American Chemical Society

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USNCO Coaching Session National Exam Preparation Tutorial Notes: Descriptive Chemistry and Laboratory

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Flame Test, the Color of Ions, the Heat of Reactions/Dissolution, etc.

- *Doing chemistry requires both understanding ideas and remembering key information!*
- *Hands-on intensive lab experience is the most efficient way to study this topic.*

[Learning Objectives]

Introduction: A flame test is an analytical procedure used in chemistry to detect the presence of certain elements, primarily _____(metal or nonmental) ions, based on each element's characteristic _____(absorption or emission) spectrum. What causes the bright colors in fireworks?

Operation: In high-school chemistry courses, wooden splints are commonly used, mostly because solutions can be dried onto them, and they are inexpensive. Bunsen burners are also commonly used as their flame is light.

[USNCO Example – *N2016-P1-Q12*] [USNCO Example – *N2020-P1-Q7*]

12. Which is the safest method for performing a flame test?

(A) Dissolve the metal salt in methanol, then squirt the solution into a lit Bunsen burner from at least 1 meter away.

(B) Dissolve the metal salt in methanol, then pour the methanol into a crystallizing dish, igniting it with the flame from a Bunsen burner.

(C) Soak a wooden splint in an aqueous solution of the metal salt, then burn the splint in the flame from a Bunsen burner.

(D) Soak a wooden splint in an aqueous solution of the metal salt, then heat the splint on top of a ceramic hotplate.

7. Which ion gives a green flame test?

(A) Potassium **(B)** Calcium

(C) Strontium **(D)** Barium

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Typical flame colors: Colored flames of methanol solutions of different compounds, burning on cotton wool.

From left to right: LiCl, $SrCl_2$, $CaCl_2$, NaCl, $BaCl_2$, $B(CH_3)_3$, $CuCl_2$, CsCl and KCl.

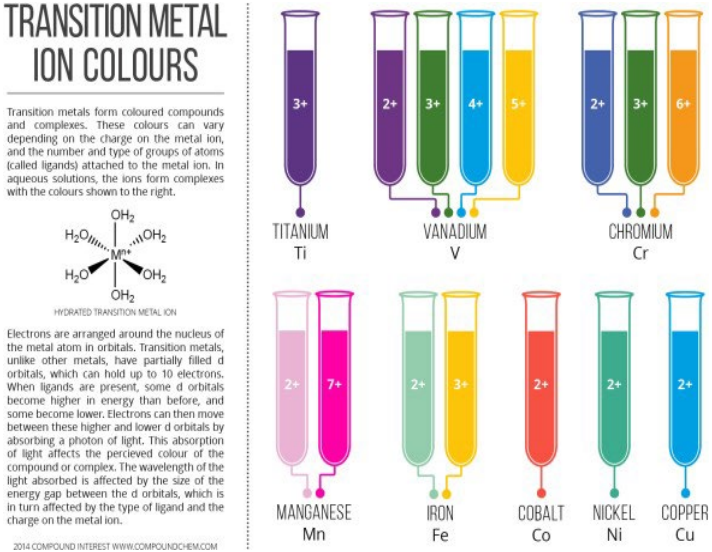
- from Wikipedia

Fill the blanks with their flame colors.

Li	Na	K	Cu/B	Ca/Sr

1.2 The Color of Aqueous Ions – commonly used for AP Chemistry experiments

name	___manganate	chromate	dichromate	/
formula	$MnO_4^-(aq)$			$Cu^{2+}(aq)/Cu(NH_3)_4^{2+}(aq)$
color				_____/deep blue
application	strong oxidant, redox titration, no extra indicator needed	LCP demo, strong oxidant _____ + $2H^+$ = _____ + H_2O		dehydration of $CuSO_4 \cdot 5H_2O$ formation of complex
name	/	/	/	
formula	$Co^{2+}(aq)$ or $Co(H_2O)_6^{2+}$	$CoCl_4^{2-}(aq)$	$Fe^{3+}(aq)$	$Ag^+/Zn^{2+}(aq)$
color				**colorless**
application	LCP demo $Co(H_2O)_6^{2+} + 4Cl^- = CoCl_4^{2-} + 6H_2O$		*K* measurement for the formation of $Fe(SCN)^{2+}$ ____	_____d subshell ➔ NO *d-d transition* ➔ no color



Extension:

- Crystal Field Theory
- *Ligand -Metal Charge Transfer

- from compounds of interest

[USNCO Example – *N2021-P1-Q9/N2020-P1-Q12*]

9. Addition of 10 mL of distilled water to 0.1 g of which salt produces a yellow, slightly cloudy solution?

(A) $KMnO_4$ **(B)** $FeCl_3$

(C) $Co(NO_3)_2$ **(D)** $CuSO_4$

12. Mixing which 0.1 M aqueous solutions results in formation of a colored precipitate?

(A) $BaCl_2$ and CH_3COOH

(B) $BaCl_2$ and Na_2CO_3

(C) $CuCl_2$ and CH_3COOH

(D) $CuCl_2$ and Na_2CO_3

3. **The Heat of Reactions/Dissolution** – fill the blanks with *exothermic* or *endothermic*

- The dilution of concentrated H_2SO_4 is_____, the dissolution of solid NaOH in water is_____.
- The dissolution of solid sodium bicarbonate in water is_____.
- The acid-base neutralizations are_____, most redox reactions are_____.
- Reaction of baking soda (formula:_____) with vinegar (formula:_____) is_____;
- Dissolution of most ammonium salts, such as NH_4Cl, NH_4NO_3 is_____.
- *Reaction of solid barium hydroxide (formula:_____) with solid ammonium chloride (formula _____) is_____.

[USNCO Example – *L2020-Q11*]

11. Which reaction is not exothermic?

(A) Dilution of concentrated hydrochloric acid in water.

(B) Dilution of concentrated sulfuric acid in water.

(C) Dissolution of solid sodium hydroxide in water.

(D) Dissolution of solid sodium bicarbonate in water.

[USNCO Example – *N2015-P1-Q7*]

7. Each of the following substances dissolves exothermically in water EXCEPT

(A) $NaOH(s)$.

(B) $NH_4NO_3(s)$.

(C) $CuSO_4(s)$.

(D) $H_2SO_4(l)$.

2. Solubility Rules

- Pretty much all nitrate, acetate, Na^+, K^+, NH_4^+ are soluble, most precipitates are white unless_____.
- Most of chlorides are soluble except_____and_____(dissolve in hot water).
- Most of sulfates are soluble except Pb^{2+} and several group_____cations, such as Ca^{2+}, Sr^{2+}, and Ba^{2+}.
- Most of hydroxides, carbonates, oxalates, sulfides are insoluble except those listed in Rule #1.
- *Fluorides are different from other halides, AgF is _____while other AgX (X = Cl, Br, I) are insoluble, MF_2 (M = Ca, Sr, Ba) are_____while other MX_2 (X = Cl, Br, I) are soluble.
- Precipitates made by conjugate base of weak acids are more soluble in_____, such as hydroxides, carbonates, oxalates, and sulfides. Why? How about the precipitates of halides (excepts fluorides)?
- Some precipitates dissolves when forming complex ions: AgCl(s) dissolved in concentrated _____(formula of complex: _____), $Al(OH)_3$(s) dissolved in concentrated _____(_____).

[USNCO Example – *N2021-P1-Q8*]

8. A solution that may contain either 0.1 M $Ag^+(aq)$, 0.1 M $Pb^{2+}(aq)$, or both, is treated with 1 M aqueous HCl. A white precipitate forms which does not appear to dissolve in hot water. Which conclusion about the cations present may be drawn?

(A) Only Ag^+ is present.

(B) Only Pb^{2+} is present.

(C) Ag^+ is present, and Pb^{2+} may be present.

(D) Pb^{2+} is present, and Ag^+ may be present.

[USNCO Example – *N2016-P1-Q8*]

8. A student has 10 mL of a solution that might contain any or all of the following cations at 0.01 M concentrations: Mn^{2+}, Ba^{2+}, Ag^+, and Cu^{2+}. Addition of 10 mL of 1 M HCl causes a precipitate to form. After the precipitate is filtered off, 1 M H_2SO_4 is added to the filtrate and another precipitate forms. What is the second precipitate?

(A) $MnSO_4$

(B) $BaSO_4$

(C) Ag_2SO_4

(D) A mixture of $BaSO_4$ and Ag_2SO_4

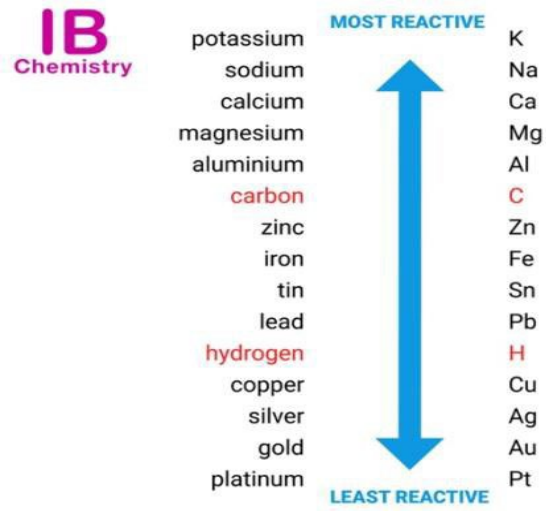
3. *Properties of Representative Metals/Nonmetals

1. General Properties of Metals

- Metals conduct heat and electricity, tend to_____electrons (lose or gain).
- _____metals and most_____metals are highly reactive, which *violently* react with water to produce $M^{I}OH$) or $M^{II}(OH)_2$ and_____.
- Metals with a standard reduction potential_____V (> or <) (**pre-H** metals) react with acid to produce the corresponding salts and_____, such as Mg, Al, and several 4th period transition mentals_and_.
- Some metals such as Cu, Ag, Pt, Au (metallic money) are unreactive,_____is commonly used an inert electrode.
- Most metal oxides are_____(acidic or basic), reacting with acids to form metal cations and__.
- More reactive metals can displace the less reactive metals from their cation solutions:

  $Cu(s) + AgNO_3(aq)$ □_____+ _____

[USNCO Example – *N2017-P1-Q8/L2020-Q9*]



8. An element is a solid at room temperature but soft enough to be cut with an ordinary knife. When placed in water, the element reacts violently. What element is it?

(A) Na **(B)** Mg **(C)** Cu **(D)** Hg

9. A strip of metallic zinc is placed in a beaker containing dilute aqueous copper(II) nitrate. Which statement correctly describes what takes place?

(A) No reaction takes place.

(B) The mass of the metal strip decreases as the zinc is oxidized.

(C) A white precipitate of $CuNO_3$ is formed.

(D) Bubbles of $NO(g)$ form as the nitrate ion is reduced.

2. General Properties of Nonmetals

- Electronegative nonmentals elements tend to _____electrons, typical examples are halogens, dioxygen.
- Most nonmentals react with hydrogen gas to produce their covalent hydrides.
- Typical nonmetal oxides are_____, reacting with_____to produce the corresponding acids.
- The more reactive halogens (X_2) can displace the less reactive halogens from their halide solutions:

  $Cl_2(aq) + KBr(aq)$ ➔_____+ _____

  (color change:_____)

[USNCO Example - *N2015-P1-Q11/L2021-Q11*]

11. Elemental silicon is oxidized by O_2 to give a compound which dissolves in molten Na_2CO_3. When this solution is treated with aqueous hydrochloric acid, a precipitate forms. What is the precipitate?

(A) SiH_4 **(B)** $SiCO_3$ **(C)** SiO_2 **(D)** $SiCl_4$

11. Chlorine gas is bubbled into a colorless aqueous solution of sodium iodide. Which is the best description of what takes place?

(A) A precipitate of white NaCl forms.

(B) A precipitate of metallic Na forms.

(C) The solution turns pale green as the chlorine dissolves.

(D) The solution turns yellow-brown as iodide reacts with the chlorine.

3.3 Amphoteric Metals

Several metals close to the metal/nonmental boundary are amphoteric, meaning that they can react with both _____and _____. Their oxides and hydroxides are also _____. The most typical example is _____.

[USNCO Example - *N2015-P1-Q12*]

12. A metal dissolves in 3.0 M NaOH solution with evolution of gas to form a clear, colorless solution. Upon neutralization, the solution forms a gelatinous precipitate. What is the metal?

(A) Al **(B)** Ag **(C)** Cu **(D)** Mg

[USNCO Example - *N2016-P1-Q9*]

9. When 6 M sodium hydroxide is added to an unknown white solid, the solid dissolves. What is a possible identity for this solid?

(A) $Mg(OH)_2$ **(B)** $Al_2(SO_4)_3$

(C) $BaCO_3$ **(D)** AgBr

4. Strong/Weak Electrolytes, Acid-Base Property of Salt Solutions

1. Commonly Used Acids and Bases

- List the THREE most commonly used strong acids in a HS chemistry lab:_____,_____, _____(first step strong, second step weak), a few more strong acids are HBr(aq), HI(aq), $HClO_4$(aq).
- HF(aq) is a_____acid, the only exception in hydrohalic acids.
- Most carboxylic acids (RCOOH) are_____acids, such as acetic acid_____(formula).
- List the THREE most used strong bases in a HS chemistry lab:_____,_____, $Ba(OH)_2$.
- NH_4OH (aqueous solution of ammonia) is a typical_____(strong or weak) base.
- Amines are weak_____, which are organic derivatives of ammonia, NH_3.

1. **Acid-Base Properties of Salt Solutions**
   - Salts made by cations of **strong** bases and conjugate bases of **strong** acids are_____(acidic, neutral, or basic), such as NaCl(aq).
   - Salts made by cations of **strong** bases and conjugate bases of **weak** acids are_____(acidic, neutral, basic), such as NaF(aq) and CH_3COONa(aq).
   - Salts made by cations of **weak** bases and conjugate bases of **strong** acids are_____(acidic, neutral, basic), such as NH_4Cl(aq).
   - Salts made by highly charged cations and conjugate bases of **strong** acids are_____(acidic, neutral, basic), such as $FeCl_3$(aq)
   - the weaker the acids are, the_____(more or less) basic the conjugate bases are (conjugate see-saw).

     *Extension: 0.1 M Na_2CO_3(aq) is_____(more or less) basic than 0.1 M $NaHCO_3$(aq).

How to explain the above statements? Taking NH_4Cl(aq) and NaF(aq) as examples.

[USNCO Example – *L2018-Q9*]

9. A 0.1 M solution of which salt is the most basic?

(A) $NaNO_3$ **(B)** $NaClO_4$

(C) $NaHSO_4$ **(D)** $NaHCO_3$

[USNCO Example - *N2017-P1-Q10*]

10. A 0.1 M solution of which salt is the most acidic?

(A) $Al(NO_3)_3$ **(B)** $MgBr_2$

(C) $NaHCO_3$ **(D)** $NaHCO_2$

5. Typical Gas Evolution and Redox Reactions

1. Typical Gas Evolution Reactions

gas evolved	reaction	net ionic equation
$H_2(g)$	Pre-H metals reacting with _____	
$CO_2(g)$	carbonates or bicarbonates reacting with _____	
$SO_2(g)$	sulfites or bisulfites reacting with _____	
$NH_3(aq)$	ammonium reacting with strong _____	
$NO_x(g)$	metals including post-H metals reacting with_____acids	why NO $H_2(g)$ produced?

[USNCO Example - *N2020-P1-Q10*]

10. Which substance produces a toxic and explosive gas when added to strong acids?

(A) NaN_3 **(B)** Na_2CO_3

(C) $NaClO_4$ **(D)** Na_2SO_3

[USNCO Example - *N2017-P1-Q10*]

10. Addition of small amounts of which solids to 4 M HCl will result in gas evolution?

I. Zn II. Na_2SO_3

(A) I only **(B)** II only

(C) Both I and II **(D)** Neither I nor II

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5.2 Typical Redox Reactions

redox reaction	characters	net ionic equation
metals reacting with water/acid/base	H^+ or H_2O is reduced into _____	
decomposition of $H_2O_2(aq)$	____thermic, catalyzed by a variety of catalysts, such as $MnO_2(s)$, Br^-, I^-, etc.	
standardization of MnO_4^- (aq) by $C_2O_4^{2-}$ or $Fe^{2+}(aq)$	MnO_4^- is_____(color), used as oxidant and indicator (turns pink when last drop of MnO_4^- is added), solution acidified	
titration of $H_2O_2(aq)$ using **standardized** $MnO_4^-(aq)$	H_2O_2 is oxidized into_____, solution acidified	
titration of $I_2(aq)$ using **standard** $S_2O_3^{2-}(aq)$	starch used as indicator (_____complex with I_2), $S_2O_3^{2-}$ is oxidized into _____	

[USNCO Example - *N2021-P1-Q10*]

10. The amount of ascorbic acid in a vitamin C tablet is determined by titration with a solution of iodine in aqueous potassium iodide. A small amount of starch is added to the vitamin C solution before the titration. What is the function of the starch?

(A) It forms an intensely colored complex with triiodide ion.

(B) It increases the viscosity of the analyte solution.

(C) It catalyzes the dissociation of triiodide into iodine and iodide.

(D) It binds to the inert ingredients of the vitamin C tablet.

[USNCO Example - *N2015-P1-Q9*]

9. A student standardizes a solution of $Na_2S_2O_3$ by titrating it against a solution containing a known mass of $NaIO_3$ that has been dissolved in an excess of a freshly prepared solution of KI in dilute HCl. Which of the following errors will lead to a value of the molarity of the thiosulfate solution that is higher than the true value?

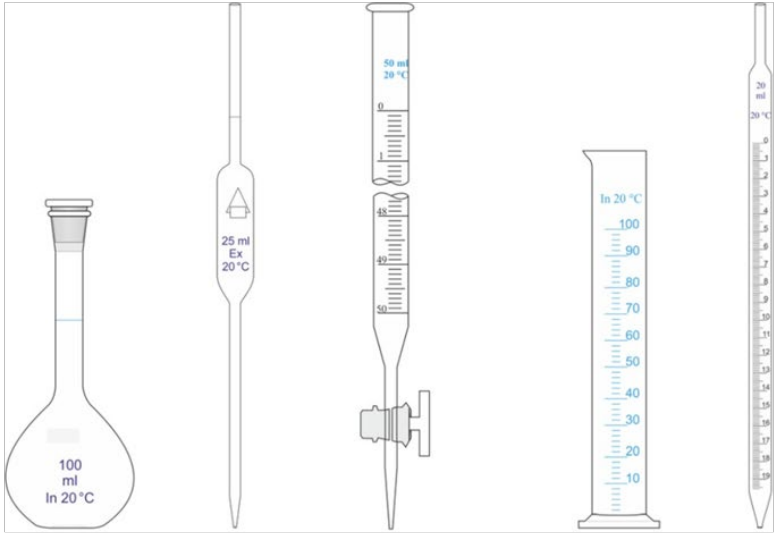
(A) The student overshoots the endpoint of the titration.

(B) The $NaIO_3$ is contaminated with NaCl.

(C) The KI/HCl solution is allowed to stand overnight before it is used in the titration.

(D) The sample of sodium thiosulfate pentahydrate used to make the $Na_2S_2O_3$ solution had partially dehydrated on standing.

6. Volumetric Glassware

volumetric glassware					
uncertainy	±0.0X mL	±0.0X mL	±0.0X mL	±0.X mL	±0.0X mL
other characters	to contain (TC)	bulb needed, *finger on top	read the volume difference	easy to use	bulb needed, *finger on top
application	preparing a solution with a certain molarity	transfer a *fix* volume of solution	titrations	transfer a certain volume of solution with a *lower* precision	transfer *a certain* volume of solution

Beakers, Erlenmeyer flasks, or disposable plastic/glass pipets can't be used for serious volume measurement as their marks are not precise and for reference only.

[USNCO Example - *N2021-P1-Q7*]

7. Which glassware would be most appropriate for measuring 10.00 mL of distilled water?

(A) A 10-mL test tube

(B) A 25-mL beaker

(C) A 50-mL buret

(D) A 100-mL graduated cylinder

[USNCO Example - *L2018-Q11*]

11. Which would be most suitable for measuring 2.7 mL of ethanol for addition to a reaction with acidified dichromate?

(A) 10-mL graduated cylinder

(B) 10-mL volumetric flask

(C) 10-mL volumetric pipet

(D) 10-mL beaker

[USNCO Example - *N2019-P1-Q12*]

12. Which is the best way to dispense liquids using a volumetric pipet?

(A) The pipet is immersed in the liquid to be dispensed, then lifted with a gloved finger on the top and the liquid allowed to drain to the mark. The remaining contents are then allowed to drain into the desired container.

(B) The pipet is immersed in the liquid to be dispensed, then lifted with a gloved finger on the top and the liquid allowed to drain to the mark. The remaining contents are then allowed to drain into the desired container, with a pipet bulb used to gently blow out any residual droplets.

(C) The tip of the pipet is submerged below the surface of the liquid and suction is applied using a pipet bulb until the liquid rises above the level of the mark. A gloved finger is then applied to the top of the pipet and the liquid allowed to drain to the mark. The remaining contents are then allowed to drain into the desired container.

(D) The tip of the pipet is submerged below the surface of the liquid and suction is applied by mouth until the liquid rises to the level of the mark. The contents are then allowed to drain into the desired container.

7. UV-Vis Spectroscopy and Beer's Law

1. Principle

UV/Vis spectroscopy is routinely used in AP and analytical chemistry for the *quantitative* determination of different analytes or sample with colors, based on the *Beer's Law*

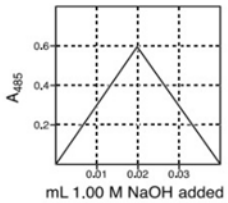
$$Abs = \varepsilon lc$$

where ε is the_____, l is_____, c is the molarity of the solution.

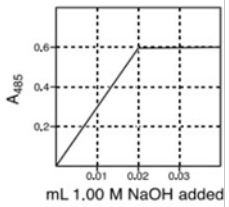
[USNCO Example - *N2015-P1-Q6*]

6. Nitrophenol is a colorless weak monoprotic acid ($pK_a = 7.2$) whose conjugate base is bright yellow. To 2.00 mL of a solution of 0.0100 M nitrophenol is added 1.00 M NaOH in 0.001 mL portions, and the absorbance of the solution at 485 nm is monitored. What does the graph of A_{485} as a function of added volume of NaOH look like?

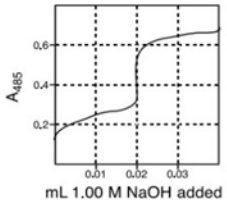
(A)



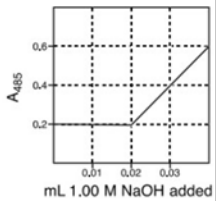
(B)



(C)



(D)



[USNCO Example - *N2021-P1-Q12*]

12. A student performs an experiment to determine the concentration of a colored salt solution by measuring the absorbance of the solution at the wavelength of maximum absorbance of the salt (λ_{max}) and using Beer's Law to calculate the concentration. Which of the following could cause the measured concentration to be higher than the actual concentration?

(A) The cuvette is not rinsed with the salt solution after being washed.

(B) The cuvette is not wiped off before it is inserted into the spectrophotometer.

(C) Less than the recommended volume of salt solution is added to the cuvette.

(D) The spectrometer is set to a wavelength different from λ_{max}.

7.3 Color Wheel

The color of the solution is the_____color of the light absorbed.

[USNCO Example - *N2020-P1-Q8*]

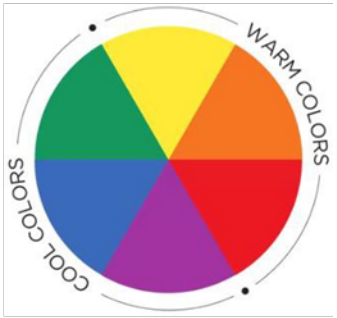
8. The equilibrium constant for the formation of $CoCl_4^{2-}$, a species that is blue in solution, is to be measured using a colorimeter. The colorimeter has wavelength settings of 470 nm ("blue"), 565 nm ("green"), and 635 nm ("red") to use in the experiment. What is the best setting to use?

(A) 470 nm

(B) 565 nm

(C) 635 nm

(D) All settings would be equally suitable for the measurement.



8. Titrations and Error Analysis

1. Error Analysis

[USNCO Example - *N2020-P1-Q9*(calorimetry)]

9. A student is using a coffee-cup calorimeter to determine the enthalpy change of the endothermic reaction of two aqueous solutions. After both solutions are added to the cup, the student neglects to put the lid on the cup. This would cause the magnitude of the calculated $\Delta H°$ value to be:

(A) too small, since some heat will escape out of the cup.

(B) too large, since some heat will escape out of the cup.

(C) too small, since the solution will absorb heat from the room.

(D) too large, since the solution will absorb heat from the room.

[USNCO Example – *L2019-Q11*(gravimetric analysis)]

11. The concentration of sulfate ion in a solution is measured by precipitating the sulfate as $BaSO_4$, filtering the precipitate on ashless filter paper, and heating the filter paper and precipitate in a tared crucible with a Bunsen burner. Which error will result in a sulfate concentration that is higher than the actual concentration?

(A) The empty crucible contains a few drops of water when it is tared.

(B) A glass fiber filter is used instead of ashless filter paper.

(C) Some fine precipitate is not captured by the filter.

(D) Some of the sulfate-containing solution spills before the $BaCl_2$ solution is added.

[USNCO Example - *N2015-P1-Q9*(iodometry)]

9. A student standardizes a solution of $Na_2S_2O_3$ by titrating it against a solution containing a known mass of $NaIO_3$ that has been dissolved in an excess of a freshly prepared solution of KI in dilute HCl. Which of the following errors will lead to a value of the molarity of the thiosulfate solution that is higher than the true value?

(A) The student overshoots the endpoint of the titration.

(B) The $NaIO_3$ is contaminated with NaCl.

(C) The KI/HCl solution is allowed to stand overnight before it is used in the titration.

(D) The sample of sodium thiosulfate pentahydrate used to make the $Na_2S_2O_3$ solution had partially dehydrated on standing.

[USNCO Example - *N2019-P1-Q12*(acid-base titration)]

12. The ammonia concentration of a solution is determined by titrating with aqueous HCl (previously standardized against Na_2CO_3) using a pH meter. Which of the following errors will lead to a measured concentration of NH_3 that is higher than the actual concentration?

(A) Some of the Na_2CO_3 used in the standardization is spilled before being transferred to the titration flask.

(B) The glass stirring rod used to stir the ammonia solution is wiped with a paper towel after each aliquot of HCl is added.

(C) The ammonia solution is allowed to stand in an open beaker for an hour before being titrated.

(D) The pH meter has been miscalibrated so that all readings are 2.00 pH units higher than the actual pH.

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2. Important Concepts in Titrations

- titrant (typical put in the burette)
- analyte (typically put in the titration flask)
- indicator (phenolphthalein, pH range 8~10, change from _____to ____)
- **standardization**
- equivalence point vs end point
- half equivalence point