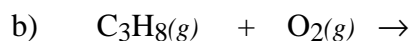
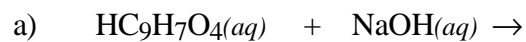


INSTRUCTIONS:

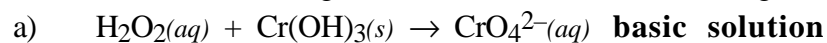
1. This examination consists of a total of 15 different pages. The last umpteen pages include a whole heck of alot of important mathematical equations, constants and tables. All work should be done in this booklet. You may *carefully* remove the last 5 pages of the examination.
2. PRINT your name, your TA's name and your laboratory section now in the space at the top of this sheet. **DO NOT SEPARATE THE PAGES.**
3. Answer all questions that you can and whenever called for show your work clearly. Your method of solving problems should pattern the approach used in lecture. You do not have to show your work for the multiple choice or short answer questions.
4. *No credit* will be awarded if your work is not shown in problems 2 – 6. Please circle your final answer!
5. Point values are shown next to the problem number.
6. Budget your time for each of the questions. Some problems may have a low point value yet be very challenging. If you do not recognize the solution to a question quickly, skip it, and return to the question after completing the easier problems.
7. Look through the exam before beginning; plan your work; then begin.
8. **Relax** and do well.

	Page 2	Page 3	Page 4	Page 5	Page 6	TOTAL
SCORES	<u> </u> (19)	<u> </u> (24)	<u> </u> (20)	<u> </u> (24)	<u> </u> (63)	<u> </u> (150)

(9) 1. Write the chemical formula(s) of the product(s) and balance the following reactions. Identify the phase of each product as either (g)as, (l)iquid, (s)olid or (aq)ueous. Soluble ionic compounds should be written in the form of their component ions.



(10) 2. Balance the following oxidation-reduction reaction using the half-reaction method.



identify the oxidizing agent _____

identify the reducing agent _____

(24) 3. The rate constant for the second order decomposition of NOBr



is $1.41 \times 10^{-5} \text{ mm Hg}^{-1}\cdot\text{s}^{-1}$ at 10°C . A sample of NOBr at a pressure of 250 mm Hg is placed in a flask at this temperature and sealed.

- a) What will be the pressure of NOBr in the flask after 100 seconds?
- b) Assuming there is no NO or Br₂ in the container initially, calculate the total pressure in the flask after 100 seconds?
- c) How much time has elapsed when the total pressure in the flask is 350 mm Hg?

(20)4a. Exactly 1 liter of a buffer solution contains 0.400 mol $(\text{CH}_3)_3\text{N}$, trimethylamine, and 0.500 mol of $(\text{CH}_3)_3\text{NHCl}$. Calculate the pH of the buffer solution.

b) Calculate the new pH if 0.0500 mol of hydrochloric acid, HCl, are added to the buffer solution in part a).

(14)5a. The mole fraction of ethylene glycol, $C_2H_6O_2$, in a particular ethylene glycol–water solution is equal to 0.03125. Determine the mass of ethylene glycol in 3.785 L (1 gallon) of this solution if the density of the solution is $1.012 \text{ g}\cdot\text{mL}^{-1}$.

b. ethylene glycol dissolves in water. Draw a Lewis structure for ethylene glycol which supports this experimental fact.

(10)6a. Write the half-reactions and determine the products of the reaction when a piece of sodium metal is added to water at 25°C .

b) Is the reaction spontaneous or nonspontaneous? Briefly explain your answer. (Note: You may show a calculation to support your conclusion.)

c) If a piece of sodium with a mass 1.00 g is added to 100 mL of water, estimate the pH of the resulting solution.

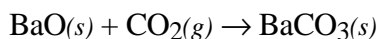
Multiple Choice: (63 points)

Print the letter (A, B, C, D, E) which corresponds to the answer selected.

7. _____ 8. _____ 9. _____ 10. _____ 11. _____
 12. _____ 13. _____ 14. _____ 15. _____ 16. _____
 17. _____ 18. _____ 19. _____ 20. _____ 21. _____
 22. _____ 23. _____ 24. _____ 25. _____ 26. _____
 27. _____

ONLY THE ANSWERS IN THE AREA ABOVE WILL BE GRADED. Select the most correct answer for each question. Each question is worth 3 points.

7. ΔG° for the reaction



is – at 25 °C. Which of the following statements is true?

- A) The reaction remains spontaneous at higher temperatures.
 B) The reaction becomes nonspontaneous at higher temperatures.
 C) The reaction is spontaneous at all temperatures.
 D) There is not enough information to answer this question.

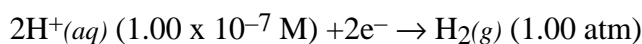
8. The standard entropy of formation, ΔS°_f of $\text{H}_2\text{O}(l)$ is

- A) $70 \frac{\text{J}}{\text{K}}$
 B) $406 \frac{\text{J}}{\text{K}}$
 C) $-163 \frac{\text{J}}{\text{K}}$
 D) $-266 \frac{\text{J}}{\text{K}}$

9. A hydrochloric acid solution is 38.0% by mass and it is also 12.5 M. Calculate the density of the solution.

- A) $0.835 \text{ g}\cdot\text{mL}^{-1}$
 B) $1.04 \text{ g}\cdot\text{mL}^{-1}$
 C) $1.20 \text{ g}\cdot\text{mL}^{-1}$
 D) $1.31 \text{ g}\cdot\text{mL}^{-1}$

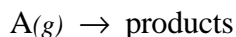
10. For the half-reaction



E_{cell} is

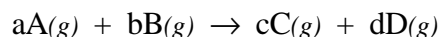
- A) +0.829 v
 B) -0.829 v
 C) +0.414 v
 D) -0.414 v

11. Which of the following compounds has the greater solubility in water?
- A) $\text{H}_3\text{C}-\text{CH}_2-\text{CH}_3$
 - B) CCl_4
 - C) CH_2Cl_2
 - D) $\text{CH}_3\text{CH}_2\text{OH}$
12. Which of the following solutions will have the lowest freezing point?
- A) 0.100 M CaCl_2
 - B) 0.100 M NaCl
 - C) 0.100 M $\text{C}_6\text{H}_{12}\text{O}_6$
 - D) 0.100 M NH_4NO_3
13. Which of the following mathematical relationships would be used to determine the time required for 30% of a reactant to decompose in the first order reaction;



- A) $t = \frac{1.20}{k}$
- B) $t = \frac{0.357}{k}$
- C) $t = \frac{2.33}{k \cdot [\text{A}_0]}$
- D) $t = \frac{0.428}{k \cdot [\text{A}_0]}$

14. In the following reaction



1.00 mol of A is mixed with 2.00 mol of B in a 1.00 L container at a given temperature. After 10 minutes the concentration of all species were found to be;

	[A]	[B]	[C]	[D]
after 10 min	0.875 M	1.81 M	0.0625 M	0.250 M

The balanced chemical equation must be;

- A) $2\text{A}(g) + 3\text{B}(g) \rightarrow \text{C}(g) + 4\text{D}(g)$
 - B) $\text{A}(g) + 2\text{B}(g) \rightarrow \text{C}(g) + \text{D}(g)$
 - C) $\text{A}(g) + 2\text{B}(g) \rightarrow \text{C}(g) + 4\text{D}(g)$
 - D) $2\text{A}(g) + \text{B}(g) \rightarrow \text{C}(g) + \text{D}(g)$
15. Increasing the temperature in an endothermic reaction will
- A) increase both the rate of the reaction and the magnitude of the equilibrium constant.
 - B) increase the rate of the reaction and decrease the magnitude of the equilibrium constant.
 - C) decrease the rate of the reaction and increase the magnitude of the equilibrium constant.
 - D) decrease both the rate of the reaction and the magnitude of the equilibrium constant.
 - E) increase the rate and have no affect on the equilibrium constant.

16. Which of the following statements is true?

- A) The half-life of a second order reaction is independent of the initial concentration of the reactant.
- B) The decay of many radioactive elements follows second order kinetics.
- C) When a plot of [reactant] versus time is a straight line the rate constant can be determined from the y-intercept.
- D) The units for the rate constant of a first and a second order reaction are different.

17. Which of the following statements is true?

- A) The activation energy is the minimum energy required for a reaction to occur.
- B) The number of collisions per second between molecules in the gas phase is independent of temperature.
- C) The activation energy can be determined knowing the difference in energy of the reactants and the products in a chemical reaction.
- D) The activation energy is generally smallest for exothermic reactions.

18. Which of the following statements is true?

- A) Bimolecular elementary reactions are less common compared to termolecular elementary reactions in most mechanisms.
- B) Intermediates in chemical reactions are short-lived species which initially appear as a product in a multi-step reaction mechanism.
- C) The overall rate law for a chemical reaction must be identical to the rate law for the fastest elementary step in a multi-step mechanism.
- D) A catalyst never appears in the elementary step(s) of a mechanism because by definition it is not consumed in the reaction.

19. Which of the following reactions has the most positive value of ΔS° ?

- A) $2\text{Mg}(s) + \text{CO}_2(g) \rightarrow 2\text{MgO}(s) + \text{C}(s)$
- B) $\text{NH}_3(g) + \text{HCl}(g) \rightarrow \text{NH}_4\text{Cl}(s)$
- C) $6\text{Li}(s) + \text{N}_2(g) \rightarrow 2\text{Li}_3\text{N}(s)$
- D) $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s) \rightarrow \text{CaSO}_4(s) + 2\text{H}_2\text{O}(g)$

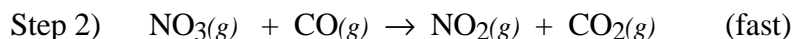
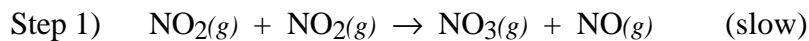
20. A reaction rate for a particular reaction triples when the temperature is raised from 17 °C to 37 °C. The activation energy is,

- A) $287 \frac{\text{J}}{\text{mol}}$
- B) $20 \frac{\text{kJ}}{\text{mol}}$
- C) $41 \frac{\text{kJ}}{\text{mol}}$
- D) $57 \frac{\text{kJ}}{\text{mol}}$

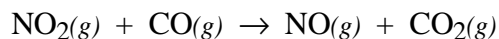
21. A solution which is 0.0100 M piperidine ($\text{C}_5\text{H}_{10}\text{NH}_2$) has a pH of 11.53. Calculate K_b for piperidine.

- A) 1.13×10^{-3}
- B) 1.70×10^{-3}
- C) 3.36×10^{-3}
- D) 2.95×10^{-12}

22. The mechanism,



has been proposed for the reaction



Based on this mechanism the expected rate law is,

- A) $\text{rate} = k[\text{NO}_2]^1[\text{CO}]^1$
- B) $\text{rate} = k[\text{NO}_2]^2[\text{CO}]^0$
- C) $\text{rate} = k[\text{NO}_3]^1[\text{CO}]^1$
- D) $\text{rate} = k[\text{NO}_2]^2[\text{CO}]^1$

23. Which of the following solutions is acidic?

- A) 0.100 M HCN/0.100 M NaCN (K_a for HCN = 4.9×10^{-10})
- B) 0.100 M NH_3 /0.900 M NH_4NO_3 (K_b for NH_3 = 1.8×10^{-5})
- C) 0.100 M $\text{C}_5\text{H}_5\text{N}$ /0.100 M $\text{C}_5\text{H}_5\text{NHCl}$ (K_b for $\text{C}_5\text{H}_5\text{N}$ = 1.7×10^{-9})
- D) 0.100 M HBrO/0.900 M NaBrO (K_a for HBrO = 2.0×10^{-9})

24. Which of the following salts, when dissolved in water, produces an acidic solution?

- A) $(\text{CH}_3)_3\text{NHCl}$
- B) NaIO_3
- C) Na_2CO_3
- D) KCl

25. Which is the strongest acid?

- A) 0.100 M H_2SO_3 ($K_{a1} = 1.7 \times 10^{-2}$ $K_{a2} = 6.4 \times 10^{-8}$)
- B) 0.100 M HF ($K_a = 7.2 \times 10^{-4}$)
- C) 0.100 M H_3PO_4 ($K_{a1} = 7.5 \times 10^{-3}$ $K_{a2} = 6.2 \times 10^{-8}$ $K_{a3} = 4.2 \times 10^{-13}$)
- D) 0.100 M H_3BO_3 ($K_a = 5.8 \times 10^{-10}$)

26. Which of the following titrations has the highest equivalence point pH?

- A) 100.0 mL of 0.500 M HCl and 0.400 M NaOH
- B) 40.0 mL of 0.400 M HBr and 0.300 M $(\text{CH}_3)_2\text{NH}$
- C) 35.0 mL of 0.900 M HF and 0.450 M NaOH
- D) 30.0 mL of 0.800 M HCN and 0.600 M NaOH

27. Rank the pure substances NF_3 , F_2 , NaF and HF in terms of increasing strength of attractive forces

- A) $\text{NaF} < \text{F}_2 < \text{NF}_3 < \text{HF}$
- B) $\text{NF}_3 < \text{F}_2 < \text{HF} < \text{NaF}$
- C) $\text{F}_2 < \text{NF}_3 < \text{HF} < \text{NaF}$
- D) $\text{HF} < \text{F}_2 < \text{NaF} < \text{NF}_3$

Useful Information

Equations

$$PV = nRT$$

$$P_{\text{solution}} = \chi_{\text{solvent}} P^{\circ}_{\text{solvent}}$$

$$\Delta T = i km$$

$$\Delta H^{\circ}_{\text{rxn}} = \sum(\Delta H_f^{\circ}(\text{products})) - \sum(\Delta H_f^{\circ}(\text{reactants}))$$

$$\Delta S^{\circ}_{\text{rxn}} = \sum(S^{\circ}(\text{products})) - \sum(S^{\circ}(\text{reactants}))$$

$$\Delta G^{\circ}_{\text{rxn}} = \sum(\Delta G_f^{\circ}(\text{products})) - \sum(\Delta G_f^{\circ}(\text{reactants}))$$

$$\Delta G^{\circ} = \Delta H^{\circ} - T\Delta S^{\circ}$$

$$\Delta G^{\circ} = -RT \ln K \quad \Delta G = \Delta G^{\circ} + RT \ln Q$$

$$\Delta G^{\circ} = -nFE^{\circ}$$

$$E_{\text{cell}} = E^{\circ} - \frac{0.0257}{n} \ln Q \quad E^{\circ} = \frac{0.0257}{n} \ln K$$

$$E_{\text{cell}} = E^{\circ} - \frac{0.059}{n} \log Q \quad E^{\circ} = \frac{0.059}{n} \log K$$

$$\ln\left(\frac{k_1}{k_2}\right) = \frac{E_a}{R} \left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

$$\ln\left(\frac{[A]_t}{[A]_o}\right) = -kt \quad \frac{1}{[A]_t} - \frac{1}{[A]_o} = kt$$

$$K_p = K_c(RT)^{\Delta n}$$

$$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad \text{for } ax^2 + bx + c = 0$$

$$\text{pH} = -\log[\text{H}^+]$$

$$\text{pH} + \text{pOH} = 14$$

Constants

$$R = 0.0821 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}} = 8.314 \frac{\text{J}}{\text{mole}\cdot\text{K}}$$

$$\text{density of H}_2\text{O} = 1.00 \frac{\text{g}}{\text{cm}^3}$$

$$k_f(\text{H}_2\text{O}) = 1.86 \frac{^{\circ}\text{C}}{\text{m}} \quad k_b(\text{H}_2\text{O}) = 0.512 \frac{^{\circ}\text{C}}{\text{m}}$$

$$F = 96,500 \frac{\text{J}}{\text{volt} \cdot \text{mol}} = 96,500 \text{ coulombs}$$

$$K_w = 1.0 \times 10^{-14}$$

Periodic Table of the Elements

	IA																VIII A	
1	1 H 1.008																	2 He 4.00
2	3 Li 6.94	IIA	4 Be 9.01									IIIA	IVA	VA	VIA	VIIA	10 Ne 20.18	
3	11 Na 22.99	12 Mg 24.30										13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95	
4	19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.0	89 Ac 227.0	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)									

Lanthanides	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
Actinides	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np 237.0	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

E.1 DISSOCIATION CONSTANTS FOR ACIDS AT 25 °C

Name	Formula	K_{a1}	K_{a2}	K_{a3}
Acetic	$\text{HC}_2\text{H}_3\text{O}_2$	1.8×10^{-5}		
Ascorbic	$\text{HC}_6\text{H}_7\text{O}_6$	8.0×10^{-3}		
Arsenic	H_3AsO_4	5.6×10^{-3}	1.0×10^{-7}	3.0×10^{-12}
Arsenous	H_3AsO_3	6.0×10^{-10}		
Benzoic	$\text{HC}_7\text{H}_5\text{O}_2$	6.5×10^{-5}		
Boric	H_3BO_3	5.8×10^{-10}		
Butyric acid	$\text{HC}_4\text{H}_7\text{O}_2$	1.5×10^{-5}		
Carbonic	H_2CO_3	4.3×10^{-7}	5.6×10^{-11}	
Cyanic	HCNO	3.5×10^{-4}		
Citric	$\text{H}_3\text{C}_6\text{H}_5\text{O}_7$	7.4×10^{-4}	1.7×10^{-5}	4.0×10^{-7}
Formic	HCHO_2	1.8×10^{-4}		
Hydroazotic	HN_3	1.9×10^{-5}		
Hydrocyanic	HCN	4.9×10^{-10}		
Hydrofluoric	HF	7.2×10^{-4}		
Hydrogen chromate ion	HCrO_4^-	3.0×10^{-7}		
Hydrogen peroxide	H_2O_2	2.4×10^{-12}		
Hydrogen selenate ion	HSeO_4^-	2.2×10^{-2}		
Hydrogen sulfate ion	HSO_4^-	1.2×10^{-2}		
Hydrogen sulfide	H_2S	5.7×10^{-8}	1.3×10^{-13}	
Hypobromous	HBrO	2.0×10^{-9}		
Hypochlorous	HClO	3.0×10^{-8}		
Hypoiodous	HIO	2.0×10^{-11}		
Iodic	HIO_3	1.7×10^{-1}		
Lactic	$\text{HC}_3\text{H}_5\text{O}_3$	1.4×10^{-4}		
Malonic	$\text{H}_2\text{C}_3\text{H}_2\text{O}_4$	1.5×10^{-3}	2.0×10^{-6}	
Oxalic	$\text{H}_2\text{C}_2\text{O}_4$	5.9×10^{-2}	6.4×10^{-5}	
Nitrous	HNO_2	4.5×10^{-4}		
Phenol	$\text{HC}_6\text{H}_5\text{O}$	1.3×10^{-10}		
Phosphoric	H_3PO_4	7.5×10^{-3}	6.2×10^{-8}	4.2×10^{-13}
Paraperiodic	H_5IO_6	2.8×10^{-2}	5.3×10^{-9}	
Propanoic	$\text{HC}_3\text{H}_5\text{O}_2$	1.4×10^{-5}		
Pyrophosphoric	$\text{H}_4\text{P}_2\text{O}_7$	3.0×10^{-2}	4.4×10^{-3}	
Selenous	H_2SeO_3	2.3×10^{-3}	5.3×10^{-9}	
Sulfuric	H_2SO_4	strong acid	1.2×10^{-2}	
Sulfurous	H_2SO_3	1.7×10^{-2}	6.4×10^{-8}	
Tartaric	$\text{H}_2\text{C}_4\text{H}_4\text{O}_6$	1.0×10^{-3}	4.6×10^{-5}	

E.2 DISSOCIATION CONSTANTS FOR BASES AT 25°C

Name	Formula	K_b	Name	Formula	K_b
Ammonia	NH_3	1.8×10^{-5}	Hydroxylamine	HONH_2	1.1×10^{-8}
Aniline	$\text{C}_6\text{H}_5\text{NH}_2$	4.3×10^{-10}	Methylamine	CH_3NH_2	4.4×10^{-4}
Dimethylamine	$(\text{CH}_3)_2\text{NH}$	5.4×10^{-4}	Pyridine	$\text{C}_5\text{H}_5\text{N}$	1.7×10^{-9}
Ethylamine	$\text{C}_2\text{H}_5\text{NH}_2$	6.4×10^{-4}	Trimethylamine	$(\text{CH}_3)_3\text{N}$	6.4×10^{-5}
Hydrazine	H_2NNH_2	1.3×10^{-6}			

E. 3 SOLUBILITY-PRODUCT CONSTANTS FOR COMPOUNDS AT 25°C

Name	Formula	K_{sp}
Barium carbonate	BaCO ₃	5.1 x 10 ⁻⁹
Barium chromate	BaCrO ₄	1.2 x 10 ⁻¹⁰
Barium Fluoride	BaF ₂	1.0 x 10 ⁻⁶
Barium hydroxide	Ba(OH) ₂	5 x 10 ⁻³
Barium oxalate	BaC ₂ O ₄	1.6 x 10 ⁻⁷
Barium phosphate	Ba ₃ (PO ₄) ₂	3.4 x 10 ⁻²³
Barium sulfate	BaSO ₄	1.1 x 10 ⁻¹⁰
Cadmium carbonate	CdCO ₃	5.2 x 10 ⁻¹²
Cadmium hydroxide	Cd(OH) ₂	2.5 x 10 ⁻¹⁴
Cadmium sulfide	CdS	8.0 x 10 ⁻²⁷
Calcium carbonate	CaCO ₃	2.8 x 10 ⁻⁹
Calcium chromate	CaCrO ₄	7.1 x 10 ⁻⁴
Calcium fluoride	CaF ₂	3.9 x 10 ⁻¹¹
Calcium hydroxide	Ca(OH) ₂	5.5 x 10 ⁻⁶
Calcium phosphate	Ca ₃ (PO ₄) ₂	2.0 x 10 ⁻²⁹
Calcium sulfate	CaSO ₄	9.1 x 10 ⁻⁶
Cerium(III) fluoride	CeF ₃	8 x 10 ⁻¹⁶
Chromium(III) fluoride	CrF ₃	6.6 x 10 ⁻¹¹
Chromium(III) hydroxide	Cr(OH) ₃	6.3 x 10 ⁻³¹
Cobalt(II) carbonate	CoCO ₃	1.4 x 10 ⁻¹³
Cobalt(II) hydroxide	Co(OH) ₂	1.6 x 10 ⁻¹⁵
Cobalt(III) hydroxide	Co(OH) ₃	1.6 x 10 ⁻⁴⁴
Copper(I) bromide	CuBr	5.3 x 10 ⁻⁹
Copper(I) chloride	CuCl	1.2 x 10 ⁻⁶
Copper(I) sulfide	Cu ₂ S	2.5 x 10 ⁻⁴⁸
Copper(II) carbonate	CuCO ₃	1.4 x 10 ⁻¹⁰
Copper(II) chromate	CuCrO ₄	3.6 x 10 ⁻⁶
Copper(II) hydroxide	Cu(OH) ₂	2.2 x 10 ⁻²⁰
Copper(II) phosphate	Cu ₃ (PO ₄) ₂	1.3 x 10 ⁻³⁷
Copper(II) sulfide	CuS	6.3 x 10 ⁻³⁶
Gold(III) chloride	AuCl ₃	3.2 x 10 ⁻²⁵
Iron(II) carbonate	FeCO ₃	3.2 x 10 ⁻¹¹
Iron(II) hydroxide	Fe(OH) ₂	8.0 x 10 ⁻¹⁶
Iron(II) sulfide	FeS	6.3 x 10 ⁻¹⁸
Iron(III) hydroxide	Fe(OH) ₃	4 x 10 ⁻³⁸
Lanthanum fluoride	LaF ₃	7 x 10 ⁻¹⁷
Lanthanum iodate	La(IO ₃) ₃	6.1 x 10 ⁻¹²
Lead carbonate	PbCO ₃	7.4 x 10 ⁻¹⁴
Lead chloride	PbCl ₂	1.6 x 10 ⁻⁵
Lead chromate	PbCrO ₄	2.8 x 10 ⁻¹³
Lead fluoride	PbF ₂	2.7 x 10 ⁻⁸
Lead hydroxide	Pb(OH) ₂	1.2 x 10 ⁻¹⁵
Lead sulfide	PbS	8.0 x 10 ⁻²⁸
Magnesium hydroxide	Mg(OH) ₂	1.8 x 10 ⁻¹¹
Magnesium oxalate	MgC ₂ O ₄	8.6 x 10 ⁻⁵
Manganese carbonate	MnCO ₃	1.8 x 10 ⁻¹¹
Mercury(I) sulfide	Hg ₂ S	1.0 x 10 ⁻⁴⁷
Mercury(II) sulfide	HgS	4.0 x 10 ⁻⁵³
Silver sulfide	Ag ₂ S	6.3 x 10 ⁻⁵⁰
Strontium fluoride	SrF ₂	2.5 x 10 ⁻⁹

Table of Standard Reduction Potentials (25 °C)

A. Acidic Solution

	$E^{\circ}(\text{V})$	$\text{Pt}^{2+} + 2\text{e}^{-} \rightarrow \text{Pt}(\text{s})$	~1.2
		$\text{ClO}_3^{-} + 3\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{HClO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$	1.21
$\text{Li}^{+} + \text{e}^{-} \rightarrow \text{Li}(\text{s})$	-3.045	$\text{O}_2(\text{g}) + 4\text{H}^{+} + 4\text{e}^{-} \rightarrow 2\text{H}_2\text{O}(\text{l})$	1.229
$\text{K}^{+} + \text{e}^{-} \rightarrow \text{K}(\text{s})$	-2.925	$\text{O}_2(\text{g}) + 4\text{H}^{+}(\text{pH} = 7) + 4\text{e}^{-} \rightarrow 2\text{H}_2\text{O}(\text{l})$	0.83
$\text{Ba}^{2+} + 2\text{e}^{-} \rightarrow \text{Ba}(\text{s})$	-2.906	$\text{MnO}_2(\text{s}) + 4\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{Mn}^{2+} + 2\text{H}_2\text{O}(\text{l})$	1.23
$\text{Sr}^{2+} + 2\text{e}^{-} \rightarrow \text{Sr}(\text{s})$	-2.888	$2\text{HNO}_2(\text{aq}) + 4\text{H}^{+} + 4\text{e}^{-} \rightarrow \text{N}_2\text{O}(\text{g}) + 3\text{H}_2\text{O}(\text{l})$	1.29
$\text{Ca}^{2+} + 2\text{e}^{-} \rightarrow \text{Ca}(\text{s})$	-2.866	$\text{Cr}_2\text{O}_7^{2-} + 14\text{H}^{+} + 6\text{e}^{-} \rightarrow 2\text{Cr}^{3+} + 7\text{H}_2\text{O}(\text{l})$	1.33
$\text{Na}^{+} + \text{e}^{-} \rightarrow \text{Na}(\text{s})$	-2.714	$\text{Cl}_2(\text{g}) + 2\text{e}^{-} \rightarrow 2\text{Cl}^{-}$	1.360
$\text{Mg}^{2+} + 2\text{e}^{-} \rightarrow \text{Mg}(\text{s})$	-2.363	$\text{PbO}_2(\text{s}) + 4\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{Pb}^{2+} + 2\text{H}_2\text{O}(\text{l})$	1.455
$\text{H}_2(\text{g}) + 2\text{e}^{-} \rightarrow 2\text{H}^{-}$	-2.25	$\text{Au}^{3+} + 3\text{e}^{-} \rightarrow \text{Au}(\text{s})$	1.498
$\text{Al}^{3+} + 3\text{e}^{-} \rightarrow \text{Al}(\text{s})$	-1.662	$\text{MnO}_4^{-} + 8\text{H}^{+} + 5\text{e}^{-} \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}(\text{l})$	1.51
$\text{Mn}^{2+} + 2\text{e}^{-} \rightarrow \text{Mn}(\text{s})$	-1.185	$2\text{HClO}(\text{aq}) + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{Cl}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$	1.63
$\text{Zn}^{2+} + 2\text{e}^{-} \rightarrow \text{Zn}(\text{s})$	-0.763	$\text{HClO}_2(\text{aq}) + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{HClO}(\text{aq}) + \text{H}_2\text{O}(\text{l})$	1.645
$\text{Cr}^{3+} + 3\text{e}^{-} \rightarrow \text{Cr}(\text{s})$	-0.744	$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow 2\text{H}_2\text{O}(\text{l})$	1.776
$\text{Fe}^{2+} + 2\text{e}^{-} \rightarrow \text{Fe}(\text{s})$	-0.440	$\text{S}_2\text{O}_8^{2-} + 2\text{e}^{-} \rightarrow 2\text{SO}_4^{2-}$	2.00
$\text{Cr}^{3+} + \text{e}^{-} \rightarrow \text{Cr}^{2+}$	-0.408	$\text{O}_3(\text{g}) + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{O}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$	2.07
$\text{Cd}^{2+} + 2\text{e}^{-} \rightarrow \text{Cd}(\text{s})$	-0.403	$\text{F}_2(\text{g}) + 2\text{e}^{-} \rightarrow 2\text{F}^{-}$	2.87
$\text{PbSO}_4(\text{s}) + 2\text{e}^{-} \rightarrow \text{Pb}(\text{s}) + \text{SO}_4^{2-}$	-0.359	$\text{F}_2(\text{g}) + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow 2\text{HF}(\text{aq})$	3.06
$\text{PbCl}_2(\text{s}) + 2\text{e}^{-} \rightarrow \text{Pb}(\text{s}) + 2\text{Cl}^{-}$	-0.268		
$\text{Ni}^{2+} + 2\text{e}^{-} \rightarrow \text{Ni}(\text{s})$	-0.250		
$\text{Sn}^{2+} + 2\text{e}^{-} \rightarrow \text{Sn}(\text{s})$	-0.136		
$\text{Pb}^{2+} + 2\text{e}^{-} \rightarrow \text{Pb}(\text{s})$	-0.126		
$2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g})$	0.000		
$\text{S}(\text{s}) + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{H}_2\text{S}(\text{aq})$	0.142		
$\text{Sn}^{4+} + 2\text{e}^{-} \rightarrow \text{Sn}^{2+}$	0.15		
$\text{Sb}_2\text{O}_3(\text{s}) + 6\text{H}^{+} + 6\text{e}^{-} \rightarrow 2\text{Sb}(\text{s}) + 3\text{H}_2\text{O}(\text{l})$	0.152		
$\text{Cu}^{2+} + \text{e}^{-} \rightarrow \text{Cu}^{+}$	0.153		
$\text{SO}_4^{2-} + 4\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{H}_2\text{SO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$	0.172		
$\text{AgCl}(\text{s}) + \text{e}^{-} \rightarrow \text{Ag}(\text{s}) + \text{Cl}^{-}$	0.222		
$\text{Cu}^{2+} + 2\text{e}^{-} \rightarrow \text{Cu}(\text{s})$	0.337		
$\text{SO}_4^{2-} + 8\text{H}^{+} + 6\text{e}^{-} \rightarrow \text{S}(\text{s}) + 4\text{H}_2\text{O}(\text{l})$	0.357		
$\text{H}_2\text{SO}_3(\text{aq}) + 4\text{H}^{+} + 4\text{e}^{-} \rightarrow \text{S}(\text{s}) + 3\text{H}_2\text{O}(\text{l})$	0.450		
$\text{I}_2(\text{s}) + 2\text{e}^{-} \rightarrow 2\text{I}^{-}$	0.536		
$\text{MnO}_4^{-} + \text{e}^{-} \rightarrow \text{MnO}_4^{2-}$	0.564		
$[\text{PtCl}_6]^{2-} + 2\text{e}^{-} \rightarrow [\text{PtCl}_4]^{2-} + 2\text{Cl}^{-}$	0.68		
$\text{O}_2(\text{g}) + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{H}_2\text{O}_2(\text{aq})$	0.682		
$\text{Fe}^{3+} + \text{e}^{-} \rightarrow \text{Fe}^{2+}$	0.771		
$\text{Hg}^{2+} + 2\text{e}^{-} \rightarrow \text{Hg}(\text{l})$	0.788		
$\text{Ag}^{+} + \text{e}^{-} \rightarrow \text{Ag}(\text{s})$	0.799		
$2\text{NO}_3^{-} + 4\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{N}_2\text{O}_4(\text{g}) + 2\text{H}_2\text{O}(\text{l})$	0.803		
$2\text{Hg}^{2+} + 2\text{e}^{-} \rightarrow \text{Hg}_2^{2+}$	0.920		
$\text{NO}_3^{-} + 4\text{H}^{+} + 3\text{e}^{-} \rightarrow \text{NO}(\text{g}) + 2\text{H}_2\text{O}(\text{l})$	0.96		
$\text{Pd}^{2+} + 2\text{e}^{-} \rightarrow \text{Pd}(\text{s})$	0.987		
$\text{Br}_2(\text{l}) + 2\text{e}^{-} \rightarrow 2\text{Br}^{-}$	1.065		
$\text{Br}_2(\text{aq}) + 2\text{e}^{-} \rightarrow 2\text{Br}^{-}$	1.087		
$\text{ClO}_4^{-} + 2\text{H}^{+} + 2\text{e}^{-} \rightarrow \text{ClO}_3^{-} + \text{H}_2\text{O}(\text{l})$	1.19		
$2\text{IO}_3^{-} + 12\text{H}^{+} + 10\text{e}^{-} \rightarrow \text{I}_2(\text{s}) + 6\text{H}_2\text{O}(\text{l})$	1.195		

B. Alkaline Solution

 $E^{\circ}(\text{V})$

$\text{Mg}(\text{OH})_2(\text{s}) + 2\text{e}^{-} \rightarrow \text{Mg}(\text{s}) + 2\text{OH}^{-}$	-2.690
$\text{Al}(\text{OH})_3(\text{s}) + 3\text{e}^{-} \rightarrow \text{Al}(\text{s}) + 3\text{OH}^{-}$	-2.30
$\text{Zn}(\text{OH})_2(\text{s}) + 2\text{e}^{-} \rightarrow \text{Zn}(\text{s}) + 2\text{OH}^{-}$	-1.245
$\text{Fe}(\text{OH})_2(\text{s}) + 2\text{e}^{-} \rightarrow \text{Fe}(\text{s}) + 2\text{OH}^{-}$	-0.877
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^{-}$	-0.828
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^{-}(\text{pH} = 7)$	-0.43
$\text{Cd}(\text{OH})_2(\text{s}) + 2\text{e}^{-} \rightarrow \text{Cd}(\text{s}) + 2\text{OH}^{-}$	-0.809
$\text{Ni}(\text{OH})_2(\text{s}) + 2\text{e}^{-} \rightarrow \text{Ni}(\text{s}) + 2\text{OH}^{-}$	-0.72
$\text{Fe}(\text{OH})_3(\text{s}) + \text{e}^{-} \rightarrow \text{Fe}(\text{OH})_2(\text{s}) + \text{OH}^{-}$	-0.56
$2\text{S}(\text{s}) + 2\text{e}^{-} \rightarrow \text{S}_2^{2-}$	-0.447
$\text{Cu}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow 2\text{Cu}(\text{s}) + 2\text{OH}^{-}$	-0.358
$\text{CrO}_4^{2-} + 4\text{H}_2\text{O}(\text{l}) + 3\text{e}^{-} \rightarrow \text{Cr}(\text{OH})_3(\text{s}) + 5\text{OH}^{-}$	-0.13
$\text{MnO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{Mn}(\text{OH})_2(\text{s}) + 2\text{OH}^{-}$	-0.05
$\text{NO}_3^{-} + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{NO}_2^{-} + 2\text{OH}^{-}$	0.01
$\text{HgO}(\text{s}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{Hg}(\text{l}) + 2\text{OH}^{-}$	0.098
$\text{PbO}_2(\text{s}) + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{PbO}(\text{s}) + 2\text{OH}^{-}$	0.247
$\text{ClO}_3^{-} + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{ClO}_2^{-} + 2\text{OH}^{-}$	0.33
$\text{ClO}_4^{-} + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{ClO}_3^{-} + 2\text{OH}^{-}$	0.36
$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^{-} \rightarrow 4\text{OH}^{-}$	0.401
$\text{NiO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{Ni}(\text{OH})_2(\text{s}) + 2\text{OH}^{-}$	0.490
$\text{MnO}_4^{-} + 2\text{H}_2\text{O}(\text{l}) + 3\text{e}^{-} \rightarrow \text{MnO}_2(\text{s}) + 4\text{OH}^{-}$	0.588
$\text{BrO}_3^{-} + 3\text{H}_2\text{O}(\text{l}) + 6\text{e}^{-} \rightarrow \text{Br}^{-} + 6\text{OH}^{-}$	0.61
$\text{ClO}^{-} + \text{H}_2\text{O}(\text{l}) + 2\text{e}^{-} \rightarrow \text{Cl}^{-} + 2\text{OH}^{-}$	0.89

Thermodynamic Values (25 °C)

Substance and State	ΔH_f° ($\frac{\text{kJ}}{\text{mol}}$)	ΔG_f° ($\frac{\text{kJ}}{\text{mol}}$)	S° ($\frac{\text{J}}{\text{K}\cdot\text{mol}}$)	Substance and State	ΔH_f° ($\frac{\text{kJ}}{\text{mol}}$)	ΔG_f° ($\frac{\text{kJ}}{\text{mol}}$)	S° ($\frac{\text{J}}{\text{K}\cdot\text{mol}}$)
Carbon				Nitrogen			
C(s) (graphite)	0	0	6	N ₂ (g)	0	0	192
C(s) (diamond)	2	3	2	NCl ₃ (g)	230	271	-137
CO(g)	-110.5	-137	198	NF ₃ (g)	-125	-83.6	-139
CO ₂ (g)	-393.5	-394	214	NH ₃ (g)	?	-17	193
CH ₄ (g)	?	-51	186	NH ₃ (aq)	?	-27	111
CH ₃ OH(g)	-201	-163	240	NH ₂ CONH ₂ (aq)	?	?	174
CH ₃ OH(l)	-239	-166	127	NO(g)	90	87	211
H ₂ CO(g)	-116	-110	219	NO ₂ (g)	32	52	240
HCOOH(g)	-363	-351	249	N ₂ O(g)	82	104	220
HCN(g)	135.1	125	202	N ₂ O ₄ (g)	10	98	304
C ₂ H ₂ (g)	227	209	201	N ₂ O ₅ (g)	-42	134	178
C ₂ H ₄ (g)	52	68	219	N ₂ H ₃ CH ₃ (l)	54	180	166
CH ₃ CHO(g)	-166	-129	250	HNO ₃ (aq)	-207	-111	146
C ₂ H ₅ OH(l)	-278	-175	161	HNO ₃ (l)	-174	-81	156
C ₂ H ₆ (g)	-84.7	-32.9	229.5	NH ₄ Cl(s)	-314	-201	95
C ₃ H ₆ (g)	20.9	62.7	266.9	NH ₄ ClO ₄ (s)	-295	-89	186
C ₃ H ₈ (g)	-104	-24	270	Silver			
Bromine				Ag(s)	0	0	42.6
Br ₂ (l)	0	0	152.	Ag ⁺ (aq)	105.6	77.1	72.7
BrCl(g)	14.64	-0.96	240	Ag(S ₂ O ₃) ³⁻ (aq)	-1285.7	--	--
Chlorine				AgBr(s)	-100.4	-96.9	107.1
Cl ₂ (g)	0	0	223	AgCl(s)	-127.1	-109.8	96.2
Cl ₂ (aq)	-23	7	121	Sulfur			
Cl ⁻ (aq)	-167	-131	57	S(rhombic)	0	0	31.8
HCl(g)	-92	-95	187	SO ₂ (g)	-296.8	-300.2	248.8
Fluorine				SO ₃ (g)	-395.7	-371.1	256.3
F ₂ (g)	0	0	203	H ₂ S(g)	-20.17	-33.0	205.6
F(aq)	-333	-279	-14	Titanium			
HF(g)	-271	-273	174	TiCl ₄ (g)	-763	-727	355
Hydrogen				TiO ₂ (s)	-945	-890	50
H ₂ (g)	0	0	131	Aluminum			
H(g)217	203	115		AlCl ₃ (s)	-526	-505	184
H ⁺ (aq)	0	0	0	Barium			
OH ⁻ (aq)	-230	-157	-11	BaCl ₂ (aq)	-872	-823	123
H ₂ O(l)	-286	-237	70	Ba(OH) ₂ ·8H ₂ O(s)	-3342	-2793	427
H ₂ O(g)	-242	-229	189	Iodine			
Magnesium				I ₂ (s)	0	0	116.7
Mg(s)	0	0	33	HI(g)	25.94	1.30	206.3
Mg(aq)	-492	-456	-118				
MgO(s)	-601	-569	26.9				
Oxygen							
O ₂ (g)	0	0	205				
O(g)249	232	161					
O ₃ (g)	143	163	239				