

2020 Spring Semester Final Examination For General Chemistry I

Date: July 1 (Wed), Time Limit: 19:00 ~ 22:00

NOTICE

- If you have a printer, print the papers and write the answers in the space of each question. If not, prepare several A4-size papers to write only question # and the answers on it in the following example. And for clarity, marking your answer is recommended. Please, print your Student ID in the upper right corner of every page for both of them. (*Handwriting only is acceptable* and typing is not.)

Example:

Professor Name	Class	Student I.D. Number	Name

#1. (a).....

(b).....

- If you have any questions during the period, please contact the TA of your class using the Zoom chat channel to “Everyone” (the only possible choice). Proctors will make any announcements relevant to all students *via* audio.
- While still in the video conference, submit your file to [Final Examination], an assignment on Turnitin of your class. **Do not leave the video conference** until your TA is confirmed and tells you that it is fine to leave.

**** This paper consists of 12 sheets with 10 problems (page 14 - 15: Equation, constants & periodic table).** Please check all page numbers before taking the exam. Please write down the unit of your answer when **applicable**. You will get 30% deduction for a value that is missing its unit.

NOTICE: SCHEDULES on RETURN and CLAIM of the MARKED EXAM PAPER.

(채점 답안지 분배 및 이의신청 일정)

1. Period, Location, and Procedure

- 1) Return and Claim Period: **July 4 (Sat 12:00~24:00)**
- 2) **Location: Each class of Turnitin site (online)**
- 3) Procedure: If you have any claims on it, email them (Question# and reasons) to your TA.
(The claim is permitted only during the designated claim period. Keep that in mind! A solution file with answers for the examination will be uploaded on the web.)

2. Final Confirmation

- 1) Period: July 6 (Mon, 12:00 ~ 24:00)
- 2) Procedure: During this period, you can check final score of the examination *on the website* again.
(No additional corrections. If no change in your score after reasoning, the claims were not accepted.)

**** For further information, please visit General Chemistry website at www.gencheminkaist.pe.kr.**

1. (Total 10 pts)

Please answer the following questions.

(a) How many groups are there in the main-group elements? (2 pts) (2 pts or 0 pt)

(Answer)

Eight.

(b) What is the reason for your answer for (a) in terms of electronic structure? (3 pts) (3 pts for a perfect answer, 1.5 pts for a working answer, 0 pt otherwise)

(Answer)

The main group elements have valence electrons in the s or p orbitals. Within the same n, there are 1 s orbital and 3 p orbitals. Each orbital can take up to 2 electrons. Thus, s and p orbitals can take up to 8 electrons. This is why there are 8 groups in the main-group elements.

(c) How many groups are there in the transition-metal elements? (2 pts) (2 pts or 0 pt)

(Answer)

Ten.

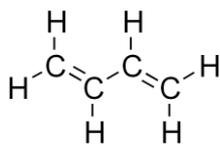
(d) What is the reason for your answer for (c) in terms of electronic structure? (3 pts) (3 pts for a perfect answer, 1.5 pts for a working answer, 0 pt otherwise)

(Answer)

The transition-metal elements have valence electrons in the d orbitals. Within the same n, there are 5 d orbitals. Each orbital can take up to 2 electrons. Therefore, d orbitals can take up to 10 electrons. This is why there are 10 groups in the transition-metal elements.

2. (Total 8 pts)

Butadiene can be approximated as a 1D particle in a box model (length = 5.22 Å). Four π electrons are confined to this length. Assume that this system holds the Pauli exclusion principle.



(a) [3 pts] What are the energies for the states $n = 1, 2,$ and 3 ?

(Answer)

Each 1pt

(if wrong answer with only equation $E = \frac{n^2 h^2}{8mL^2}$, ... + 1pt)

$$E_1 = \frac{n^2 h^2}{8mL^2} = \frac{1^2 (6.63 \times 10^{-34} \text{ Js})^2}{8(9.11 \times 10^{-31} \text{ kg})(5.22 \times 10^{-10} \text{ m})^2} = 2.21 \times 10^{-19} \text{ J}$$

$$E_2 = \frac{n^2 h^2}{8mL^2} = \frac{2^2 (6.63 \times 10^{-34} \text{ Js})^2}{8(9.11 \times 10^{-31} \text{ kg})(5.22 \times 10^{-10} \text{ m})^2} = 8.84 \times 10^{-19} \text{ J}$$

$$E_3 = \frac{n^2 h^2}{8mL^2} = \frac{3^2 (6.63 \times 10^{-34} \text{ Js})^2}{8(9.11 \times 10^{-31} \text{ kg})(5.22 \times 10^{-10} \text{ m})^2} = 1.99 \times 10^{-18} \text{ J}$$

(b) [3 pts] What is the minimum energy required to excite one of its outermost electron into a higher level?

(Answer)

The four π electrons in butadiene are placed in the energy levels E_1 and E_2 (2 each) and the smallest excitation energy is needed to excite an electron from level 2 to level 3 with energy

$$E_{\min} = E_3 - E_2 \quad \dots \quad + 1\text{pt}$$

$$= 1.11 \times 10^{-18} \text{ J}$$

(c) [2 pts] What is the maximum wavelength of light to excite butadiene?

(Answer)

$$\lambda = \frac{hc}{E_3 - E_2} \quad \dots \quad + 1\text{pt}$$
$$= \frac{(6.63 \times 10^{-34} \text{ Js})(3.00 \times 10^8 \text{ m s}^{-1})}{1.11 \times 10^{-18} \text{ J}} = 1.79 \times 10^{-7} \text{ m}$$

3. (Total 10 pts)

Use the energy expression for the hydrogen-like atom,

$$E_n = -\frac{Z^2 e^4 m_e}{8h^2 \epsilon_0^2 n^2} = -R \frac{Z^2}{n^2}$$

where the Rydberg constant $R = 2.1799 \times 10^{-18}$ J.

- (a) [4 pts] Ionization energy is the energy required to remove an electron from an atom or a molecule. Calculate the ratio between ionization energies of ground state and n-th excited state of a hydrogen atom.

(Answer)

The ionization energy of n-th excited state for H ($Z=1$) can be calculated as

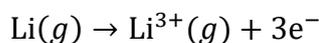
$$IE_n = R \left(\frac{1}{n_i^2} - \frac{1}{n_f^2} \right) = \frac{R}{(n+1)^2} \quad \dots + 2\text{pt}$$

because n_f goes to infinity. Therefore, the ratio is given by

$$\frac{IE(n\text{-th excited state})}{IE(\text{ground state})} = \frac{R/(n+1)^2}{R/1^2} = \frac{1}{(n+1)^2}$$

+2pt for correct ratio value

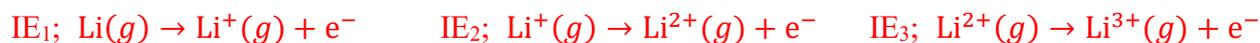
- (b) [6 pts] The energy required for the following process is 1.96×10^4 kJ mol⁻¹.



If the first ionization energy of Li is 520 kJ mol⁻¹, calculate the second ionization energy of Li.

(Answer)

The overall process is a sum of the following three processes:



Therefore, $IE = IE_1 + IE_2 + IE_3 = 1.96 \times 10^4$ kJ mol⁻¹, which gives

$$IE_2 = IE - IE_1 - IE_3 = 1.96 \times 10^4 \text{ kJ mol}^{-1} - 520 \text{ kJ mol}^{-1} - IE_3 \quad \dots + 1\text{pt}$$

$$IE_3 \text{ can be calculated by } IE_3 = (2.1799 \times 10^{-18} \text{ J}) \frac{3^2}{1^2} = 1.96191 \times 10^{-17} \text{ J}$$

$$\text{or } IE_3 = (1.96191 \times 10^{-17} \text{ J}) \times \frac{6.022 \times 10^{23}}{1 \text{ mol}} = 1.1815 \times 10^4 \text{ kJ mol}^{-1} \quad \text{+2pt for correct } IE_3$$

Therefore, $IE_2 = 1.96 \times 10^4 \text{ kJ mol}^{-1} - 520 \text{ kJ mol}^{-1} - 1.1815 \times 10^4 \text{ kJ mol}^{-1} = 7.3 \times 10^3 \text{ kJ mol}^{-1}$
+3pt for correct IE_2 , +2pt for calculation mistake.

4. (Total 12 pts)

Suppose a special gas phase system where gas molecules can move only in a 2 dimensional space instead of 3 dimensional space. Please answer the following questions for this special system. Note that the volume (V) and the area (A) in the 3D space are regarded as the area (A) and the length (L) in the corresponding 2D space, respectively, and therefore, the ideal gas equation ($PV = nRT$) and the definition of pressure ($P = F/A$) in 3D are replaced by $PA = nRT$ and $P = F/L$ in 2D, respectively.

- (a) [7 pts] Derive the expression of pressure in terms of the area (A), the number of molecules (N), the root-mean-square speed (v_{rms}), and the mass of the molecule (m).

(Answer)

$$P = Nm v_{rms}^2 / 2A$$

According to the procedure in the pages of 411~412 in the textbook,

$$P = \frac{F}{L}, \text{ where } F = \frac{\Delta p}{\Delta t} = \frac{NmL \overline{v_x^2}}{A} \quad \dots + 2\text{pt}$$

And $\overline{v_x^2} = \frac{1}{2} v_{rms}^2$, instead of $\overline{v_x^2} = \frac{1}{3} v_{rms}^2$ when gas molecules move in a 3 dimensional space.

... + 3pt

$$\text{Therefore, } P = \frac{Nm v_{rms}^2}{2A} = Nm v_{rms}^2 / 2A$$

- (b) [5 pts] Derive the expression of the total energy in terms of temperature (T).

(Answer)

$$E = nRT$$

From the answer in (a),

$$PA = \frac{Nm v_{rms}^2}{2} = E \quad \dots + 3\text{pt}$$

And $PA = Nk_B T$.

$$\text{Therefore, } E = Nk_B T = nRT$$

5. (Total 11 pts)

A sample of pure solid naphthalene ($C_{10}H_8$) weighing 1.2820 g is burned completely with oxygen to $CO_2(g)$ and $H_2O(l)$ in a constant-volume calorimeter at $25^\circ C$. The amount of heat evolved is observed to be 25.79 kJ. (the molar mass of $C_{10}H_8$ is 128.17g/mol, $R=8.3145J K^{-1} mol^{-1}$)

(a) [3 pts] Write and balance the chemical equation for the combustion reaction.

(Answer)



No partial point for missing phase

(b) [4 pts] Calculate the standard change in internal energy (ΔU°) for the combustion of 1.000 mol naphthalene to $CO_2(g)$ and $H_2O(l)$.

(Answer)

The amount of heat evolved ($-q$) in the combustion of 1.2820 g of naphthalene was observed to equal 25.79 kJ. Since the combustion was performed at constant volume, no work was done on the system ($w = 0$). Therefore, $\Delta U^\circ = q + w = -25.79 \text{ kJ} + 0 = -25.79 \text{ kJ}$ + 2pt

Put this ΔU° on a molar basis to correspond to the 1 mol of naphthalene appearing in the balanced equation

$$\Delta U^\circ = \left(\frac{-25.79 \text{ kJ}}{1.2820 \text{ } C_{10}H_8} \right) \times \left(\frac{128.17 \text{ g } C_{10}H_8}{1 \text{ mol } C_{10}H_8} \right) = -2578 \text{ kJ/mol}$$

The temperature is $25^\circ C$ both before and after the reaction. Therefore, for the equation written above (which shows 1 mol of naphthalene), $\Delta U = -2578 \text{ kJ}$

(c) [4 pts] Calculate the standard enthalpy change (ΔH°) for the same reaction as in part (b) (Assume that the gases are ideal and that the volume of the solids and liquids is negligible.).

(Answer)

To calculate ΔH° use the definition $\Delta H^\circ = \Delta U^\circ + \Delta(PV)$

Assume that the gases are ideal and that the volume of the solids are negligible.

Then $\Delta(PV) = (\Delta n_g) RT$, and $\Delta H^\circ = \Delta U^\circ + (\Delta n_g) RT$... + 2pt

The Δn_g is the change in the number of moles of gases during the reaction. The combustion of 1 mol of naphthalene produces 10 mol of gas, while consuming 12 mol of gas, Accordingly,

$$(\Delta n_g) RT = (-2 \text{ mol}) (8.3145 \text{ JK}^{-1}\text{mol}^{-1}) (298.15 \text{ K}) = -4.96 \text{ kJ}$$

$$\Delta H^\circ = \Delta U^\circ + (\Delta n_g) RT = -2578 \text{ kJ} - 4.96 \text{ kJ} = -2583 \text{ kJ}$$

6. (Total 10 pts)

Assume that H₂, CH₄, NH₃, and H₂O gases obey the van der Waals equation of state.

$$\left(P + a \frac{n^2}{V^2}\right)(V - nb) = nRT$$

Species	a (atm L ² mol ⁻²)	b (L mol ⁻¹)
H ₂	0.2444	0.02661
H ₂ O	5.464	0.03049

(a) [5 pts] Explain the meaning of 'a' and 'b' in the equation. What are these values for the ideal gas?

(Answer)

'a' stands for the attractive force between molecules. ... + 2pt

'b' stands for the excluded volume per mole of molecules. ... + 2pt

The ideal gas has no intermolecular interaction, and has no spatial occupancy.

Thus, 'a' = 0, and 'b' = 0. ... + 1pt

(b) [5 pts] Assume that 1 mol of H₂ gas is contained in the volume of 22.4 L at 273.15 K. Calculate the deviation of pressure in the case of an ideal gas from that of a real gas. Calculate the deviation of pressure for H₂O. Which of them is closer to the ideal gas and why?

(Answer)

From the van der Waals equation of state, $P_{real} = \frac{nRT}{V-nb} - a \frac{n^2}{V^2}$, $P_{ideal} = \frac{nRT}{V}$

In the case of H₂, $P_{real} = \frac{0.082 \cdot 273.15}{22.4 - 0.02661} \text{ atm} - 0.2444 \frac{1}{22.4^2} \text{ atm} = 1.000626291 \text{ atm}$.

For ideal gas, $P_{ideal} = \frac{0.082 \cdot 273.15}{22.4} \text{ atm} = 0.9999241071 \text{ atm}$.

Thus, the deviation is given by $\Delta P = |P_{real} - P_{ideal}| = 7.02183857 \times 10^{-4} \text{ atm}$ + 2pt

In the case of H₂O, $P_{real} = \frac{0.082 \cdot 273.15}{22.4 - 0.03049} \text{ atm} - 5.464 \frac{1}{22.4^2} \text{ atm} = 0.9903973513 \text{ atm}$.

Thus, the deviation is given by $\Delta P = |P_{real} - P_{ideal}| = 9.526755843 \times 10^{-3} \text{ atm}$ + 2pt

The deviation in the case of H₂ is much smaller, meaning that the case of H₂ is closer to the ideal gas.

This is because H₂ has a weaker intermolecular interaction and a smaller molecular size than the case of H₂O. ... + 1pt

7. (Total 8 pts)

You have at your disposal an ample quantity of a solution of 0.100M HCl and 400 mL of a solution of 0.0800M NaCN. How much of the HCl solution should be added to the NaCN solution to produce a buffer of pH 9.60? For HCN, $K_a = 6.17 * 10^{-10}$.

(Answer)

The desired concentration of hydronium ion is $[H_3O^+] = 10^{-9.60} = 2.5 * 10^{-10} \text{ mol L}^{-1}$ + **1pt**

$$\frac{[H_3O^+][CN^-]}{[HCN]} = K_a = 6.17 * 10^{-10} \text{ from which } \frac{[CN^-]}{[HCN]} = \frac{6.17 * 10^{-10}}{2.5 * 10^{-10}} = 2.46$$

The amount of "cyanide stuff" in the solution is $(0.400 \text{ L}) (0.0800 \text{ mol L}^{-1}) = 0.0320 \text{ mol}$. It is present as either HCN or CN^- .

$$n_{HCN} + n_{CN^-} = 0.0320 \text{ mol} \quad \dots + \mathbf{1pt}$$

Adding HCl(aq) does not affect this equality. After the correct amount of HCl(aq) has been added

$$\frac{n_{CN^-}}{n_{HCN}} = \frac{[CN^-]}{[HCN]} = 2.46 \quad \dots + \mathbf{2pt}$$

Combine this equation with the preceding and solve for n_{HCN} :

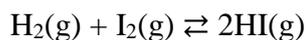
$$\frac{0.0320 - n_{HCN}}{n_{HCN}} \text{ from which } n_{HCN} = 0.00925 \text{ mol} \quad \dots + \mathbf{2pt}$$

This is the chemical amount of H_3O^+ that must be added, because each mole of H_3O^+ gives one of HCN. Then

$$V_{HCl} = \frac{0.00925 \text{ mol}}{0.100 \text{ mol L}^{-1}} = 0.0925 \text{ L} = \mathbf{92.5 \text{ ml}}$$

8. (Total 10 pts)

(a) [3 pts] Hydrogen and iodine react according to the following equation.



The equilibrium constant is 50 at 460°C. Suppose that a vessel at this temperature contains 2M H₂ and 3M I₂, and 2M HI. Is the mixture in equilibrium? Explain your answer.

(Answer)

$$Q = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = \frac{(2)^2}{(2)(3)} = 0.66 < K \quad \dots \quad + 2\text{pt}$$

With Q smaller than K, there are too many reactants and too few products. To attain equilibrium, the system must consume H₂ and I₂. \dots + 1pt

(b) [3 pts] Determine the concentrations of H₂ and I₂, and HI when the mixture comes to equilibrium.

(Answer)

	H ₂ (g)	+ I ₂ (g)	⇌	2HI(g)
Starting	2	3		2
Change	-x	-x		+2x
Equilibrium	2-x	3-x		2+2x

$$K = \frac{[\text{HI}]^2}{[\text{H}_2][\text{I}_2]} = \frac{(2 + 2x)^2}{(2 - x)(3 - x)} = 50 \quad \dots \quad + 1\text{pt}$$

$$46x^2 - 258x + 296 = 0$$

$$x = 4\text{M} \text{ or } 1.60\text{M}$$

We reject $x = 4\text{M}$

$$[\text{H}_2] = 2 - 1.60 = 0.4\text{M} \quad [\text{I}_2] = 3 - 1.60 = 1.4\text{M} \quad [\text{HI}] = 2 + 2 \times 1.60 = 5.2\text{M}$$

(c) [4 pts] When a mixture of H_2 , I_2 and HI exists at equilibrium at $460^\circ C$, what would happen if the concentration of HI is suddenly increased to $9M$? Calculate the concentration of each species at the new equilibrium.

(Answer)

$$Q = \frac{[HI]^2}{[H_2][I_2]} = \frac{(9)^2}{(0.4)(1.4)} = 145 > K$$

To relieve the stress, the system must destroy enough HI to bring Q to its equilibrium value of 50 .

... + **1pt**

	$H_2(g)$	+ $I_2(g)$	\rightleftharpoons	$2HI(g)$
Starting	0.4M	1.4M		9M
Change	+x	+x		-2x
Equilibrium	0.4+x	1.4+x		9-2x

$$K = \frac{[HI]^2}{[H_2][I_2]} = \frac{(9 - 2x)^2}{(0.4 + x)(1.4 + x)} = 50 \quad \dots + \mathbf{1pt}$$

$$46x^2 + 126x + 53 = 0$$

$$x = 0.37M \text{ or } -3.1M$$

We reject $x = -3.1M$

$$[H_2] = 0.4 + 0.37 = 0.77M \quad [I_2] = 1.4 - 0.37 = 1.77M \quad [HI] = 9 - 2 \times 0.37 = 8.26M$$

... + **2pt**

The reaction is once again at a new equilibrium.

$$K = \frac{[HI]^2}{[H_2][I_2]} = \frac{(8.26)^2}{(0.77)(1.77)} = 50$$

9. (Total 9 pts)

A galvanic cell is constructed by linking a $\text{Co}^{2+}|\text{Co(s)}$ half-cell to an $\text{Ag}^+|\text{Ag(s)}$ half-cell through a salt bridge and then connecting the cobalt and silver electrodes through an external circuit. When the circuit is closed, the cell potential is measured to be 1.08 V, and silver is seen to plate out while cobalt dissolves.

(a) [3 pts] Write the half-reactions that occur at the anode and at the cathode and the balanced overall cell reaction.

(Answer)



(b) [3 pts] The cobalt electrode is weighed after 150 minutes of operation and is found to have decreased in mass by 0.36 g. By what amount has the silver electrode increased in mass?

(Answer)

$$\Delta m = \frac{0.36 \text{ g Co}}{58.93 \text{ g mol}^{-1}} \left(\frac{2 \text{ mol Ag}}{1 \text{ mol Co}} \right) \left(\frac{107.868 \text{ g Ag}}{1 \text{ mol Ag}} \right) = 1.32 \text{ g Ag}$$

+1pt for correct mole number of Ag with wrong answer

(c) [3 pts] What is the average current drawn from the cell during this period?

(Answer)

$$I = \frac{0.36 \text{ g Co}}{58.93 \text{ g mol}^{-1}} \left(\frac{2 \text{ mol e}^-}{1 \text{ mol Co}} \right) \left(\frac{96485 \text{ C}}{1 \text{ mol e}^-} \right) \left(\frac{1}{150 \text{ min}} \right) \left(\frac{1 \text{ min}}{60 \text{ s}} \right) = \frac{0.13 \text{ C}}{\text{s}} = 0.13 \text{ A}$$

(No partial points)

10. (Total 12 pts)

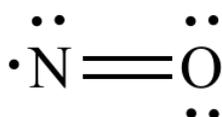
Nitric oxide (NO) is an essential molecule in the nitrogen cycle. It was Science's "Molecule of the Year" in 1992 ("NO news is good news"). NO serves as a messenger molecule in cells, and therefore there is great interest in developing electrochemical sensors for NO.

Nitrite ion (NO_2^-) or nitrate ion (NO_3^-) can be electrochemically reduced to NO(g).

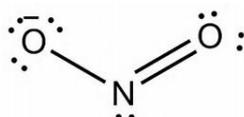
(a) [3 pts] Draw Lewis structures of NO, NO_2^- , and NO_3^- , and predict their molecular geometries using VSEPR theory.

(Answer)

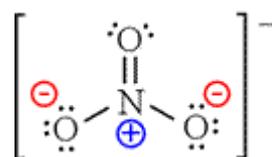
each 1 pt



linear geometry



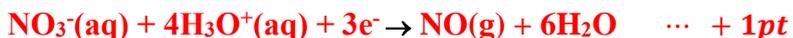
bent geometry
(SN=3, number of lone pair=1)



trigonal planar
(SN=3)

(b) [2 pts] Write down balanced electrochemical reactions reducing NO_2^- to NO, and also reducing NO_3^- to NO in aqueous phase.

(Answer)



(c) [3 pts] Standard reduction potential (E°) of NO_2^- to NO is $E^\circ = 1.20$ V. Suppose that the NO_2^- is reduced to NO in a buffer solution, which is composed of 0.1 M of NaNO_2 and 0.2 M of HNO_2 . When the NO gas is bubbled in the cell with the partial pressure of 1 atm, predict the initial half-cell reduction potential at 25°C. (pK_a of HNO_2 is 3.34)

(Answer)

Using Handersen-Hasselbalch equation, the pH of buffer solution is calculated as

$$\text{pH} = \text{pK}_a - \log_{10} \frac{[\text{HNO}_2]_0}{[\text{NO}_2^-]_0} = 3.34 - \log_{10} \frac{0.2}{0.1} = 3.04 \quad \dots + 1\text{pt}$$

Using Nernst equation, the half-cell reduction potential is calculated as

$$E = E^\circ - \frac{0.0592}{n} \log_{10} \frac{p_{\text{NO}}}{[\text{NO}_2^-]_0 [\text{H}_3\text{O}^+]_0^2} \quad \dots + 1\text{pt}$$

$$= 1.20 - \frac{0.0592}{1} \log_{10} \frac{1}{0.1 \times 10^{(-3.04) \times 2}} = \mathbf{0.78 \text{ V}}$$

(d) [4 pts] The standard reduction potential (E°) of NO_3^- to NO is $E^\circ = 0.96 \text{ V}$. Suppose that NO_3^- is reduced to NO in an unbuffered HNO_3 solution, with bubbling the NO gas in the cell with the partial pressure of 1 atm. When the initial half-cell reduction potential is the same as that of (c) system at 25°C , calculate the initial concentration of HNO_3 (in M). (pKa of HNO_3 is -1.3)

(Answer)

Because the HNO_3 is a strong acid with a negative pKa value, x M of HNO_3 produces x M of NO_3^- and x M of H_3O^+ .

Using Nernst equation, the half-cell reduction potential is calculated as

$$\begin{aligned} E &= E^\circ - \frac{0.0592}{n} \log_{10} \frac{p_{\text{NO}}}{[\text{NO}_3^-]_0 [\text{H}_3\text{O}^+]_0^4} \quad \dots + \mathbf{1pt} \\ &= 0.96 - \frac{0.0592}{3} \log_{10} \frac{1}{x^5} \end{aligned}$$

Since the half-cell reduction potential is the same to that of (c) system, that is 0.78 V, $\dots + \mathbf{1pt}$

$x = [\text{HNO}_3] = \mathbf{0.015 \text{ M}}$.

Physical Constants

Avogadro's number	$N_A = 6.02214179 \times 10^{23} \text{ mol}^{-1}$
Bohr radius	$a_0 = 0.52917720859 \text{ \AA} = 5.2917720859 \times 10^{-11} \text{ m}$
Boltzmann's constant	$K_B = 1.3806504 \times 10^{-23} \text{ J K}^{-1}$
Electronic charge	$e = 1.602176487 \times 10^{-19} \text{ C}$
Faraday constant	$F = 96485.3399 \text{ C mol}^{-1}$
Masses of fundamental particles:	
Electron	$m_e = 9.10938215 \times 10^{-31} \text{ kg}$
Proton	$m_P = 1.672621637 \times 10^{-27} \text{ kg}$
Neutron	$m_n = 1.674927211 \times 10^{-27} \text{ kg}$
Permittivity of vacuum	$\epsilon_0 = 8.854187817 \times 10^{-12} \text{ C}^{-2} \text{ J}^{-1} \text{ m}^{-1}$
Planck's constant	$h = 6.62606896 \times 10^{-34} \text{ J s}$
Ratio of proton mass to electron mass	$m_P / m_e = 1836.15267247$
Speed of light in a vacuum	$c = 2.99792458 \times 10^8 \text{ m s}^{-1}$ (exactly)
Standard acceleration of terrestrial gravity	$g = 9.80665 \text{ m s}^{-2}$ (exactly)
Universal gas constant	$R = 8.314472 \text{ J mol}^{-1} \text{ K}^{-1}$ $= 0.0820574 \text{ L atm mol}^{-1} \text{ K}^{-1}$

Values are taken from the 2006 CODATA recommended values, as listed by the National Institute of Standards and Technology.

Conversion factors

Ångström	$1 \text{ \AA} = 10^{-10} \text{ m}$
Atomic mass unit	$1 \text{ u} = 1.660538782 \times 10^{-27} \text{ kg}$ $1 \text{ u} = 1.492417830 \times 10^{-10} \text{ J} = 931.494028 \text{ MeV}$ (energy equivalent form $E = mc^2$)
Calorie	$1 \text{ cal} = 4.184 \text{ J}$ (exactly)
Electron volt	$1 \text{ eV} = 1.602177 \times 10^{-19} \text{ J} = 96.485335 \text{ kJ mol}^{-1}$
Foot	$1 \text{ ft} = 12 \text{ in} = 0.3048 \text{ m}$ (exactly)
Gallon (U. S.)	$1 \text{ gallon} = 4 \text{ quarts} = 3.785412 \text{ L}$ (exactly)
Liter	$1 \text{ L} = 10^{-3} \text{ m}^3 = 10^3 \text{ cm}^3$ (exactly)
Liter-atmosphere	$1 \text{ L atm} = 101.325 \text{ J}$ (exactly)
Metric ton	$1 \text{ t} = 1000 \text{ kg}$ (exactly)
Pound	$1 \text{ lb} = 16 \text{ oz} = 0.4539237 \text{ kg}$ (exactly)
Rydberg	$1 \text{ Ry} = 2.17987197 \times 10^{-18} \text{ J} = 1312.7136 \text{ kJ mol}^{-1} = 13.60569193 \text{ eV}$
Standard atmosphere	$1 \text{ atm} = 1.01325 \times 10^5 \text{ Pa} = 1.01325 \times 10^5 \text{ kg m}^{-1} \text{ s}^{-2}$ (exactly)
Torr	$1 \text{ torr} = 133.3224 \text{ Pa}$

PERIODIC TABLE OF THE ELEMENTS

<http://www.kjrf-split.hr/periodni/en/>

GROUP		PERIOD																																									
1 IA		2 IIA		3 IIIB 4 IVB 5 VB 6 VIB 7 VIIB 8 VIIIB 9 VIIIB 10 VIII										13 IIIA 14 IVA 15 VA 16 VIA 17 VIIA		18 VIIIA																											
1		2		3										13		18																											
H		He												B		Ne																											
HYDROGEN		HELIUM												BORON		NEON																											
3		4		5										6		7		8		9		10																					
6,941		9,0122		10,811										12,011		14,007		15,999		18,998		20,180																					
Li		Be		Al										C		N		O		F		Ne																					
LITHIUM		BERYLLIUM		ALUMINIUM										CARBON		NITROGEN		OXYGEN		FLUORINE		NEON																					
11		12		13										14		15		16		17		18																					
22,990		24,305		26,982										28,086		30,974		32,065		35,453		39,948																					
Na		Mg		Si										P		S		Cl		Ar																							
SODIUM		MAGNESIUM		SILICON										PHOSPHORUS		SULPHUR		CHLORINE		ARGON																							
19		20		21										22		23		24		25		26		27		28		29		30		31		32		33		34		35		36	
39,098		40,078		44,956										47,867		50,942		51,996		54,938		55,845		58,933		58,693		63,546		65,39		69,723		72,64		74,922		78,96		79,904		83,80	
K		Ca		Sc										Ti		V		Cr		Mn		Fe		Co		Ni		Cu		Zn		Ga		Ge		As		Se		Br		Kr	
POTASSIUM		CALCIUM		SCANDIUM										TITANIUM		VANADIUM		CHROMIUM		MANGANESE		IRON		COBALT		NICKEL		COPPER		ZINC		GALLIUM		GERMANIUM		ARSENIC		SELENIUM		BROMINE		KRYPTON	
37		38		39										40		41		42		43		44		45		46		47		48		49		50		51		52		53		54	
85,468		87,62		88,906										91,224		92,906		95,94		(99)		101,07		102,91		106,42		107,87		112,41		114,82		118,71		121,76		127,60		126,90		131,29	
Rb		Sr		Y										Zr		Nb		Mo		Tc		Ru		Rh		Pd		Ag		Cd		In		Sn		Sb		Te		I		Xe	
RUBIDIUM		STRONTIUM		YTRBIUM										ZIRCONIUM		NIOBIUM		MOLYBDENUM		TECHNETIUM		RUTHENIUM		RHODIUM		PALLADIUM		SILVER		CADMIUM		INDIUM		ANTIMONY		TELLURIUM		IODINE		XENON			
55		56		57-71										72		73		74		75		76		77		78		79		80		81		82		83		84		85		86	
132,91		137,33		Lanthanide										178,49		180,95		183,84		186,21		190,23		192,22		195,08		196,97		200,59		204,38		207,2		208,98		(209)		(210)		(222)	
Cs		Ba		La-Lu										Hf		Ta		W		Re		Os		Ir		Pt		Au		Hg		Tl		Pb		Bi		Po		At		Rn	
CAESIUM		BARIUM		Lanthanide										HAFNIUM		TANTALUM		TUNGSTEN		RHENIUM		OSMIUM		IRIDIUM		PLATINUM		GOLD		MERCURY		THALLIUM		LEAD		BISMUTH		POLONIUM		ASTATINE		RADON	
87		88		89-103										104		105		106		107		108		109		110		111		112		113		114		115		116		117		118	
Fr		Ra		Ac-Lr										Rf		Db		Sg		Bh		Hs		Mt		Uu		Uuq		Uub		Uut		Uuq		Uuq		Uuq		Uuq		Uuq	
FRANCIUM		RADIUM		Actinide										RUTHERGIUM		DUBNIUM		SEABERGIUM		BOHRIUM		HASSIUM		MEITNERIUM		UNUNNIUM		UNUNNIUM		UNUNNIUM		UNUNNIUM		UNUNNIUM		UNUNNIUM		UNUNNIUM		UNUNNIUM			

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(1) Pure Appl. Chem., 73, No. 4, 657-693 (2001)
 Relative atomic mass is shown with five significant figures. For elements having no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of this element.

However, these such elements (Fr, Ra, and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

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LANTHANIDE																													
57		58		59		60		61		62		63		64		65		66		67		68		69		70		71	
138,91		140,12		140,91		144,24		(145)		150,36		151,96		157,25		158,93		162,50		164,93		167,26		168,93		173,04		174,97	
La		Ce		Pr		Nd		Pm		Sm		Eu		Gd		Tb		Dy		Ho		Er		Tm		Yb		Lu	
LANTHANUM		CERMIUM		PRASEODYMIUM		NEODYMIUM		PROMETHIUM		SAMARIUM		EUROPIUM		GADOLINIUM		TERBIUM		DYSPROSIUM		HOLMIUM		ERBIUM		THULIUM		YTERBIUM		LUTETIUM	

ACTINIDE																													
89		90		91		92		93		94		95		96		97		98		99		100		101		102		103	
(227)		232,04		231,04		238,03		(237)		(244)		(243)		(247)		(247)		(251)		(252)		(257)		(258)		(259)		(262)	
Ac		Th		Pa		U		Np		Pu		Am		Cm		Bk		Cf		Es		Fm		Md		No		Lr	
ACTINIUM		THORIUM		PROTACTINIUM		URANIUM		NEPTUNIUM		PLUTONIUM		AMERICIUM		CURIUM		BERKELIUM		CALIFORNIUM		EINSTEINIUM		FERMIUM		MENDELEVIUM		NOBELIUM		LAWRENCIUM	