XI. Solutions – How To Make Them and Shake Them

This chapter is excerpted from the book *Shake It - Make It* by Mike McMillan. The complete book has much more detail, and includes a 40-page unit on solutions, both theory and practice. **Safety note: Making solutions can be hazardous if appropriate precautions are not taken.**

General precautions include:

- Always use eye protection. The recommended eyewear is a pair of chemical splash goggles with full-face coverage, which comply with the ANSI-Z87.1 specifications.
- A pair of appropriate gloves is recommended. This handbook includes a glove selection guide.
- Some solutions should be prepared under a fume hood, which has been tested for appropriate face velocity.
- A volumetric flask is calibrated to contain at 25 °C. When making a solution, the final concentration is attained by adding distilled water until the bottom of the meniscus is at the fill line of the flask. If the initial solution was prepared in warm water, the solution must be allowed to cool before doing the final volume adjustment.
- When diluting a solution, always add the more concentrated solution to distilled water. In some cases a cooling water bath may be required.
- Always prepare a solution by first measuring 40-50% of the solvent into the bottle or flask that will hold the final product. Add the solute slowly, stirring if necessary. Once all the solute has been added and has dissolved, dilute the solution to final volume and mix well.
- If a magnetic stirrer is used to mix the solution, do not fill the volumetric flask to the fill line until the magnetic stir bar has been removed from the flask. A better procedure is to mix 400-500 milliliter (mL) of solution in beaker, transfer the beaker contents to a volumetric flask, rinse the beaker thoroughly with distilled water (add the rinse water to the volumetric flask), and then fill the volumetric flask to the mark.

Solution Definitions

Accounting for solutes with a specified purity

Sometimes a solute has an assay of less than 100% and an exact concentration is desired. If, for example, the solute has a formula weight of 120 and a purity of 85%, the amount of solute for a 0.1 M solution would normally be 12.0g. To account for the purity, divide the solute amount by the purity. 12.0g/0.85=14.12g required.

[Actual Amount of Solute Required] = [Original Amount of Solute]/[Purity(%)/100]

Molarity (M) - Molarity is the number of moles of the solute in a fixed volume of solution. A 1 M solution of sodium chloride is made by dissolving 58.44g of NaCl in 1L of distilled water. Smaller volumes require proportionately smaller amounts of the solute and solvent. A 0.5 M solution of NaCl in 1L would require 29.72g of NaCl.

Normality (N) - The number of equivalents of the ion desired in 1L of solvent. In acid-base chemistry, the equivalent is defined as the mass of solute that accepts or donates 1 mole of protons. Phosphoric acid is a

triprotic acid, and each mole can donate 3 equivalents (3 moles of protons). A 1 M solution of phosphoric acid is also a 3N solution. Hydrochloric acid is a monoprotic acid, so the molarity and normality of hydrochloric acid are the same. If redox chemistry is being used, a 1N solution is one that accepts or donates 1 mole of electrons. Copper $^{(+2)}$ donates 2 electrons as a part of the reduction of the ion to copper metal. A 1 M $Cu^{(2+)}$ solution is also a 2N solution. The molarity and normality of a Copper$^{(+1)}$ solution are equal.

Percent (%) - When a solid is dissolved in a liquid on a weight/volume basis, this is a solution whose concentration is expressed as *x* %. Ten grams (10 g) of sodium chloride dissolved in 1L of water is a 1% weight-to-volume solution. Volume-to-volume solutions (a solution composed of two liquids with both the components measured on a volume basis) are also possible. Percent solutions are most used for biological stains, for pH indicators, and for special purposes.

Serial Dilutions - Dilute solutions are prepared most exactly using this technique. If a 0.001 M HCl solution is desired, it can be prepared by measuring 0.8 mL of concentrated acid and diluting to 1 L. The potential error of measurement in the 0.8 mL is fairly high. To minimize errors of measurement, a serial dilution is done. The usual method is to prepare a 0.1 M or 1.0 M solution first. Once that is made, a portion of that solution is diluted to the final concentration. If the first solution is 1 M in 1 L, and a final concentration of 0.001 M is desired, that can be made by diluting 10 mL of the 1 M solution to 1 L final volume. The potential measurement error is much lower, because 10X the amount of concentrated material was measured to start with.

Solute - The chemical being dissolved *into* solution. Also, defined as the chemical in lower concentration in the mixture.

Solvent - The chemical that is in higher concentration in the mixture. Typical solvents include distilled water, ethyl alcohol, and isopropyl alcohol

Standard Solutions - Whenever quantitative results are needed, a standard solution must be used to determine the exact molarity or normality of the solution being prepared. Hydrochloric acid (concentrated) is supplied with the approximate molarity of 12.1 M. If the exact concentration of the HCl solution is required, the HCl solution must be standardized against a known standard solution, one whose exact concentration is known.

Solution Recipes

To prepare a 0.1 M solution of the following, dissolve the amount shown in the table in about 500 mL of distilled water inside a volumetric flask. After all the solute has been dissolved, dilute to final volume of 1 L.

Chemical Name	Formula	f.w.	g/L (0.1 M)
Aluminum chloride 6-hydrate	$AlCl_3 \bullet 6H_2O$	241.43	24.143
Aluminum potassium sulfate 12-hydrate	$AlK(SO_4)2 \bullet 12H_2O$	474.40	47.440
Ammonium chloride	NH_4Cl	53.49	5.349
Ammonium dichromate	$(NH_4)_2Cr_2O_7$	252.06	25.206
Ammonium nitrate	NH_4NO_3	80.04	8.004
Barium chloride dihydrate	$BaCl_2 \bullet 2H_2O$	244.28	24.428
Barium hydroxide 8-hydrate	$Ba(OH)_2 \bullet 8H_2O$	315.48	31.550
Calcium carbonate	$CaCO_3$	100.09	10.009
Calcium chloride dihydrate	$CaCl_2 \bullet 2H_2O$	147.02	14.702

Chemical Name	Formula	f.w.	g/L (0.1 M)
Calcium hydroxide	$Ca(OH)_2$	78.08	7.808
Calcium nitrate 4-hydrate	$Ca(NO_3)_2 \bullet 4H_2O$	236.15	23.615
Calcium oxide	CaO	56.08	5.608
Calcium sulfate dihydrate	$CaSO_4 \bullet 2H_2O$	172.17	17.217
Citric acid monohydrate	$C_6H_7O_8 \bullet H_2O$	210.14	21.014
Cobalt chloride 6-hydrate	$CoCl_2 \bullet 6H_2O$	237.95	23.795
Copper(II) chloride dihydrate	$CuCl_2 \bullet 2H_2O$	170.48	17.048
Copper(II) nitrate 3-hydrate	$CuNO_3 \bullet 3H_2O$	241.6	24.160
Copper(II) sulfate 5-hydrate	$CuSO_4\ 5H_2O$	249.69	24.969
Dextrose monohydrate (glucose)	$C_6H_{12}O_6 \bullet H_2O$	180.16	18.016
d-Fructose	$C_6H_{12}O_6$	180.16	18.016
Iron(II) ammonium sulfate 6-hydrate	$Fe(NH_4)_2(SO_4)_2 \bullet 6H_2O$	392.13	39.213
Iron(II) sulfate 7-hydrate	$FeSO_4 \bullet 7H_2O$	278.02	27.802
Iron(III) chloride 6-hydrate	$FeCl_3 \bullet 6H_2O$	270.32	27.032
Iron(III) nitrate 9-hydrate	$Fe(NO_3)_3 \bullet 9H_2O$	404.00	40.400
Lead nitrate	$Pb(NO_3)_2$	331.23	33.120
Lithium chloride	LiCl	42.400	42.400
Magnesium chloride 6-hydrate	$MgCl_2 \bullet 6H_2O$	203.33	20.333
Magnesium nitrate 6-hydrate	$Mg(NO_3)_2 \bullet 6H_2O$	256.41	25.643
Magnesium sulfate 7-hydrate	$MgSO_4 \bullet 7H_2O$	246.48	24.648
Manganese dioxide	MnO_2	86.94	8.694
Nickel chloride 6-Hydrate	$NiCl_2 \bullet 6H_2O$	237.72	23.772
Nickel nitrate 6-hydrate	$Ni(NO_3)_2 \bullet 6H_2O$	290.82	29.082
Nickel sulfate 6-hydrate	$NiSO_4 \bullet 6H_2O$	262.87	26.287
Potassium bromide	KBr	119.02	11.902
Potassium chlorate	$KClO_3$	122.56	12.256
Potassium chloride	KCl	74.56	7.456
Potassium dichromate	$K_2Cr_2O_7$	294.19	29.419
Potassium hydroxide	KOH	56.11	5.611
Potassium iodate	$KClO_3$	214.00	21.400
Potassium iodide	KCl	166.01	16.601
Potassium nitrate	KNO_3	101.11	10.111
Potassium permanganate	$KMnO_4$	158.04	15.804
Potassium sodium tartrate 4-hydrate	$KNaC_4H_4O_6 \bullet 4H_2O$	282.23	28.223
Potassium thiocyanate	KSCN	97.18	9.718
Silver nitrate	$AgNO_3$	169.87	16.987
Sodium acetate	CH_3COONa	82.03	8.203
Sodium bicarbonate anhydrous	$NaHCO_3$	84.01	8.401
Sodium bisulfate anhydrous	$NaHSO_4$	120.07	12.007
Sodium borate 10-hydrate	$NaB_4O_7 \bullet 10H_2O$	381.33	38.133
Sodium carbonate anhydrous	$NaCO_3$	105.99	10.599
Sodium chlorate	$NaClO_3$	106.44	10.644
Sodium chloride	NaCl	58.45	5.845
Sodium hydroxide	NaOH	40.00	4.000
Sodium iodide	NaI	149.84	14.984

Chemical Name	Formula	f.w.	g/L (0.1 M)
Sodium lauryl sulfate	$C_{12}N_{25}O_4SNa$	288.38	18.838
Sodium nitrate	$NaNO_3$	84.99	8.499
Sodium oxalate	$Na_2C_2O_4$	134.00	13.400
Sodium phosphate dibasic anhydrous	Na_2HPO_4	141.90	14.190
Sodium phosphate tribasic 12-hydrate	$Na_3PO_4 \bullet 12H_2O$	380.12	38.012
Sodium sulfate 10-hydrate	$Na_2SO_4 \bullet 10H_2O$	322.19	32.219
Sodium thiosulfate 5-hydrate	$Na_2S_2O_3 \bullet 5H_2O$	248.18	24.818
Strontium chloride 6-hydrate	$SrCl_2 \bullet 6H_2O$	266.62	26.662
Strontium nitrate	$Sr(NO_3)_2$	211.63	21.163
Tin(II) chloride dihydrate	$SnCl_2 \bullet 2H_2O$	225.36	22.536
Tin(IV) chloride 5-hydrate	$SnCl_4 \bullet 5H_2O$	350.61	35.061
Zinc nitrate 6-hydrate	$Zn(NO_3)_2 \bullet 6H_2O$	297.48	29.748
Zinc sulfate 7-hydrate	$ZnSO_4 \bullet 7H_2O$	287.54	28.754

Acid/Base Solutions (Dilutions)

Chemical Name	Formula	f.w.	mL/L (1.0 M)	mL/L (0.1 M)
Acetic acid (~17.4 M)	CH_3COOH	60.05	57.5	100.0
Hydrochloric acid (~12.1 M)	HCl	36.46	82.7	100.0
Nitric acid (~15.8 M)	HNO_3	63.01	63.3	100.0
Phosphoric acid (~14.8 M)	H_3PO_4	98.0	67.6	100.0
Sulfuric acid (~18 M)	H_2SO_4	98.08	55.6	100.0
Ammonium hydroxide	NH_4OH	35.05	67.6	100.0

Biological Stains and Indicators

Chemical Name	Formula	g/100 mL
Phenolphthalein (1% in alcohol)	$C_{20}H_{14}O_4$	1.000
Methylene Blue (1% in water)	$C_{16}H_{18}ClN_3SCl$	1.000
Congo Red (0.1% in alcohol)	$C_{32}N_{17}O_5SNa$	0.100
Methyl Orange (0.1% in water)	$4\text{-}(CH_3)_2NC_6H_4N{:}NC_6H_4\text{-}4\text{-}SO_3Na$	0.100

Serial Dilutions

Chemical Name	Formula	mL/L Original Solution/ Concentration	Final Concentration (1 L dilution)
Hydrochloric acid (~12.1 M)	HCl	495.9 mL (12.1 M)	6 M
		82.7 mL (15.8 M)	1 M
		100 mL (1 M)	0.1 M
		500 mL (1 M)	0.05 M
Nitric acid (~15.8 M)	HNO_3	189.9 mL (15.8 M)	6 M
		63.3 mL (15.8 M)	1 M
		100 mL (1 M)	0.1 M
Sulfuric acid (~18.0 M)	H_2SO_4	333.33 mL (18.0 M)	6.0 M
		55.6 mL (18.0 M)	1.0 M
		27.8 mL (18.0 M)	0.5 M
		500 mL (1.0 M)	0.5 M

Standard Solution

Chemical Name	Formula	f.w.	g/L (0.1 M)
Potassium acid phthalate (Potassium hydrogen phthalate)	$KHC_8H_4O_4$	204.23	20.423

5100 West Henrietta Rd • PO Box 92912 • Rochester, NY 14692-9012 • p: 800 962-2660 • f: 800 635-8439 • wardsci.com