CHEM 1515
Exam V
John V. Gelder
December 14, 1993

Name ____________________
TA's Name ____________________

Lab Section ____________________

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	______ (19)	______ (24)	______ (20)	______ (24)	______ (63)	______ (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.

a) $HC_9H_7O_4(aq) + NaOH(aq) \rightarrow$

b) $C_3H_8(g) + O_2(g) \rightarrow$

c) $Al(s) + Fe_2O_3(s) \rightarrow$

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

a) $H_2O_2(aq) + Cr(OH)_3(s) \rightarrow CrO_4^{2-}(aq)$ **basic solution**

identify the oxidizing agent ________ identify the reducing agent ________

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

$$2NOBr(g) \rightarrow Br_2(g) + 2NO(g)$$

is 1.41×10^{-5} mm $Hg^{-1} \cdot s^{-1}$ 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 Br_2 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 $(CH_3)_3N$, trimethylamine, and 0.500 mol of $(CH_3)_3NHCl$. 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 $g \cdot mL^{-1}$.

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

$$BaO(s) + CO_2(g) \rightarrow BaCO_3(s)$$

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 $H_2O(l)$ is

A) $70 \frac{J}{K}$

B) $406 \frac{J}{K}$

C) $-163 \frac{J}{K}$

D) $-266 \frac{J}{K}$

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

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

10. For the half-reaction

$$2H^+(aq)\ (1.00 \times 10^{-7}\ M) + 2e^- \rightarrow H_2(g)\ (1.00\ atm)$$

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) $H_3C–CH_2–CH_3$
B) CCl_4
C) CH_2Cl_2
D) CH_3CH_2OH

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 $C_6H_{12}O_6$
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;

$$A(g) \rightarrow \text{products}$$

A) $t = \frac{1.20}{k}$
B) $t = \frac{0.357}{k}$
C) $t = \frac{2.33}{k \cdot [A_0]}$
D) $t = \frac{0.428}{k \cdot [A_0]}$

14. In the following reaction

$$aA(g) + bB(g) \rightarrow cC(g) + dD(g)$$

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) $2A(g) + 3B(g) \rightarrow C(g) + 4D(g)$
B) $A(g) + 2B(g) \rightarrow C(g) + D(g)$
C) $A(g) + 2B(g) \rightarrow C(g) + 4D(g)$
D) $2A(g) + B(g) \rightarrow C(g) + D(g)$

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) $2Mg(s) + CO_2(g) \rightarrow 2MgO(s) + C(s)$
B) $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$
C) $6Li(s) + N_2(g) \rightarrow 2Li_3N(s)$
D) $CaSO_4 \cdot 2H_2O(s) \rightarrow CaSO_4(s) + 2H_2O(g)$

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

21. A solution which is 0.0100 M piperidine ($C_5H_{10}NH_2$) 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,

Step 1) $NO_2(g) + NO_2(g) \rightarrow NO_3(g) + NO(g)$ (slow)

Step 2) $NO_3(g) + CO(g) \rightarrow NO_2(g) + CO_2(g)$ (fast)

has been proposed for the reaction

$$NO_2(g) + CO(g) \rightarrow NO(g) + CO_2(g)$$

Based on this mechanism the expected rate law is,

A) rate = $k[NO_2]^1[CO]^1$
B) rate = $k[NO_2]^2[CO]^0$
C) rate = $k[NO_3]^1[CO]^1$
D) rate = $k[NO_2]^2[CO]^1$

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 C_5H_5N/0.100 M C_5H_5NHCl (K_b for C_5H_5N = 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 a acidic solution?

A) $(CH_3)_3NHCl$
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 $(CH_3)_2NH$
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) NaF < F_2 < NF_3 < HF
B) NF_3 < F_2 < HF < NaF
C) F_2 < NF_3 < HF < NaF
D) HF < F_2 < NaF < NF_3

Useful Information

Equations

$PV = nRT$

$P_{solution} = \chi_{solvent}P^\circ_{solvent}$

$\Delta T = ikm$

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

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

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

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

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

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

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

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

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

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

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

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

$pH = -\log[H^+]$

$pH + pOH = 14$

Constants

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

density of $H_2O = 1.00 \frac{g}{cm^3}$

$k_f(H_2O) = 1.86 \frac{^\circ C}{m}$ $k_b(H_2O) = 0.512 \frac{^\circ C}{m}$

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

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

Periodic Table of the Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 **H** 1.008																	2 **He** 4.00
2	3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	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	$HC_2H_3O_2$	1.8×10^{-5}		
Ascorbic	$HC_6H_7O_6$	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	$HC_7H_5O_2$	6.5×10^{-5}		
Boric	H_3BO_3	5.8×10^{-10}		
Butyric acid	$HC_4H_7O_2$	1.5×10^{-5}		
Carbonic	H_2CO_3	4.3×10^{-7}	5.6×10^{-11}	
Cyanic	$HCNO$	3.5×10^{-4}		
Citric	$H_3C_6H_5O_7$	7.4×10^{-4}	1.7×10^{-5}	4.0×10^{-7}
Formic	$HCHO_2$	1.8×10^{-4}		
Hydroazoic	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}		
Hypoiodus	HIO	2.0×10^{-11}		
Iodic	HIO_3	1.7×10^{-1}		
Lactic	$HC_3H_5O_3$	1.4×10^{-4}		
Malonic	$H_2C_3H_2O_4$	1.5×10^{-3}	2.0×10^{-6}	
Oxalic	$H_2C_2O_4$	5.9×10^{-2}	6.4×10^{-5}	
Nitrous	HNO_2	4.5×10^{-4}		
Phenol	HC_6H_5O	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	$HC_3H_5O_2$	1.4×10^{-5}		
Pyrophosphoric	H_4P_2O	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	$H_2C_4H_4O_6$	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	$C_6H_5NH_2$	4.3×10^{-10}	Methylamine	CH_3NH_2	4.4×10^{-4}
Dimethylamine	$(CH_3)_2NH$	5.4×10^{-4}	Pyridine	C_5H_5N	1.7×10^{-9}
Ethylamine	$C_2H_5NH_2$	6.4×10^{-4}	Trimethylamine	$(CH_3)_3N$	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	$BaCO_3$	5.1×10^{-9}
Barium chromate	$BaCrO_4$	1.2×10^{-10}
Barium Fluoride	BaF_2	1.0×10^{-6}
Barium hydroxide	$Ba(OH)_2$	5×10^{-3}
Barium oxalate	BaC_2O_4	1.6×10^{-7}
Barium phosphate	$Ba_3(PO_4)_2$	3.4×10^{-23}
Barium sulfate	$BaSO_4$	1.1×10^{-10}
Cadmium carbonate	$CdCO_3$	5.2×10^{-12}
Cadmium hydroxide	$Cd(OH)_2$	2.5×10^{-14}
Cadmium sulfide	CdS	8.0×10^{-27}
Calcium carbonate	$CaCO_3$	2.8×10^{-9}
Calcium chromate	$CaCrO_4$	7.1×10^{-4}
Calcium fluoride	CaF_2	3.9×10^{-11}
Calcium hydroxide	$Ca(OH)_2$	5.5×10^{-6}
Calcium phosphate	$Ca_3(PO_4)_2$	2.0×10^{-29}
Calcium sulfate	$CaSO_4$	9.1×10^{-6}
Cerium(III) fluoride	CeF_3	8×10^{-16}
Chromium(III) fluoride	CrF_3	6.6×10^{-11}
Chromium(III) hydroxide	$Cr(OH)_3$	6.3×10^{-31}
Cobalt(II) carbonate	$CoCO_3$	1.4×10^{-13}
Cobalt(II) hydroxide	$Co(OH)_2$	1.6×10^{-15}
Cobalt(III) hydroxide	$Co(OH)_3$	1.6×10^{-44}
Copper(I) bromide	$CuBr$	5.3×10^{-9}
Copper(I) chloride	$CuCl$	1.2×10^{-6}
Copper(I) sulfide	Cu_2S	2.5×10^{-48}
Copper(II) carbonate	$CuCO_3$	1.4×10^{-10}
Copper(II) chromate	$CuCrO_4$	3.6×10^{-6}
Copper(II) hydroxide	$Cu(OH)_2$	2.2×10^{-20}
Copper(II) phosphate	$Cu_3(PO_4)_2$	1.3×10^{-37}
Copper(II) sulfide	CuS	6.3×10^{-36}
Gold(III) chloride	$AuCl_3$	3.2×10^{-25}
Iron(II) carbonate	$FeCO_3$	3.2×10^{-11}
Iron(II) hydroxide	$Fe(OH)_2$	8.0×10^{-16}
Iron(II) sulfide	FeS	6.3×10^{-18}
Iron(III) hydroxide	$Fe(OH)_3$	4×10^{-38}
Lanthanum fluoride	LaF_3	7×10^{-17}
Lanthanum iodate	$La(IO_3)_3$	6.1×10^{-12}
Lead carbonate	$PbCO_3$	7.4×10^{-14}
Lead chloride	$PbCl_2$	1.6×10^{-5}
Lead chromate	$PbCrO_4$	2.8×10^{-13}
Lead fluoride	PbF_2	2.7×10^{-8}
Lead hydroxide	$Pb(OH)_2$	1.2×10^{-15}
Lead sulfide	PbS	8.0×10^{-28}
Magnesium hydroxide	$Mg(OH)_2$	1.8×10^{-11}
Magnesium oxalate	MgC_2O_4	8.6×10^{-5}
Manganese carbonate	$MnCO_3$	1.8×10^{-11}
Mercury(I) sulfide	Hg_2S	1.0×10^{-47}
Mercury(II) sulfide	HgS	4.0×10^{-53}
Silver sulfide	Ag_2S	6.3×10^{-50}
Strontium fluoride	SrF_2	2.5×10^{-9}

Table of Standard Reduction Potentials (25 ˚C)

A. Acidic Solution	E^o(V)
$Li^+ + e^- \rightarrow Li(s)$	–3.045
$K^+ + e^- \rightarrow K(s)$	–2.925
$Ba^{2+} + 2e^- \rightarrow Ba(s)$	–2.906
$Sr^{2+} + 2e^- \rightarrow Sr(s)$	–2.888
$Ca^{2+} + 2e^- \rightarrow Ca(s)$	–2.866
$Na^+ + e^- \rightarrow Na(s)$	–2.714
$Mg^{2+} + 2e^- \rightarrow Mg(s)$	–2.363
$H_2(g) + 2e^- \rightarrow 2H^-$	–2.25
$Al^{3+} + 3e^- \rightarrow Al(s)$	–1.662
$Mn^{2+} + 2e^- \rightarrow Mn(s)$	–1.185
$Zn^{2+} + 2e^- \rightarrow Zn(s)$	–0.763
$Cr^{3+} + 3e^- \rightarrow Cr(s)$	–0.744
$Fe^{2+} + 2e^- \rightarrow Fe(s)$	–0.440
$Cr^{3+} + e^- \rightarrow Cr^{2+}$	–0.408
$Cd^{2+} + 2e^- \rightarrow Cd(s)$	–0.403
$PbSO_4(s) + 2e^- \rightarrow Pb(s) + SO_4^{2-}$	–0.359
$PbCl_2(s) + 2e^- \rightarrow Pb(s) + 2Cl^-$	–0.268
$Ni^{2+} + 2e^- \rightarrow Ni(s)$	–0.250
$Sn^{2+} + 2e^- \rightarrow Sn(s)$	–0.136
$Pb^{2+} + 2e^- \rightarrow Pb(s)$	–0.126
$2H^+ + 2e^- \rightarrow H_2(g)$	0.000
$S(s) + 2H^+ + 2e^- \rightarrow H_2S(aq)$	0.142
$Sn^{4+} + 2e^- \rightarrow Sn^{2+}$	0.15
$Sb_2O_3(s) + 6H^+ + 6e^- \rightarrow 2Sb(s) + 3H_2O(l)$	0.152
$Cu^{2+} + e^- \rightarrow Cu^+$	0.153
$SO_4^{2-} + 4H^+ + 2e^- \rightarrow H_2SO_3(aq) + H_2O(l)$	0.172
$AgCl(s) + e^- \rightarrow Ag(s) + Cl^-$	0.222
$Cu^{2+} + 2e^- \rightarrow Cu(s)$	0.337
$SO_4^{2-} + 8H^+ + 6e^- \rightarrow S(s) + 4H_2O(l)$	0.357
$H_2SO_3(aq) + 4H^+ + 4e^- \rightarrow S(s) + 3H_2O(l)$	0.450
$I_2(s) + 2e^- \rightarrow 2I^-$	0.536
$MnO_4^- + e^- \rightarrow MnO_4^{2-}$	0.564
$[PtCl_6]^{2-} + 2e^- \rightarrow [PtCl_4]^{2-} + 2Cl^-$	0.68
$O_2(g) + 2H^+ + 2e^- \rightarrow H_2O_2(aq)$	0.682
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	0.771
$Hg^{2+} + 2e^- \rightarrow Hg(l)$	0.788
$Ag^+ + e^- \rightarrow Ag(s)$	0.799
$2NO_3^- + 4H^+ + 2e^- \rightarrow N_2O_4(g) + 2H_2O(l)$	0.803
$2Hg^{2+} + 2e^- \rightarrow Hg_2^{2+}$	0.920
$NO_3^- + 4H^+ + 3e^- \rightarrow NO(g) + 2H_2O(l)$	0.96
$Pd^{2+} + 2e^- \rightarrow Pd(s)$	0.987
$Br_2(l) + 2e^- \rightarrow 2Br^-$	1.065
$Br_2(aq) + 2e^- \rightarrow 2Br^-$	1.087
$ClO_4^- + 2H^+ + 2e^- \rightarrow ClO_3^- + H_2O(l)$	1.19
$2IO_3^- + 12H^+ + 10e^- \rightarrow I_2(s) + 6H_2O(l)$	1.195
$Pt^{2+} + 2e^- \rightarrow Pt(s)$	~1.2
$ClO_3^- + 3H^+ + 2e^- \rightarrow HClO_2(aq) + H_2O(l)$	1.21
$O_2(g) + 4H^+ + 4e^- \rightarrow 2H_2O(l)$	1.229
$O_2(g) + 4H^+(pH = 7) + 4e^- \rightarrow 2H_2O(l)$	0.83
$MnO_2(s) + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O(l)$	1.23
$2HNO_2(aq) + 4H^+ + 4e^- \rightarrow N_2O(g) + 3H_2O(l)$	1.29
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightarrow 2Cr^{3+} + 7H_2O(l)$	1.33
$Cl_2(g) + 2e^- \rightarrow 2Cl^-$	1.360
$PbO_2(s) + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O(l)$	1.455
$Au^{3+} + 3e^- \rightarrow Au(s)$	1.498
$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O(l)$	1.51
$2HClO(aq) + 2H^+ + 2e^- \rightarrow Cl_2(g) + 2H_2O(l)$	1.63
$HClO_2(aq) + 2H^+ + 2e^- \rightarrow HClO(aq) + H_2O(l)$	1.645
$H_2O_2(aq) + 2H^+ + 2e^- \rightarrow 2H_2O(l)$	1.776
$S_2O_8^{2-} + 2e^- \rightarrow 2SO_4^{2-}$	2.00
$O_3(g) + 2H^+ + 2e^- \rightarrow O_2(g) + H_2O(l)$	2.07
$F_2(g) + 2e^- \rightarrow 2F^-$	2.87
$F_2(g) + 2H^+ + 2e^- \rightarrow 2HF(aq)$	3.06

B. Alkaline Solution	E^o(V)
$Mg(OH)_2(s) + 2e^- \rightarrow Mg(s) + 2OH^-$	–2.690
$Al(OH)_3(s) + 3e^- \rightarrow Al(s) + 3OH^-$	–2.30
$Zn(OH)_2(s) + 2e^- \rightarrow Zn(s) + 2OH^-$	–1.245
$Fe(OH)_2(s) + 2e^- \rightarrow Fe(s) + 2OH^-$	–0.877
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-$	–0.828
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(pH = 7)$	–0.43
$Cd(OH)_2(s) + 2e^- \rightarrow Cd(s) + 2OH^-$	–0.809
$Ni(OH)_2(s) + 2e^- \rightarrow Ni(s) + 2OH^-$	–0.72
$Fe(OH)_3(s) + e^- \rightarrow Fe(OH)_2(s) + OH^-$	–0.56
$2S(s) + 2e^- \rightarrow S_2^{2-}$	–0.447
$Cu_2O(s) + H_2O(l) + 2e^- \rightarrow 2Cu(s) + 2OH^-$	–0.358
$CrO_4^{2-} + 4H_2O(l) + 3e^- \rightarrow Cr(OH)_3(s) + 5OH^-$	–0.13
$MnO_2(s) + 2H_2O(l) + 2e^- \rightarrow Mn(OH)_2(s) + 2OH^-$	–0.05
$NO_3^- + H_2O(l) + 2e^- \rightarrow NO_2^- + 2OH^-$	0.01
$HgO(s) + H_2O(l) + 2e^- \rightarrow Hg(l) + 2OH^-$	0.098
$PbO_2(s) + H_2O(l) + 2e^- \rightarrow PbO(s) + 2OH^-$	0.247
$ClO_3^- + H_2O(l) + 2e^- \rightarrow ClO_2^- + 2OH^-$	0.33
$ClO_4^- + H_2O(l) + 2e^- \rightarrow ClO_3^- + 2OH^-$	0.36
$O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-$	0.401
$NiO_2(s) + 2H_2O(l) + 2e^- \rightarrow Ni(OH)_2(s) + 2OH^-$	0.490
$MnO_4^- + 2H_2O(l) + 3e^- \rightarrow MnO_2(s) + 4OH^-$	0.588
$BrO_3^- + 3H_2O(l) + 6e^- \rightarrow Br^- + 6OH^-$	0.61
$ClO^- + H_2O(l) + 2e^- \rightarrow Cl^- + 2OH^-$	0.89

Thermodynamic Values (25 ˚C)

Substance and State	ΔH^o_f $\left(\frac{kJ}{mol}\right)$	ΔG^o_f $\left(\frac{kJ}{mol}\right)$	S^o $\left(\frac{J}{K\cdot mol}\right)$
Carbon			
C(*s*) (graphite)	0	0	6
C(*s*) (diamond)	2	3	2
CO(*g*)	-110.5	-137	198
$CO_2(g)$	-393.5	-394	214
$CH_4(g)$	?	-51	186
$CH_3OH(g)$	-201	-163	240
$CH_3OH(l)$	-239	-166	127
$H_2CO(g)$	-116	-110	219
HCOOH(*g*)	-363	-351	249
HCN(*g*)	135.1	125	202
$C_2H_2(g)$	227	209	201
$C_2H_4(g)$	52	68	219
$CH_3CHO(g)$	-166	-129	250
$C_2H_5OH(l)$	-278	-175	161
$C_2H_6(g)$	-84.7	-32.9	229.5
$C_3H_6(g)$	20.9	62.7	266.9
$C_3H_8(g)$	-104	-24	270
Bromine			
$Br_2(l)$	0	0	152.
BrCl(*g*)	14.64	-0.96	240
Chlorine			
$Cl_2(g)$	0	0	223
$Cl_2(aq)$	-23	7	121
$Cl^-(aq)$	-167	-131	57
HCl(*g*)	-92	-95	187
Fluorine			
$F_2(g)$	0	0	203
$F^-(aq)$	-333	-279	-14
HF(*g*)	-271	-273	174
Hydrogen			
$H_2(g)$	0	0	131
H(*g*)217	203	115	
$H^+(aq)$	0	0	0
$OH^-(aq)$	-230	-157	-11
$H_2O(l)$	-286	-237	70
$H_2O(g)$	-242	-229	189
Magnesium			
Mg(s)	0	0	33
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

Substance and State	ΔH^o_f $\left(\frac{kJ}{mol}\right)$	ΔG^o_f $\left(\frac{kJ}{mol}\right)$	S^o $\left(\frac{J}{K\cdot mol}\right)$
Nitrogen			
$N_2(g)$	0	0	192
$NCl_3(g)$	230	271	-137
$NF_3(g)$	-125	-83.6	-139
$NH_3(g)$	?	-17	193
$NH_3(aq)$	?	-27	111
$NH_2CONH_2(aq)$	?	?	174
NO(*g*)	90	87	211
$NO_2(g)$	32	52	240
$N_2O(g)$	82	104	220
$N_2O_4(g)$	10	98	304
$N_2O_5(g)$	-42	134	178
$N_2H_3CH_3(l)$	54	180	166
$HNO_3(aq)$	-207	-111	146
$HNO_3(l)$	-174	-81	156
$NH_4Cl(s)$	-314	-201	95
$NH_4ClO_4(s)$	-295	-89	186
Silver			
Ag(*s*)	0	0	42.6
$Ag^+(aq)$	105.6	77.1	72.7
$Ag(S_2O_3)^{3-}(aq)$	-1285.7	--	--
AgBr(s)	-100.4	-96.9	107.1
AgCl(s)	-127.1	-109.8	96.2
Sulfur			
S(rhombic)	0	0	31.8
$SO_2(g)$	-296.8	-300.2	248.8
$SO_3(g)$	-395.7	-371.1	256.3
$H_2S(g)$	-20.17	-33.0	205.6
Titanium			
$TiCl_4(g)$	-763	-727	355
$TiO_2(s)$	-945	-890	50
Aluminum			
$AlCl_3(s)$	-526	-505	184
Barium			
$BaCl_2(aq)$	-872	-823	123
$Ba(OH)_2\cdot 8H_2O(s)$	-3342	-2793	427
Iodine			
$I_2(s)$	0	0	116.7
HI(*g*)	25.94	1.30	206.3