

Compound	Formula	K _{sp} at 298 K, 1 atm
Aluminum hydroxide	Al(OH) ₃	1.3x10 ⁻³³
Aluminum phosphate	Al(PO ₄) ₃	9.84x10 ⁻²¹
Aluminum nitrate	Al(NO ₃) ₃	1.6x10 ⁻²
Barium carbonate	BaCO ₃	2.58x10 ⁻¹⁰
Barium hydroxide	Ba(OH) ₂	5.0x10 ⁻³
Barium nitrate	Ba(NO ₃) ₂	2.7x10 ¹
Barium phosphate	Ba ₃ (PO ₄) ₂	6x10 ⁻³⁹
Calcium carbonate	CaCO ₃	4.96x10 ⁻⁹
Calcium hydroxide	Ca(OH) ₂	4.68x10 ⁻⁶
Calcium nitrate	Ca(NO ₃) ₂	1.6x10 ²
Calcium phosphate	Ca ₃ (PO ₄) ₂	2.07x10 ⁻³³
Copper (II) carbonate	CuCO ₃	2.4x10 ⁻¹⁰
Copper (II) hydroxide	Cu(OH) ₂	2.2x10 ⁻²⁰
Copper (II) nitrate	Cu(NO ₃) ₂	2.67x10 ⁻¹
Copper (II) phosphate	Cu ₃ (PO ₄) ₂	1.4x10 ⁻³⁷
Iron (II) carbonate	FeCO ₃	3.07x10 ⁻¹¹
Iron (II) hydroxide	Fe(OH) ₂	4.87x10 ⁻¹⁷
Iron (III) hydroxide	Fe(OH) ₃	2.79x10 ⁻³⁹
Iron (II) nitrate	Fe(NO ₃) ₂	6.7x10 ⁺²
Iron (II) phosphate	Fe ₃ (PO ₄) ₂	3.6x10 ⁻⁴¹
Cobalt (II) carbonate	CoCO ₃	1.0x10 ⁻¹⁰
Cobalt (II) hydroxide	Co(OH) ₂	5.9x10 ⁻¹⁵
Cobalt (II) nitrate	Co(NO ₃) ₂	5.32x10 ⁻²
Cobalt (II) phosphate	Co ₃ (PO ₄) ₂	2.05x10 ⁻³⁵
Potassium carbonate	K ₂ CO ₃	1x10 ⁺¹
Potassium hydroxide	KOH	1.26x10 ²
Potassium Nitrate	KNO ₃	5.6x10 ²
Potassium phosphate	K ₃ PO ₄	7.6x10 ⁺²

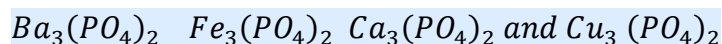
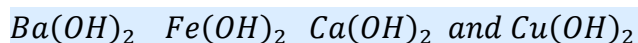
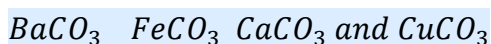
I have a solution that is 0.100 M Ba(NO₃)₂, 0.200 M Fe(NO₃)₂, 0.300 M Ca(NO₃)₂ and 0.400 M Cu(NO₃)₂. I want the BEST possible separation of the metals that I can get. For this purpose, I have available SOLID K₂CO₃, SOLID K₃PO₄, and SOLID KOH.

Please answer the following questions:

1. Which solid should I use to get the best separation of at least the first 3 ions? How did you determine this?

I have a solution that is 0.100 M $\text{Ba}(\text{NO}_3)_2$, 0.200 M $\text{Fe}(\text{NO}_3)_2$, 0.300 M $\text{Ca}(\text{NO}_3)_2$ and 0.400 M $\text{Cu}(\text{NO}_3)_2$. I want the BEST possible separation of the metals that I can get. For this purpose, I have available SOLID K_2CO_3 , SOLID K_3PO_4 , and SOLID KOH .

Separation is based on solubility. Getting the BEST separation means having the biggest difference in solubility. Solubility is based on K_{sp} ...so...what are my possibly precipitates?



Compound	Formula	K_{sp} at 298 K, 1 atm
Barium carbonate	BaCO_3	2.58×10^{-10}
Barium hydroxide	$\text{Ba}(\text{OH})_2$	5.0×10^{-3}
Barium phosphate	$\text{Ba}_3(\text{PO}_4)_2$	6×10^{-39}
Calcium carbonate	CaCO_3	4.96×10^{-9}
Calcium hydroxide	$\text{Ca}(\text{OH})_2$	4.68×10^{-6}
Calcium phosphate	$\text{Ca}_3(\text{PO}_4)_2$	2.07×10^{-33}
Copper (II) carbonate	CuCO_3	2.4×10^{-10}
Copper (II) hydroxide	$\text{Cu}(\text{OH})_2$	2.2×10^{-20}
Copper (II) phosphate	$\text{Cu}_3(\text{PO}_4)_2$	1.4×10^{-37}
Iron (II) carbonate	FeCO_3	3.07×10^{-11}
Iron (II) hydroxide	$\text{Fe}(\text{OH})_2$	4.87×10^{-17}
Iron (II) phosphate	$\text{Fe}_3(\text{PO}_4)_2$	3.6×10^{-41}

The issue is a little confused by the stoichiometry differences. If you want to calculate the actual solubility:

$$K_{sp} = [\text{Ba}^{2+}][\text{CO}_3^{2-}] = 2.58 \times 10^{-10}$$

$$[S][S] = 2.58 \times 10^{-10}$$

$$\text{Solubility} = \sqrt{2.58 \times 10^{-10}} = 1.61 \times 10^{-5} \text{ M}$$

$$K_{sp} = [\text{Ba}^{2+}][\text{OH}^-]^2 = 5.0 \times 10^{-3}$$

$$[S][2S]^2 = 5.0 \times 10^{-3}$$

$$\text{Solubility} = \sqrt[3]{\frac{5.0 \times 10^{-3}}{4}} = 0.108 \text{ M}$$

$$K_{sp} = [Ba^{2+}]^3 [PO_4^{3-}]^2 = 6.0 \times 10^{-39}$$

$$[3S]^3 [2S]^2 = 6.0 \times 10^{-39}$$

$$\text{Solubility} = \sqrt[5]{\frac{6.0 \times 10^{-39}}{3^3 2^2}} = 8.9 \times 10^{-09} \text{ M}$$

If I do this for all of my compounds, I get the following solubilities:

Compound	Formula	K_{sp} at 298 K, 1 atm	Solubility
Barium carbonate	BaCO ₃	2.58×10^{-10}	$1.61 \times 10^{-5} \text{ M}$
Barium hydroxide	Ba(OH) ₂	5.0×10^{-3}	0.108 M
Barium phosphate	Ba ₃ (PO ₄) ₂	6×10^{-39}	$8.9 \times 10^{-09} \text{ M}$
Calcium carbonate	CaCO ₃	4.96×10^{-9}	$7.04 \times 10^{-5} \text{ M}$
Calcium hydroxide	Ca(OH) ₂	4.68×10^{-6}	0.0105 M
Calcium phosphate	Ca ₃ (PO ₄) ₂	2.07×10^{-33}	$1.14 \times 10^{-7} \text{ M}$
Copper (II) carbonate	CuCO ₃	2.4×10^{-10}	$1.56 \times 10^{-5} \text{ M}$
Copper (II) hydroxide	Cu(OH) ₂	2.2×10^{-20}	$1.77 \times 10^{-7} \text{ M}$
Copper (II) phosphate	Cu ₃ (PO ₄) ₂	1.4×10^{-37}	$1.67 \times 10^{-8} \text{ M}$
Iron (II) carbonate	FeCO ₃	3.07×10^{-11}	$5.54 \times 10^{-6} \text{ M}$
Iron (II) hydroxide	Fe(OH) ₂	4.87×10^{-17}	$2.30 \times 10^{-6} \text{ M}$
Iron (II) phosphate	Fe ₃ (PO ₄) ₂	3.6×10^{-41}	$3.20 \times 10^{-9} \text{ M}$

If you compare solubilities, it's pretty clear that carbonate won't work at all: they are too similar with only a factor of about 10 between the smallest and largest solubilities.

$$1.61 \times 10^{-5} \text{ M} \quad 7.04 \times 10^{-5} \text{ M} \quad 1.56 \times 10^{-5} \text{ M} \quad 5.54 \times 10^{-6} \text{ M}$$

Phosphate is somewhat better You've got a factor of about 800 between the smallest and the biggest although only about a factor of 3 between the 2 smallest.

$$8.9 \times 10^{-09} \text{ M} \quad 1.14 \times 10^{-7} \text{ M} \quad 1.67 \times 10^{-8} \text{ M} \quad 3.20 \times 10^{-9} \text{ M}$$

The hydroxide is probably best with two different groups of solubilities. Barium hydroxide and calcium hydroxide are both very soluble with a factor of 10 between their solubilities. The iron hydroxide and copper hydroxide aren't very soluble but there is

still a factor of 10 between them. If there's any downside, it's that you're going to have to add a LOT of hydroxide to get the barium and calcium to precipitate.

$$\frac{1.77 \times 10^{-7} M}{0.108 M} \quad \frac{2.30 \times 10^{-6} M}{0.0105 M}$$

2. What metal precipitates first?

So, if I'm using hydroxide, the copper should go first – it's the least soluble.

3. What metal precipitates last?

If I'm using the hydroxide, the barium should go last – it's the most soluble.

4. How efficient is the separation of the first ion? [Or, in other words, what percent of the first metal ion do I isolate in pure form?]

Well, let's precipitate them and find out!

The first metal stops precipitating in pure form when the 2nd metal starts to precipitate. So, when does the second metal (iron) start to precipitate?

$$K_{sp} = 4.87 \times 10^{-17} = [Fe^{2+}][OH^-]^2 = (0.2 M)(x)^2$$
$$x = 1.56 \times 10^{-8} M$$

So, how much copper has precipitated by then? Well, how much is left?

$$K_{sp} = 2.20 \times 10^{-20} = [Cu^{2+}][OH^-]^2 = (x)(1.56 \times 10^{-8})^2$$
$$x = 9.04 \times 10^{-5} M$$

So, if there's $9.04 \times 10^{-5} M$ left and I started with $0.400 M Cu^{2+}$, that means that I precipitated:

$$0.400 - 9.04 \times 10^{-5} = 0.39991 M$$

$$\frac{0.39991}{0.4} \times 100 = 99.98\% \text{ of the metal precipitate!}$$

Pretty good.

5. How much of the second metal do I precipitate before the third metal starts to precipitate?

Well, let's precipitate them and find out!

The 3rd metal, calcium, starts to precipitate when

$$K_{sp} = 4.68 \times 10^{-6} = [Ca^{2+}][OH^{-}]^2 = (0.3 M)(x)^2$$

$$x = 3.94 \times 10^{-3} M OH^{-}$$

So, how much iron (2nd metal) has precipitated by then? Well, how much is left?

$$K_{sp} = 4.87 \times 10^{-17} = [Fe^{2+}][OH^{-}]^2 = (x)(3.94 \times 10^{-3} M)^2$$

$$x = 3.14 \times 10^{-12} M$$

So, if there's $3.14 \times 10^{-12} M$ left and I started with $0.200 M Fe^{2+}$, that means that I precipitated:

$$0.200 - 3.14 \times 10^{-12} = 0.1999999999997 M$$

So, basically 100% of the metal precipitate!

Pretty good.

6. How much of the third metal do I precipitate before the fourth metal starts to precipitate?

Again, it's just a question of how much of 3 is left when 4 starts:

The 4th metal is Barium:

$$K_{sp} = 5.0 \times 10^{-3} = [Ba^{2+}][OH^{-}]^2 = (0.1 M)(x)^2$$

$$x = 0.223 M OH^{-}$$

So, how much Calcium (3rd metal) has precipitated by then? Well, how much is left?

$$K_{sp} = 4.68 \times 10^{-6} = [Ca^{2+}][OH^{-}]^2 = (x)(0.223)^2$$

$$x = 9.77 \times 10^{-5} M OH^{-}$$

$$0.300 - 9.77 \times 10^{-5} M = 0.2999 M$$

$$\frac{0.2999}{0.300} \times 100 = 99.97\% \text{ of the metal precipitate!}$$

7. What is the % purity of the 3rd metal that I isolate in question #6?
Here's a fun question!!!

The issue is over the co-precipitation of metals 1 and 2 with the 3rd metal. So, technically, we need to look at how much of the copper and iron ions are in solution before and after precipitation 3.

We already know that when Precipitation 3 starts there is

$$K_{sp} = 4.87 \times 10^{-17} = [Fe^{2+}][OH^{-}]^2 = (x)(3.94 \times 10^{-3}M)^2$$
$$x = 3.14 \times 10^{-12} M Fe^{2+}$$

Frankly, we can calculate how much is left at the end but there ain't much to begin with.

$$K_{sp} = 4.87 \times 10^{-17} = [Fe^{2+}][OH^{-}]^2 = (x)(0.223 M)^2$$
$$x = 9.79 \times 10^{-16} M Fe^{2+}$$

So, the amount of Fe(OH)₂ that precipitates with the Ca(OH)₂ is:

$$3.14 \times 10^{-12} M Fe^{2+} \text{ at start} - 9.79 \times 10^{-16} M Fe^{2+} \text{ at end}$$
$$= 3.139 \times 10^{-12} M \text{ precipitated} - A SMIDGE!$$

Same calculation for copper:

$$K_{sp} = 2.2 \times 10^{-20} = [Cu^{2+}][OH^{-}]^2 = (x)(3.94 \times 10^{-3}M)^2$$
$$x = 1.42 \times 10^{-15} M Cu^{2+}$$

Frankly, we can calculate how much is left at the end but there ain't much to begin with.

$$K_{sp} = 2.2 \times 10^{-20} = [Cu^{2+}][OH^{-}]^2 = (x)(0.223 M)^2$$
$$x = 4.42 \times 10^{-19} M Cu^{2+}$$

So, the amount of Cu(OH)₂ that precipitates with the Ca(OH)₂ is:

$$1.42 \times 10^{-15} M Cu^{2+} \text{ at start} - 4.42 \times 10^{-19} M Cu^{2+} \text{ at end}$$
$$= 1.419 \times 10^{-15} M Cu^{2+} \text{ precipitated} - A SMIDGE!$$

So, my 3rd metal is essentially 99.9999999998% pure!!!

GREAT SEPARATION!