Table F Solubility Guidelines for Aqueous Solutions

Ions That Form *Soluble* Compounds	**Exceptions**
Group 1 ions (Li^+, Na^+, etc.)	
ammonium (NH_4^+)	
nitrate (NO_3^-)	
acetate ($C_2H_3O_2^-$ or CH_3COO^-)	
hydrogen carbonate (HCO_3^-)	
chlorate (ClO_3^-)	
perchlorate (ClO_4^-)	
halides (Cl^-, Br^-, I^-)	when combined with Ag^+, Pb^{2+}, and Hg_2^{2+}
sulfates (SO_4^{2-})	when combined with Ag^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, and Pb^{2+}

Ions That Form *Insoluble* Compounds	**Exceptions**
carbonate (CO_3^{2-})	when combined with Group 1 ions or ammonium (NH_4^+)
chromate (CrO_4^{2-})	when combined with Group 1 ions, Ca^{2+}, Mg^{2+}, or ammonium (NH_4^+)
phosphate (PO_4^{3-})	when combined with Group 1 ions or ammonium (NH_4^+)
sulfide (S^{2-})	when combined with Group 1 ions or ammonium (NH_4^+)
hydroxide (OH^-)	when combined with Group 1 ions, Ca^{2+}, Ba^{2+}, Sr^{2+}, or ammonium (NH_4^+)

Overview:

This table is used to determine whether a particular compound is soluble or insoluble in water (aqueous) solution. If an insoluble substance is formed in the reaction between two aqueous solutions of different salts (ionic compounds), it is called a precipitate and settles to the bottom of the container.

The Table:

The top chart shows ions that form soluble compounds with some exceptions noted. The bottom chart shows ions that form insoluble or nearly insoluble compounds with some exceptions noted.

Some general rules for solubility can be stated using information from this table:

- all compounds containing Group 1 ions are soluble in water.
- all compounds containing ammonium, nitrate, acetate, hydrogen carbonate, chlorate and perchlorate ions are soluble in water.

Be very careful to note the **Exceptions** columns. Many questions on the regents involve these examples.

Additional Information:

- The halides are negative ions formed from Group 17 elements, known as the halogens.
- Since a relatively large amount of a soluble substance may be dissolved in a given amount of water, these solutions may be concentrated (strong solutions).
- Since only a small amount of an insoluble substance dissolves in a given amount of water, these solutions are dilute (weak solutions).
- Soluble ionic substances (salts) dissolved in water form solutions that readily conduct an electric current. They are referred to as strong electrolytes.
- The notation (s) following the formula of a substance indicates that the substance is a solid or insoluble in water (a precipitate) and the notation (aq) following a formula indicates an aqueous solution of that substance (soluble in water).
- When an insoluble substance (precipitate) is formed, it may be separated from the rest of the solution by the process of filtration. However, a soluble solute cannot be separated from the solvent by filtration.

Set 1 — Solubility Guidelines for Aqueous Solutions

1. According to Table F, which of these salts is *least* soluble in water?

(1) LiCl (3) $FeCl_2$
(2) RbCl (4) $PbCl_2$ 1 ____

2. Which compound is insoluble in water?

(1) $BaSO_4$ (3) $KClO_3$
(2) $CaCrO_4$ (4) Na_2S 2 ____

3. Which ion, when combined with chloride ions, Cl^-, forms an insoluble substance in water?

(1) Fe^{2+} (3) Pb^{2+}
(2) Mg^{2+} (4) Zn^{2+} 3 ____

4. Based on Reference Table F, which of these saturated solutions has the *lowest* concentration of dissolved ions?

(1) NaCl(aq)
(2) $MgCl_2$(aq)
(3) $NiCl_2$(aq)
(4) AgCl(aq) 4 ____

5. According to Reference Table F, which of these compounds is most soluble at 298 K and 1 atm?

(1) AgCl (3) $MgCrO_4$
(2) AgI (4) $PbCO_3$ 5 ____

6. Based on Reference Table F, which salt is the most soluble?

(1) AgI (3) $ZnCO_3$
(2) AgBr (4) K_2SO_4 6 ____

7. Based on Reference Table F, which compound could form a concentrated solution?

(1) AgBr (3) Ag_2CO_3
(2) AgCl (4) $AgNO_3$ 7 ____

8. Which compound when stirred in water will not pass through filter paper?

(1) NaCl (3) $Mg(OH)_2$
(2) NH_4S (4) LiCl 8 ____

9. A student observed the following reaction:

$AlCl_3(aq) + 3NaOH(aq) \rightarrow Al(OH)_3(s) + 3NaCl(aq)$

After the products were filtered, which substance remained on the filter paper?

(1) NaCl (3) $AlCl_3$
(2) NaOH (4) $Al(OH)_3$ 9 ____

10. Which barium salt is insoluble in water?

(1) $BaCO_3$ (3) $Ba(ClO_4)_2$
(2) $BaCl_2$ (4) $Ba(NO_3)_2$ 10 ____

Base your answers to question 11 using the information below and your knowledge of chemistry.

In a laboratory activity, 0.500 mole of NaOH(s) is partially dissolved in distilled water to form 400. milliliters of NaOH(aq). This solution is then used to titrate a solution of $HNO_3(aq)$.

11. *a*) Identify the negative ion produced when the NaOH(s) is dissolved in distilled water.

_____

b) Another student substituted $Mg(OH)_2$ for NaOH to make a solution to be use in this tritration. Which compound would be more soluble?

_____

Base your answers to question 12 using the information below and your knowledge of chemistry.

Calcium hydroxide is commonly known as agricultural lime and is used to adjust the soil pH. Before the lime was added to a field, the soil pH was 5. After the lime was added, the soil underwent a 100-fold decrease in hydronium ion concentration.

12. *a*) According to Reference Table F, is calcium hydroxide soluble in water?

_____

b) Identify another hydroxide compound that contains a Group 2 element and is soluble in water.

_____

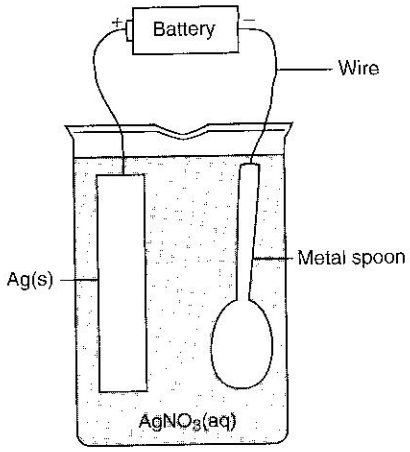
13. Give a statement on the solubility of $Pb(C_2H_3O_2)_2$.

_____

Base your answer to question 20 using the information below and your knowledge of chemistry.

Electroplating is an electrolytic process used to coat metal objects with a more expensive and less reactive metal. The diagram below shows an electroplating cell that includes a battery connected to a silver bar and a metal spoon. The bar and spoon are submerged in $AgNO_3(aq)$.

An Electroplating Cell



20. Explain why $AgNO_3(aq)$ is a better choice than $AgCl(aq)$ for use in this electrolytic process.

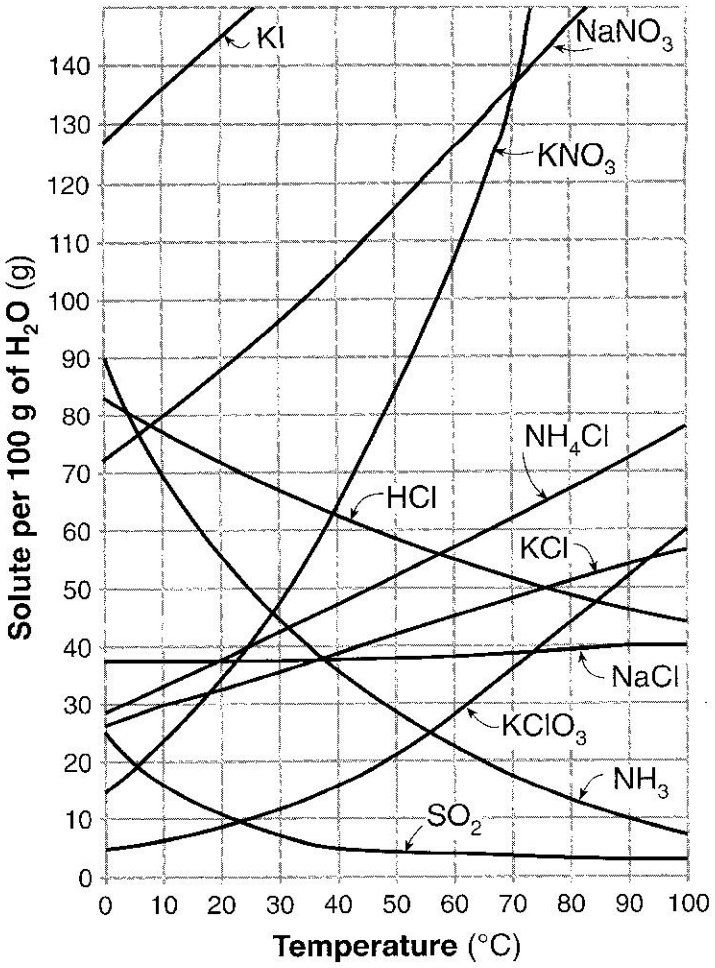
21. Based on Reference Table F, describe the solubility of zinc sulfide in water.

22. Based on Reference Table F, describe the solubility of magnesium hydroxide in water.

23. Solutions of ammonium sulfide and calcium nitrate are allowed to react according to the equation:

$$(NH_4)_2S + Ca(NO_3)_2 \rightarrow 2NH_4NO_3 + CaS$$

If the mixture of products is filtered, identify which product, if any, will remain on the filter paper.



Overview:

A solution is a homogeneous mixture of two or more substances. A solution has two components, the dissolved substance, called the solute, and the dissolving substance, called the solvent. In most solutions, the solvent is water and these are called aqueous solutions (aq). Temperature is one factor that determines the solubility of a solute in water. If the solute is a gas, pressure, as well as temperature, determines the solubility of that solute. The solubility of a solute as a function of temperature gives rise to a solubility curve.

The Table:

This table shows the mass of solute (dissolved substance), in grams (g), that can be dissolved in 100 g of H_2O as a function of temperature. From the intersection point of a solubility curve and a given temperature line, reading directly to the left gives the amount of that solute, in g, needed to saturate 100 g of H_2O at that temperature. A saturated solution contains the maximum amount of that solute that can be dissolved in 100 g of H_2O at that temperature. An equilibrium exists between dissolved solute and excess undissolved solute in a saturated solution.

Since the solubility of a solid solute increases with temperature, if the solution is cooled sufficiently, solute may start to drop out or precipitate out of solution. The resulting solution is then a saturated solution.

If the amount of solute dissolved in 100 g of H_2O is below the amount read from the solubility curve at that temperature, the solution is unsaturated.

If the amount of solute dissolved in 100 g of H_2O is greater than that amount read from the solubility curve at that temperature, the solution is supersaturated.

The graph shows that the solubility of solid solutes in H_2O generally increases as the temperature increases, while the solubility of gases (HCl, NH_3 and SO_2) decreases as the temperature increases.

If the amount of H_2O is different from 100 g, the amount of solute needed to saturate that amount of H_2O will change accordingly. For example, if 50 g of H_2O is used, take half the amount of solute as read from the table. If 200 g of H_2O is used, take twice the amount of solute as read from the table.

Additional Information:

- A solution is homogeneous since the solute is distributed uniformly throughout.
- The dissolved solute in a solution cannot be separated from the solvent by filtration.
- A supersaturated solution is very unstable. Any disturbance, such as stirring or adding a crystal of the solute, will cause the excess solute to crystallize or drop out of solution, forming a saturated solution.
- The presence of solute raises the boiling point of the solvent and lowers the freezing point of the solvent.
- In using this table, be sure to use the correct solubility curve and the correct temperature line.
- Pressure has a negligible effect on the solubility of a solid in water. However, an increase in pressure increases the solubility of a gas in water and a decrease in pressure decreases the solubility of a gas in water.

Set 1 — Solubility Curves

1. A dilute, aqueous potassium nitrate solution is best classified as a

(1) homogeneous compound
(2) homogeneous mixture
(3) heterogeneous compound
(4) heterogeneous mixture

1 _____

2. According to Reference Table G, which substance forms an unsaturated solution when 80 grams of the substance is added in 100 grams of H_2O at 10°C?

(1) KI (3) $NaNO_3$
(2) KNO_3 (4) NaCl

2 _____

3. A saturated solution of $NaNO_3$ is prepared at 60°C using 100. grams of water. As this solution is cooled to 10°C, $NaNO_3$ precipitates (settles) out of the solution. The resulting solution is saturated. Approximately how many grams of $NaNO_3$ settled out of the original solution?

(1) 46 g (3) 85 g
(2) 61 g (4) 126 g

3 _____

4. One hundred grams of water is saturated with NH_4Cl at 50°C. According to Table G, if the temperature is lowered to 10°C, what is the total amount of NH_4Cl that will precipitate?

(1) 5.0 g (3) 30. g
(2) 17. g (4) 50. g

4 _____

5. Based on *Reference Table G, what is* the maximum number of grams of KCl(s) that will dissolve in 200 grams of water at 50°C to produce a saturated solution?

(1) 38g (3) 58 g
(2) 42 g (4) 84 g

5 _____

6. According to Reference Table G, which solution is saturated at 30°C?

(1) 12 grams of $KClO_3$ in 100 grams of water
(2) 12 grams of $KClO_3$ in 200 grams of water
(3) 30 grams of NaCl in 100 grams of water
(4) 30 grams of NaCl in 200 grams of water

6 _____

7. A mixture of crystals of salt and sugar is added to water and stirred until all solids have dissolved. Which statement best describes the resulting mixture?

(1) The mixture is homogeneous and can be separated by filtration.
(2) The mixture is homogeneous and cannot be separated by filtration.
(3) The mixture is heterogeneous and can be separated by filtration.
(4) The mixture is heterogeneous and cannot be separated by filtration.

7 _____

8. A solution that is at equilibrium must be

(1) concentrated (3) saturated
(2) dilute (4) unsaturated

8 _____

9. What occurs when NaCl(s) is added to water?

(1) The boiling point of the solution increases, and the freezing point of the solution decreases.
(2) The boiling point of the solution increases, and the freezing point of the solution increases.
(3) The boiling point of the solution decreases, and the freezing point of the solution decreases.
(4) The boiling point of the solution decreases, and the freezing point of the solution increases.

9 ____

10. According to Reference Table G, how many grams of $KClO_3$ must be dissolved in 100 grams of H_2O at 10°C to produce a saturated solution?

_____

Base your answers to question 11 on the information below and on your knowledge of chemistry.

When cola, a type of soda pop, is manufactured, $CO_2(g)$ is dissolved in it.

11. *a*) A capped bottle of cola contains $CO_2(g)$ under high pressure. When the cap is removed, how does pressure affect the solubility of the dissolved $CO_2(g)$?

_____

_____

b) A glass of cold cola is left to stand 5 minutes at room temperature. How does temperature affect the solubility of the $CO_2(g)$?

_____

_____

c) In the accompanying space, draw a set of axes and label one of them "Solubility" and the other "Temperature."

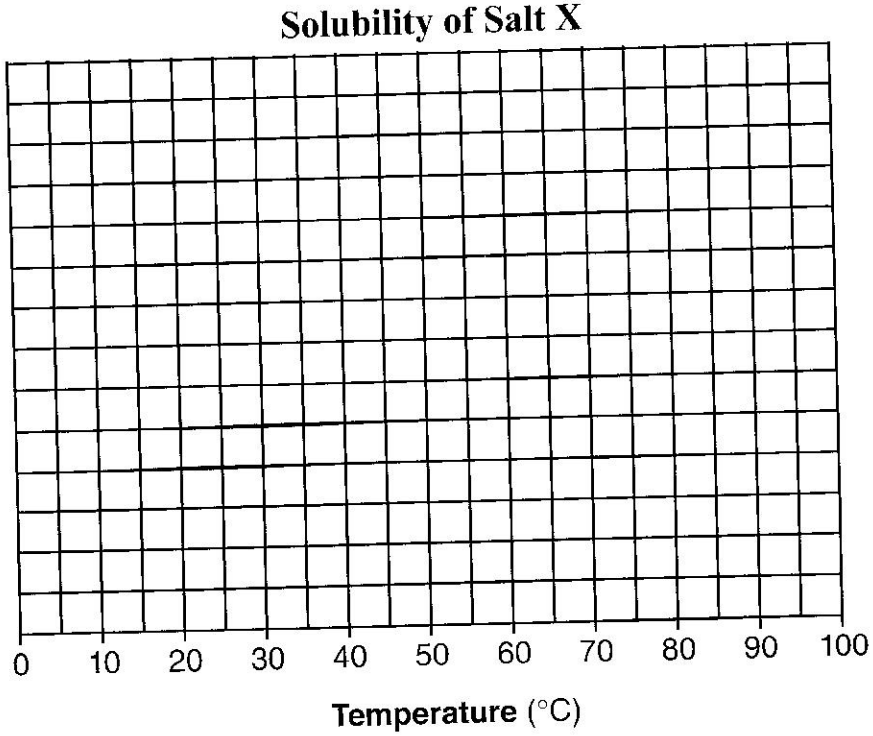
d) Draw a line to indicate the solubility of $CO_2(g)$ versus temperature on the axes drawn in part *c*.

12. Given the data table below showing the solubility of salt **X**:

Temperature (C°)	Mass of Solute per 100 g of H_2O
10	22
25	40
30	48
60	107
70	135

a) Which salt on Table G is most likely to be salt **X**? _____

b) On the graph below, scale and label the *y*-axis including appropriate units.



c) Plot the data from the data table. Surround each point with a small circle and draw a best-fit curve for the solubility of salt **X**.

d) Using your graph, predict the solubility of salt **X** at 50°C. _____

e) If the pressure on the salt solution was increased, what affect would this pressure change have on the solubility of the salt?

_____

13. According to Reference Table G, which solution at equilibrium contains 50 grams of solute per 100 grams of H_2O at 75°C?

(1) an unsaturated solution of KCl
(2) an unsaturated solution of $KClO_3$
(3) a saturated solution of KCl
(4) a saturated solution of $KClO_3$ 13 ____

14. At STP, which of these substances is most soluble in H_2O?

(1) NH_3 (3) HCl
(2) KCl (4) $NaNO_3$ 14 ____

15. Which compound forms a saturated solution at 40°C that contains 46 grams per 100 grams of water?

(1) KNO_3 (3) $NaNO_3$
(2) NH_4Cl (4) KCl 15 ____

16. An unsaturated solution is formed when 80. grams of a salt is dissolved in 100. grams of water at 40.°C. This salt could be

(1) KCl (3) NaCl
(2) KNO_3 (4) $NaNO_3$ 16 ____

17. Which solution has the lowest freezing point?

(1) 10. g of KI dissolved in 100. g of water
(2) 20. g of KI dissolved in 200. g of water
(3) 30. g of KI dissolved in 100. g of water
(4) 40. g of KI dissolved in 200. g of water

17 ____

18. A solution contains 35 grams of KNO_3 dissolved in 100 grams of water at 40°C. How much more KNO_3 would have to be added to make it a saturated solution?

(1) 29 g (3) 12 g
(2) 24 g (4) 4 g 18 ____

19. A student prepares four aqueous solutions, each with a different solute. The mass of each dissolved solute is shown in the table below.

Mass of Dissolved Solute for Four Aqueous Solutions

Solution Number	Solute	Mass of Dissolved Solute (per 100. g of H_2O at 20.°C)
1	KI	120. g
2	$NaNO_3$	88 g
3	KCl	25 g
4	$KClO_3$	5 g

Which solution is saturated?

(1) 1 (3) 3
(2) 2 (4) 4 19 ____

20. Based on Reference Table G, a solution of $NaNO_3$ that contains 120 grams of solute dissolved in 100 grams of H_2O at 50°C is best described as

(1) saturated and dilute
(2) saturated and concentrated
(3) supersaturated and dilute
(4) supersaturated and concentrated

20 ____

21. A student adds solid KCl to water in a flask. The flask is sealed with a stopper and thoroughly shaken until no more solid KCl dissolves. Some solid KCl is still visible in the flask. The solution in the flask is

(1) saturated and is at equilibrium with the solid KCl
(2) saturated and is not at equilibrium with the solid KCl
(3) unsaturated and is at equilibrium with the solid KCl
(4) unsaturated and is not at equilibrium with the solid KCl 21 ____

22. Which sample is a homogeneous mixture?

(1) NaCl(s) (3) NaCl(g)
(2) NaCl(l) (4) NaCl(aq) 22 ____

23. Compared to pure water, an aqueous solution of calcium chloride has a

(1) higher boiling point and higher freezing point
(2) higher boiling point and lower freezing point
(3) lower boiling point and higher freezing point
(4) lower boiling point and lower freezing point 23 ____

Base your answers to question 24 using the information below and your knowledge of chemistry.

A student uses 200 grams of water at a temperature of 60°C to prepare a saturated solution of potassium chloride, KCl.

24. *a*) Identify the solute in this solution. _____

b) According to Reference Table G, how many grams of KCl must be used to create this saturated solution? _____

c) This solution is cooled to 10°C and the excess KCl precipitates (settles out). The resulting solution is saturated at 10°C. How many grams of KCl precipitated out of the original solution?

_____

25. Sulfur dioxide, SO_2, is one of the gases that reacts with water to produce acid rain. According to Reference Table G, describe how the solubility of sulfur dioxide in water is affected by an increase in water temperature.

_____

_____

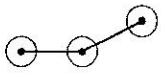
Base your answers to question 26 using your knowledge of chemistry and the accompanying data table, which shows the solubility of a solid solute.

The Solubility of the Solute at Various Temperatures

Temperature (°C)	Solute per 100 g of H_2O(g)
0	18
20	20
40	24
60	29
80	36
100	49

26. *a*) On the grid below, mark an appropriate scale on the axis labeled "Solute per 100 g of H_2O(g)." An appropriate scale is one that allows a trend to be seen.

b) On the same grid, plot the data from the data table. Circle and connect the points.

Example: 

c) Based on the data table, if 15 grams of solute is dissolved in 100 grams of water at 40°C, how many more grams of solute can be dissolved in this solution to make it saturated at 40°C?

_____ g