cobalt violet pigment which uses 2.00 g \( \text{CoCl}_2 \cdot \text{6H}_2\text{O} \) dissolved in water and added to 1.3 g \( \text{Na}_3\text{PO}_4 \cdot 10 \text{H}_2\text{O} \). The product has the same formula, \( \text{Co}_3(\text{PO}_4)_2 \).

Which will produce the greatest mass of cobalt violet pigment, A or B? (Do calculations on back of page)

A: 2.00 g \( \text{CoCl}_2 \cdot \text{6H}_2\text{O} \) dissolved in water and added to 1.3 g \( \text{Na}_3\text{PO}_4 \).
B: 2.00 g \( \text{CoCl}_2 \cdot \text{6H}_2\text{O} \) dissolved in water and added to 1.3 g \( \text{Na}_2\text{HPO}_4 \cdot 10 \text{H}_2\text{O} \).

\[
\begin{align*}
2.00 \text{ g } \text{CoCl}_2 \cdot \text{6H}_2\text{O} & \times (1 \text{ mol } \text{CoCl}_2 \cdot 6\text{H}_2\text{O} / 238 \text{ g}) = 8.4 \times 10^{-3} \text{ mol CoCl}_2 \\
1.3 \text{ g } \text{Na}_3\text{PO}_4 & \times (1 \text{ mol } \text{Na}_3\text{PO}_4 / 163.9 \text{ g}) = 7.9 \times 10^{-3} \text{ mol } \text{Na}_3\text{PO}_4
\end{align*}
\]

Now the amount of \( \text{Na}_3\text{PO}_4 \) needed to react exactly with \( 8.4 \times 10^{-3} \text{ mol } \text{CoCl}_2 \) is:
\[8.4 \times 10^{-3} \text{ mol Co}^{2+} \times \left(2 \text{ mol PO}_4^{3-} / 3 \text{ mol Co}^{2+}\right) = 5.6 \times 10^{-3} \text{ mol Na}_3\text{PO}_4\]

This is less than the amount of phosphate in the 1.3 g, so that means the Co will react completely and there is phosphate in excess. The amount of cobalt violet produced, \(\text{g Co}_3(\text{PO}_4)_2\), will be:

\[8.4 \times 10^{-3} \text{ mol Co}^{2+} \times \left(1 \text{ mol Co}_3(\text{PO}_4)_2 / 3 \text{ mol Co}^{2+}\right) \times (366.7 \text{ g} / 1 \text{ mol Co}_3(\text{PO}_4)_2) = 1.03 \text{ g Co}_3(\text{PO}_4)_2\]

We know already that 2.00 g CoCl\(_2\)·6H\(_2\)O = 8.4 \times 10^{-3} \text{ mol CoCl}_2
And we know the amount of Na\(_3\)PO\(_4\) needed to react exactly with 8.4 \times 10^{-3} \text{ mol CoCl}_2 is:

\[8.4 \times 10^{-3} \text{ mol Co}^{2+} \times \left(2 \text{ mol PO}_4^{3-} / 3 \text{ mol Co}^{2+}\right) = 5.6 \times 10^{-3} \text{ mol Na}_3\text{PO}_4 \text{ needed.}\]

How much phosphate is available from the 1.3 g Na\(_2\)HPO\(_4\)·10 H\(_2\)O?

\[1.3 \text{ g Na}_2\text{HPO}_4·10 \text{ H}_2\text{O} \times \left(1 \text{ mol Na}_2\text{HPO}_4·10 \text{ H}_2\text{O} / 322 \text{ g}\right) = 4.0 \times 10^{-3} \text{ mol PO}_4^{3-}\]

This is less than is needed to completely react with the 8.4 \times 10^{-3} \text{ mol Co}^{2+}
So now some of the cobalt will be leftover. At this point we already know that less cobalt violet can be formed.

Mass of cobalt violet, \(\text{Co}_3(\text{PO}_4)_2\) formed is:

\[4.0 \times 10^{-3} \text{ mol PO}_4^{3-} \times \left(1 \text{ mol Co}_3(\text{PO}_4)_2 / 2 \text{ mol PO}_4^{3-}\right) \times (366.7 \text{ g} / 1 \text{ mol Co}_3(\text{PO}_4)_2) = 0.79 \text{ g Co}_3(\text{PO}_4)_2\]

The answer is: A will produce more cobalt violet pigment than B.

Here’s another cobalt violet production problem a chemist might have:
What mass of solid Na\(_3\)PO\(_4\) should be dissolved in 100 mL of water to completely react with 50.0 mL of a 2 M CoCl\(_2\) solution in water? (‘Completely react’ means no leftover reagents.)

\[0.50 \text{ L} \times (2 \text{ mol/L Co}) \times \left(2 \text{ mol PO}_4^{3-} / 3 \text{ mol Co}^{2+}\right) \times 163.9 \text{ g} / 1 \text{ mol Na}_3\text{PO}_4. = 10.9 \text{ g Na}_3\text{PO}_4.\]

Note how the units cancel:

\[0.50 \text{ L} \times (2 \text{ mol/L Co}) \times \left(2 \text{ mol PO}_4^{3-} / 3 \text{ mol Co}^{2+}\right) \times 163.9 \text{ g} / 4 \text{ mol Na}_3\text{PO}_4. = 10.9 \text{ g Na}_3\text{PO}_4.\]

**Reason Fresco Paintings Deteriorate**

<table>
<thead>
<tr>
<th>Solubilities</th>
<th>Unit (L or mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{SO}_4)</td>
<td>(3 \times 10^{-3}) M</td>
</tr>
<tr>
<td>(\text{CO}_3)</td>
<td>(6 \times 10^{-5}) M</td>
</tr>
<tr>
<td>(\text{PO}_4)</td>
<td>(1.5 \times 10^{-6}) M</td>
</tr>
<tr>
<td>(\text{Cl}_2)</td>
<td>?</td>
</tr>
</tbody>
</table>
\[ \text{CaSO}_4 \] 20 g /100 mL water
\[ \text{CaSO}_4 \] 1 x 10^{-5} M 0.0023 g /L 0.00023 g / 100mL

Which is most soluble? \text{CaCl}_2 @ 75 g /100 mL water
Which is least soluble? \text{Ca}_3(\text{PO}_4)_2 @ 0.000047 g / 100mL

How is molar solubility of calcium sulfate converted to a mass solubility?

\[ \text{mass solubility} = \text{molar solubility} \times \text{molar mass} \]

\[ 3 \times 10^{-3} \text{ mol/L} \times 136 \text{ g/ mol Ca(SO}_4) = 0.41 \text{ g/L} \]

By view of solubility trends:
\[ \Delta E_{\text{total}} = \Delta E_{\text{solvation}} - \Delta E_{\text{lattice}} \]

This is like what you plotted last week to explain the exothermicity or endothermicity.

Solution most favorable when \( \Delta E_{\text{total}} < 0 \) (exothermic), so when \( \Delta E_{\text{solvation}} >> \Delta E_{\text{lattice}} \)

And \( \Delta E_{\text{lattice}} \) depends on \( q^+ q^-/d \) so it is largest for multiply charged ions.

Review Table 2.3: Which data are consistent with that?

All the \( \Delta E_{\text{lattice}} \) values for 2+ cations at more than twice as large as \( \Delta E_{\text{lattice}} \) values for 1+ cation salts.

What happens when a fresco (= \text{Ca(CO}_3)\) is in contact with pure water?

Tiny amount of \text{Ca(CO}_3)\) will dissolve into the water, until the calcium and carbonate concentration is exactly 6 x 10^{-5} M (see numbers at top).

What happens when a fresco (= \text{Ca(CO}_3)\) is in contact with water that has sulfate ion dissolved in it?

How more calcium will dissolve because the solubility of \text{Ca(SO}_4)\) is greater (i.e., more soluble) until calcium concentration is 3 x 10^{-3} M.

\text{CaSO}_4 \) is the mineral gypsum that precipitates within the fresco. Because its crystal lattice is larger than \text{Ca(CO}_3)\) of the fresco base, to causes cracks to form.

The “barium treatment” is one method to “save” frescos; to prevent further deterioration. How might adding Ba^{2+} ions help?

Barium sulfate is very insoluble, so the Ba2+ acts to “trap” the sulfate and prevent it from aiding calcium carbonate, i.e. the fresco, dissolution.