

Chemistry 2000 Final Exam (Version A)
April 24th, 2010

INSTRUCTIONS

- 1) Read the exam carefully before beginning. There are 18 questions on pages 2 to 15 followed by 2 pages of data/formulas/periodic table as well as a blank page for rough work. **Please ensure that you have a complete exam. If not, let an invigilator know immediately.** All pages must be submitted at the end of the exam.
- 2) If your work is not legible, it will be given a mark of zero.
- 3) Marks will be deducted for incorrect information added to an otherwise correct answer.
- 4) Marks will be deducted for improper use of significant figures and/or missing units.
- 5) Show your work for all calculations. Numerical answers without supporting calculations will not be given full credit.
- 6) You may use a calculator but only for the purposes of calculation. No text-capable calculators are allowed.
- 7) **DO NOT OPEN THE EXAM UNTIL YOU ARE TOLD TO BEGIN.** Beginning prematurely will result in removal of your exam paper and a mark of 0.
- 8) You have **3 hours** to complete this exam. Nobody may leave the exam room during the first hour or the last 15 minutes of the exam.

Confidentiality Agreement:

I agree not to discuss (or in any other way divulge) the contents of this exam with or in the presence of any CHEM 2000 student who has not yet written their final exam. *(The last official timeslot ends at noon on Wednesday, April 28th, 2010.)*

Signature: _____

Date: _____

Course: CHEM 2000 (General Chemistry II)

Semester: Spring 2010

The University of Lethbridge

Q	Mark
1	/ 3
2	/ 6
3	/ 5
4	/ 3
5	/ 10
6	/ 4

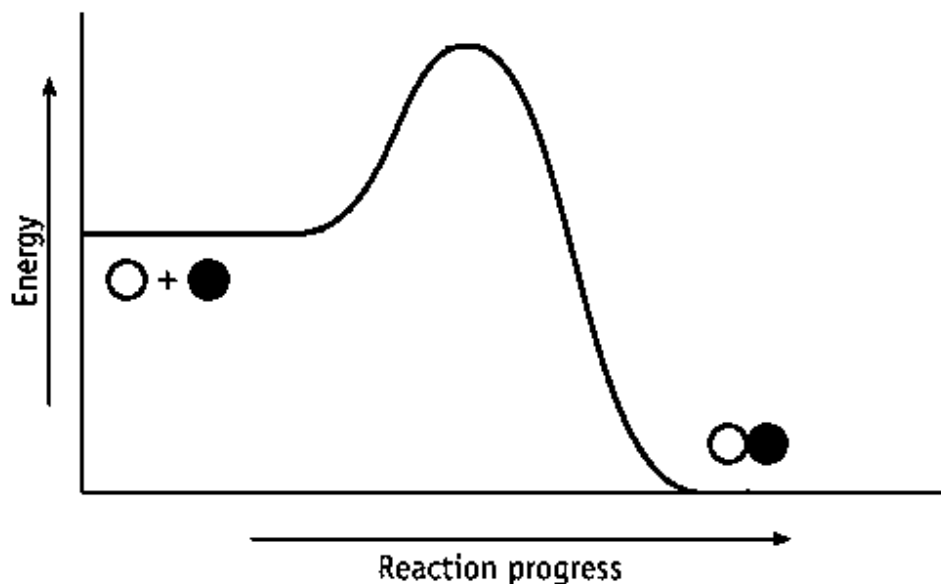
Q	Mark
7	/ 3
8	/ 6
9	/ 4
10	/ 12
11	/ 9
12	/ 4

Q	Mark
13	/ 2
14	/ 2
15	/ 7
16	/ 11
17	/ 3
18	/ 1

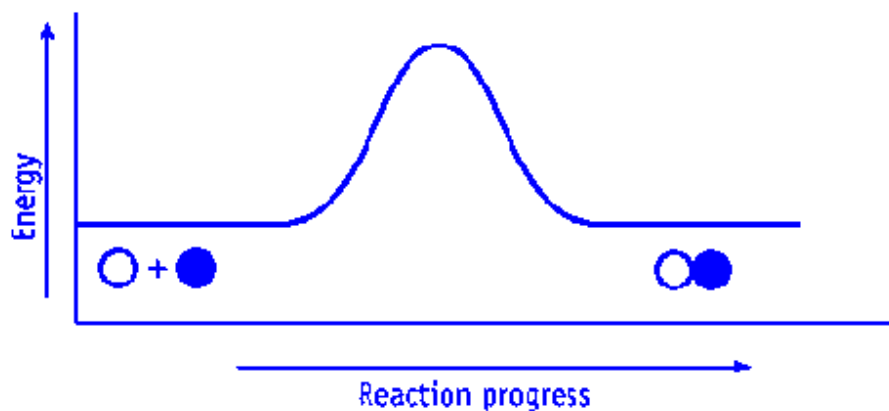
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1. Consider the reaction described by the following reaction profile diagram:
 ("Energy" = Gibbs free energy under current conditions = G)

[3 marks]



- (a) Is this reaction spontaneous in the forward or reverse direction?
 forward
- (b) Sketch a reaction profile diagram for this reaction once it has reached equilibrium.



*Sketch must show reactants and products with same free energy (i.e. $\Delta G = 0$)
 There must still be an activation energy (i.e. curve is not a flat line)*

- (c) Would you expect this reaction to have a positive or negative value for ΔS ?
 Briefly, justify your answer.

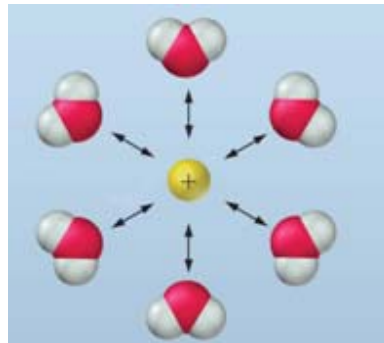
negative

This reaction shows an increase in order (two atoms joining to make one molecule) therefore there is a decrease in the entropy of the system.

2. Consider two common salts: sodium bromide (NaBr) and sodium iodide (NaI). [6 marks]
- (a) Sodium bromide and sodium iodide are both soluble in water. Describe the major intermolecular forces involved in the dissolution. As part of your answer, include a picture of a solvated sodium cation. [3 marks]

Ion-ion forces between Na^+ and X^- must be overcome to break apart the NaX crystal.

Once the salt is dissolved, the dominating intermolecular forces are ion-dipole forces between the ions and the water molecules:

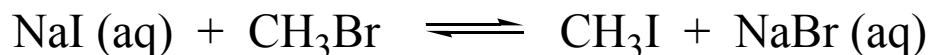


- (b) Sodium iodide is soluble in acetone (an aprotic solvent named propanone according to IUPAC rules) whereas sodium bromide is not soluble in acetone. Explain why this might be the case. [1 mark]

The ion-ion forces in NaBr are stronger than in NaI because Br^- is a smaller anion than I^- therefore it has greater charge density and the cation-anion distance is shorter. As such, it requires more energy to break apart the NaBr lattice.

Since acetone is less polar than water, the new ion-dipole attractions are weaker. While they are strong enough to allow dissolution of NaI, they are not strong enough to allow dissolution of NaBr.

- (c) Attempts to achieve the following preparation of methyl iodide lead to an equilibrium in which all species are present in roughly equal amounts.



What simple change might you make to this reaction that would force complete conversion of reactants into products? Briefly explain why this change would work.

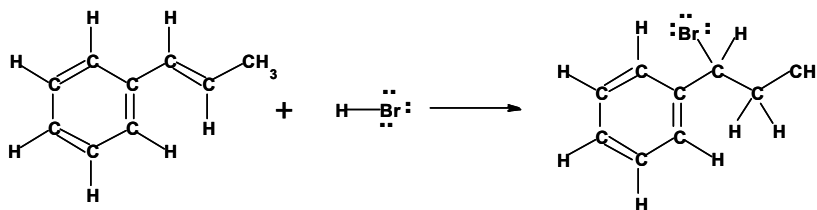
[1 mark]

Do the reaction in acetone. The NaBr will precipitate, thereby “removing” a product from the reaction. Thus, the equilibrium will be driven forward.

- (d) To which of the main categories of organic reaction does the reaction in part (c) belong? [1 mark]
- substitution

3. Consider the following reaction:

[5 marks]



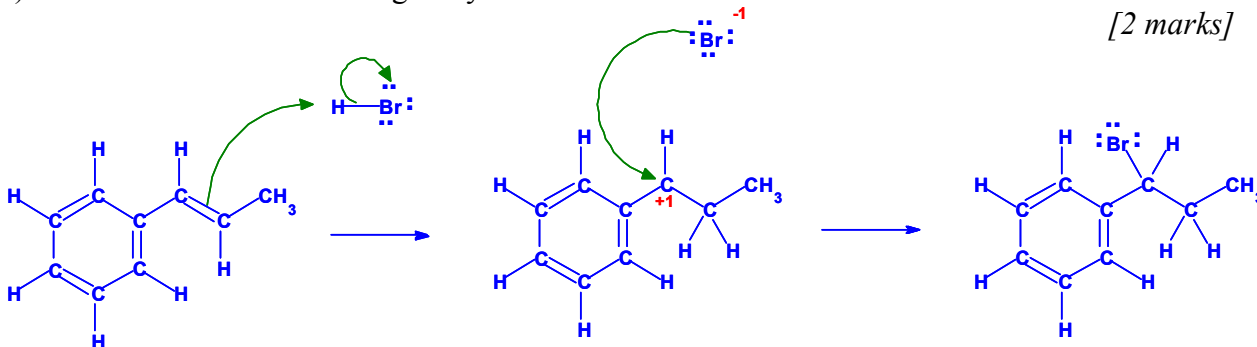
(a) To which of the main categories of organic reaction does this belong?

[1 mark]

addition

(b) Draw a mechanism using curly arrows to show electron movement for this reaction.

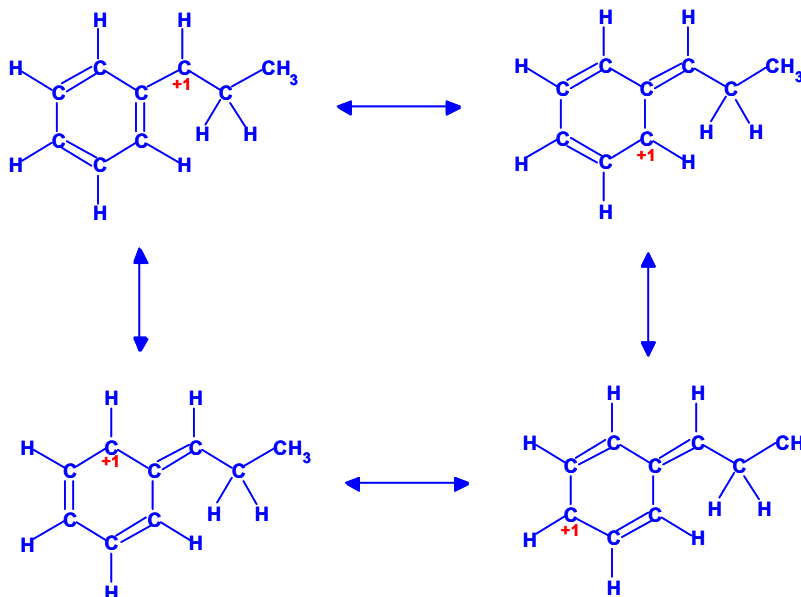
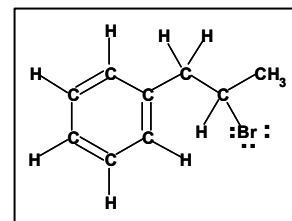
[2 marks]



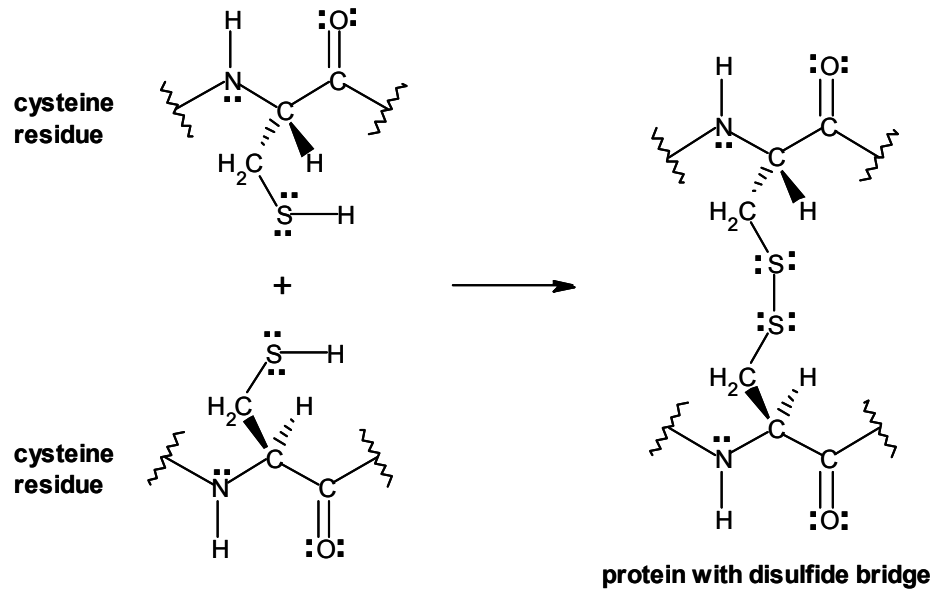
(c) Explain why the product above is formed rather than the product in the box below.

[2 marks]

The carbocation intermediate in the mechanism above is more stable than the carbocation intermediate ($C_6H_5CH_2CH^+CH_3$) that would lead to the product shown in the box. While both carbocations are secondary, the one above is also resonance stabilized. In other words, the positive charge is delocalized over multiple carbon atoms as shown in the resonance structures below:



4. Proteins are long chains of amino acids that fold up to make three-dimensional structures. One of the ways in which the chains are held in those three-dimensional shapes is through “disulfide bridges” between the cysteine amino acid residues: **[3 marks]**

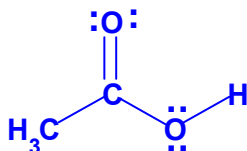


(The ~ represents the rest of the protein and can be ignored for the purposes of this question.)

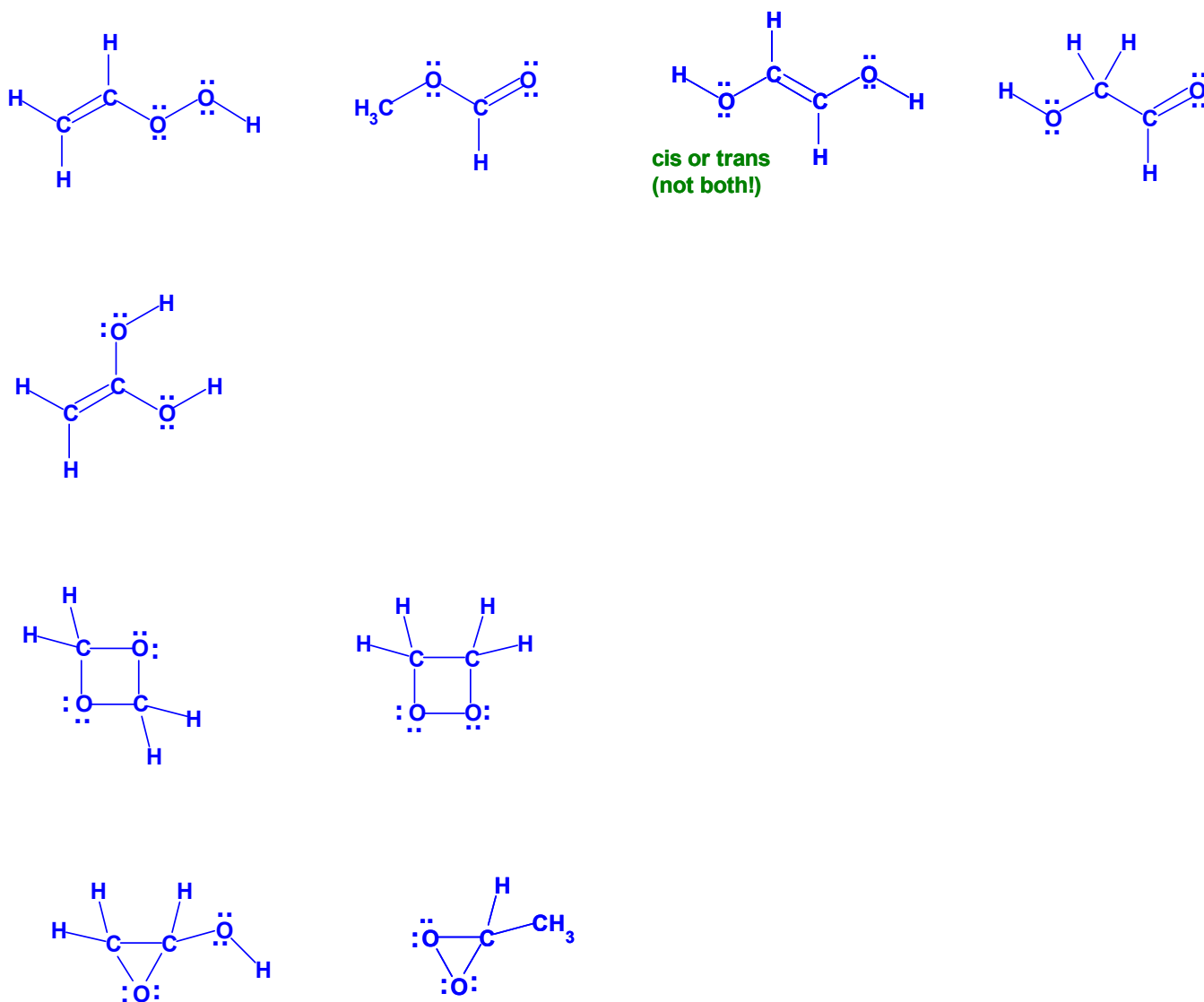
- (a) What is the oxidation state of the sulfur atom in a cysteine residue? **-2**
- (b) What is the oxidation state of the a sulfur atom that is part of a disulfide bridge? **-1**
- (c) Circle the statement which best describes the reaction shown above:
- The sulfur atom in the cysteine residue is reduced. For this to occur, it must react with a reducing agent.
 - The sulfur atom in the cysteine residue is reduced. For this to occur, it must react with an oxidizing agent.
 - The sulfur atom in the cysteine residue is oxidized. For this to occur, it must react with a reducing agent.
 - The sulfur atom in the cysteine residue is oxidized. For this to occur, it must react with an oxidizing agent.
 - The sulfur atom in the cysteine residue is neither oxidized nor reduced. As such, no oxidizing or reducing agent is necessary.

5. Ethanoic acid (more commonly known as acetic acid) is responsible for the flavor and acidity of vinegar. It has a molecular formula of $C_2H_4O_2$. **[10 marks]**

(a) Draw ethanoic acid. *For full credit, your structure must include all lone pairs.* [1 mark]

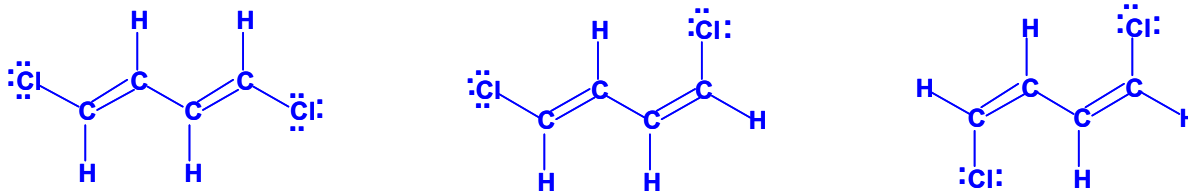


(b) Draw all nine structural isomers of ethanoic acid. If more than nine structures are drawn, only the first nine will be marked. *For full credit, all structures must include the lone pairs.* [9 marks]



6. 1,4-dichloro-1,3-butadiene is an incomplete name since it could refer to more than one stereoisomer. Draw all of the stereoisomers corresponding to the name 1,4-dichloro-1,3-butadiene. *Full credit will only be given to answers with no duplicate structures.*

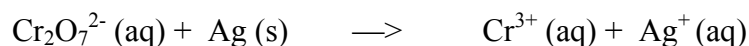
[4 marks]



There are two double bonds therefore we can have:

- *both cis*
- *both trans*
- *one cis and one trans (they both have the same substituents so this is the same as one trans and one cis)*

7. Balance the following redox reaction that occurs in acidic solution. Label each half reaction as oxidation or reduction. [3 marks]



8. Consider the following formula. [6 marks]

$$\Delta_r G = \Delta_r G^\circ + RT \ln Q$$

- (a) What must the value for Q be if all reactants/products are in the standard state? Briefly explain how you arrived at this value. [2 marks]

In the standard state, all activities are 1 therefore Q = 1.

This makes $\ln Q = 0$ therefore $\Delta G = \Delta G^\circ$

- (b) Explain the origin of each of the following applications of Le Chatelier's Principle:
- (i) Increasing the concentration of a reactant will shift an equilibrium to the product side. [2 marks]

Increasing the concentration of a reactant increases its activity. This decreases Q .

As Q decreases, $\ln Q$ decreases. Therefore, ΔG becomes more negative and the reaction becomes more favoured in the forward direction.

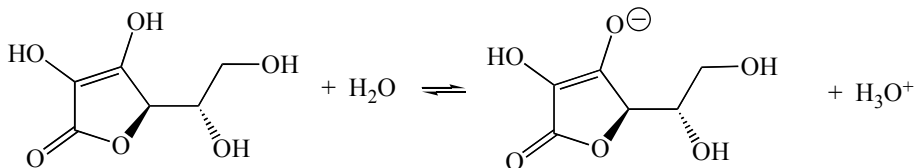
- (ii) Decreasing the volume of an equilibrium reaction involving gases will shift it to the side of the fewest gas molecules. [2 marks]

Decreasing the volume increases the pressures of all reactants and products that are gases. This increases all of their activities.

If there are more gas molecules on the reactant side then the denominator of Q will increase by more than the numerator therefore Q decreases. As Q decreases, $\ln Q$ decreases. Therefore, ΔG becomes more negative and the reaction becomes more favoured in the forward direction.

The second part of the argument could equally be made for a reaction with more gaseous products – in which case, Q increases, $\ln Q$ increases and ΔG becomes more positive, making the reaction more favoured in the reverse direction.

9. What is the pH of a solution that is made up to be 0.25 M in ascorbic acid ($pK_a = 4.17$)?



You may abbreviate "ascorbic acid" as HA.

[4 marks]

	HA	\rightleftharpoons	H⁺	+	A⁻
i (M)	0.25		10^{-7}		0
c (M)	- x		+ x		+ x
e (M)	0.25 - x		$x + 10^{-7}$		x
	≈ 0.25 ($[HA]_{\text{initial}} > 10^{-3}$ M and acid is weak)		$\approx x$ ($[HA]_{\text{initial}} > 10^{-6}$ M)		

$$pK_a = -\log K_a$$

$$K_a = 10^{-pK_a}$$

$$K_a = 10^{-4.17}$$

$$K_a = 6.8 \times 10^{-5}$$

$$K_a = \frac{a_{H^+} \cdot a_{A^-}}{a_{HA}}$$

$$6.8 \times 10^{-5} = \frac{x \cdot x}{0.25}$$

$$x^2 = (0.25)(6.8 \times 10^{-5})$$

$$x = \sqrt{(0.25)(6.8 \times 10^{-5})}$$

$$x = 0.0041$$

$$pH = -\log a_{H^+}$$

$$pH = -\log(0.0041)$$

$$pH = 2.39$$

check assumptions: $0.25 - 0.0041 = 0.25$

$0.0041 + 10^{-7} = 0.0041$

10. One of the main issues that must be addressed in designing hydrogen-fueled vehicles is how to store the hydrogen. In order to store a large amount of $\text{H}_{2(\text{g})}$ in a small volume, it must be stored at high pressure; however, hydrogen only behaves as an ideal gas at pressures below 10 MPa. **[12 marks]**

- (a) (i) What mass of $\text{H}_{2(\text{g})}$ could be stored in a 1.00 L fuel tank at a pressure of 100. MPa if the gas behaved ideally? The temperature is 25 °C. **[3 marks]**

$$25^\circ\text{C} = 298 \text{ K (use 298.15 in calculations but only 3 sig. fig.)}$$

$$100. \text{ MPa} = 100. \times 10^6 \text{ Pa} = 1.00 \times 10^8 \text{ Pa}$$

$$1.00 \text{ L} = 1.00 \times 10^{-3} \text{ m}^3$$

$$PV = nRT$$

$$n_{\text{H}_2} = \frac{PV}{RT}$$

$$n_{\text{H}_2} = \frac{(1.00 \times 10^8 \text{ Pa})(1.00 \times 10^{-3} \text{ m}^3)}{(8.3145 \frac{\text{J}}{\text{mol}\cdot\text{K}})(298.15 \text{ K})}$$

$$n_{\text{H}_2} = 40.3 \text{ mol}$$

$$m_{\text{H}_2} = n_{\text{H}_2} \cdot M_{\text{H}_2}$$

$$m_{\text{H}_2} = (40.3 \text{ mol})(2.0158 \frac{\text{g}}{\text{mol}})$$

$$m_{\text{H}_2} = 81.3 \text{ g}$$

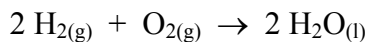
- (ii) 41 g of $\text{H}_{2(\text{g})}$ can actually be stored in a 1.00 L fuel tank at a pressure of 100. MPa and temperature of 25 °C. Rationalize the difference between this value and the one you calculated in part (i). Your explanation should specifically address which of the two masses of $\text{H}_{2(\text{g})}$ is larger and why that is the case. *No credit will be given for answers that just restate information from the question.* **[2 marks]**

H_2 behaves nonideally at pressures above 10 MPa. This means that the gas particles will take up a significant fraction of the container's volume and that they are close enough to experience IMF. These two factors have opposite effects on the amount of gas that the container can hold.

Given that we can store less gas in the fuel tank than if the gas behaved ideally, the main factor must be the fact that the H_2 molecules are taking up a significant fraction of the space in the container, making it have less than 1.00 L of "empty space".

10. *continued*

(b) In a fuel cell, the hydrogen reacts with oxygen as described by the following chemical equation:



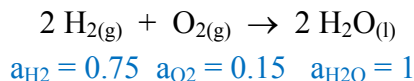
- (i) Calculate the cell potential for this reaction under standard conditions. [3 marks]
-
- Hint:
- H_2
- is oxidized to
- H^+
- .

balancing the reaction via half reactions gives $\nu_e = 4$

$$\begin{aligned} \Delta_r G^\circ &= 2 \Delta_f G^\circ(\text{H}_2\text{O}_{(l)}) - [2 \Delta_f G^\circ(\text{H}_{2(g)}) + \Delta_f G^\circ(\text{O}_{2(g)})] \\ \Delta_r G^\circ &= 2(-237.1 \frac{\text{kJ}}{\text{mol}}) - [2(0 \frac{\text{kJ}}{\text{mol}}) + \Delta_f G^\circ(0 \frac{\text{kJ}}{\text{mol}})] \\ \Delta_r G^\circ &= -474.2 \frac{\text{kJ}}{\text{mol}} \end{aligned}$$

$$\begin{aligned} \Delta_r G^\circ &= -\nu_e F E^\circ \\ E^\circ &= -\frac{\Delta_r G^\circ}{\nu_e F} \\ E^\circ &= -\frac{(-474.2 \frac{\text{kJ}}{\text{mol}})}{(4)(96485 \frac{\text{C}}{\text{mol}})} \times \frac{1000 \text{ J}}{1 \text{ kJ}} \times \frac{1 \text{ V}}{1 \frac{\text{J}}{\text{C}}} \\ E^\circ &= +1.229 \text{ V} \end{aligned}$$

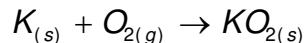
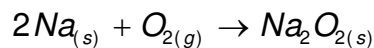
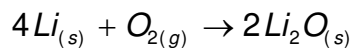
- (ii) A fuel cell would not actually operate under standard conditions. What would the cell potential be for a fuel cell in which the partial pressure of the hydrogen gas is 75 kPa (0.75 bar) and the partial pressure of the oxygen gas is 15 kPa (0.15 bar)? The temperature is still 25 °C (298K). [4 marks]



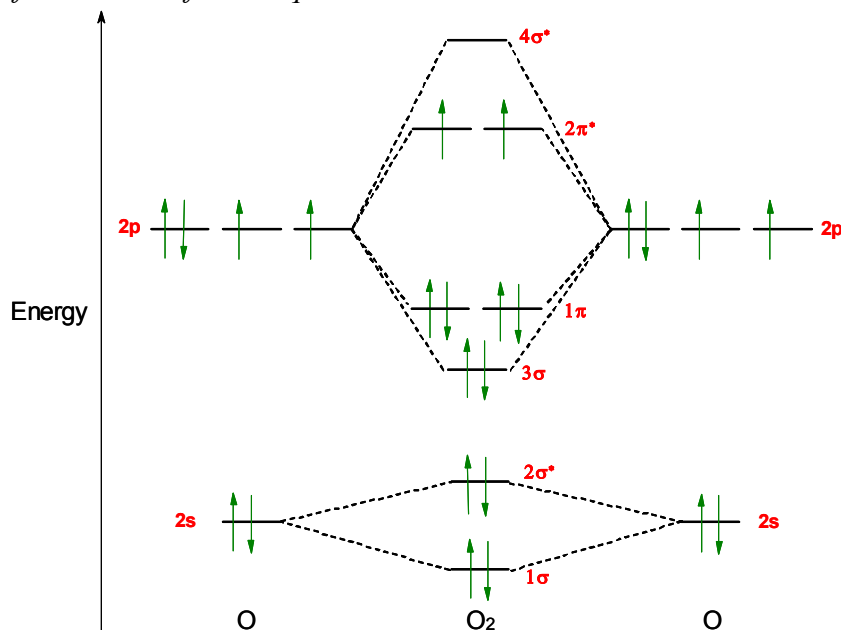
$$\begin{aligned} Q &= \frac{a_{\text{H}_2\text{O}}^2}{a_{\text{H}_2}^2 \cdot a_{\text{O}_2}} \\ Q &= \frac{(1)^2}{(0.75)^2 (0.15)} \\ Q &= 12 \end{aligned}$$

$$\begin{aligned} E &= E^\circ - \frac{RT}{\nu_e F} \ln Q \\ E &= +1.229 \text{ V} - \frac{(8.3145 \frac{\text{J}}{\text{mol}\cdot\text{K}})(298.15 \text{ K})}{(4)(96485 \frac{\text{C}}{\text{mol}})} \ln(12) \\ E &= +1.229 \text{ V} - 0.0159 \text{ V} \\ E &= +1.213 \text{ V} \end{aligned}$$

11. In Chemistry 1000, we saw that different alkali metals reacted with oxygen to give different oxygen-containing anions: **[9 marks]**



- (a) Draw a **valence** molecular orbital diagram for the neutral oxygen molecule (O_2). Label all orbitals on your diagram and include electrons. It is **not** necessary to draw pictures of the orbitals for this question. **[6 marks]**



- (b) Compare the oxygen molecule (O_2), superoxide ion (O_2^-) and peroxide ion (O_2^{2-}) with regard to three properties: **[3 marks]**
- bond length,
 - bond order, **and**
 - behavior in the presence of a magnet

	O_2	O_2^-	O_2^{2-}
bond order	2	1.5	1
bond length	shortest	between O_2 and O_2^{2-}	longest
magnetic behaviour	paramagnetic (attracted to magnet)	paramagnetic (attracted to magnet)	diamagnetic (slightly repelled by magnet)

Recall that stronger bonds (higher bond order) are shorter than weaker bonds.

12. Sulfuric acid is one of the more common strong acids. **[4 marks]**

(a) Draw one valid Lewis structure for sulfuric acid (H_2SO_4).



(b) Consider sulfuric acid according to valence bond theory.

(i) What is the hybridization of the sulfur atom? sp^3

(ii) What is the hybridization of the oxygen atoms between sulfur and hydrogen? sp^3

(c) What is the conjugate base of sulfuric acid? *You may give the formula instead of another Lewis structure.*



13. All of the hydrogen halides are strong acids except for HF. Explain why HF is a weaker acid than HCl, HBr and HI. **[2 marks]**

The strength of an acid is determined based on the stability of its conjugate base. Acids with weaker conjugate bases (i.e. more stable conjugate bases) give up H^+ more easily so they are stronger acids.

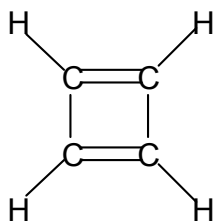
The conjugate base of HF is F^- which is a much smaller ion than Cl^- , Br^- or I^- . As such, the negative charge is spread over a smaller surface area so F^- has a higher charge density than the other halide anions. This makes F^- less stable than the other halide anions and therefore makes HF a weaker acid than the other hydrogen halides.

14. What is the difference between an intrinsic semiconductor and an extrinsic semiconductor? *Your answer should clearly indicate that you know what both terms mean.* **[2 marks]**

An intrinsic semiconductor is a pure substance with a band gap of moderate size ($\sim 10k_B T$) which gives it some conductivity.

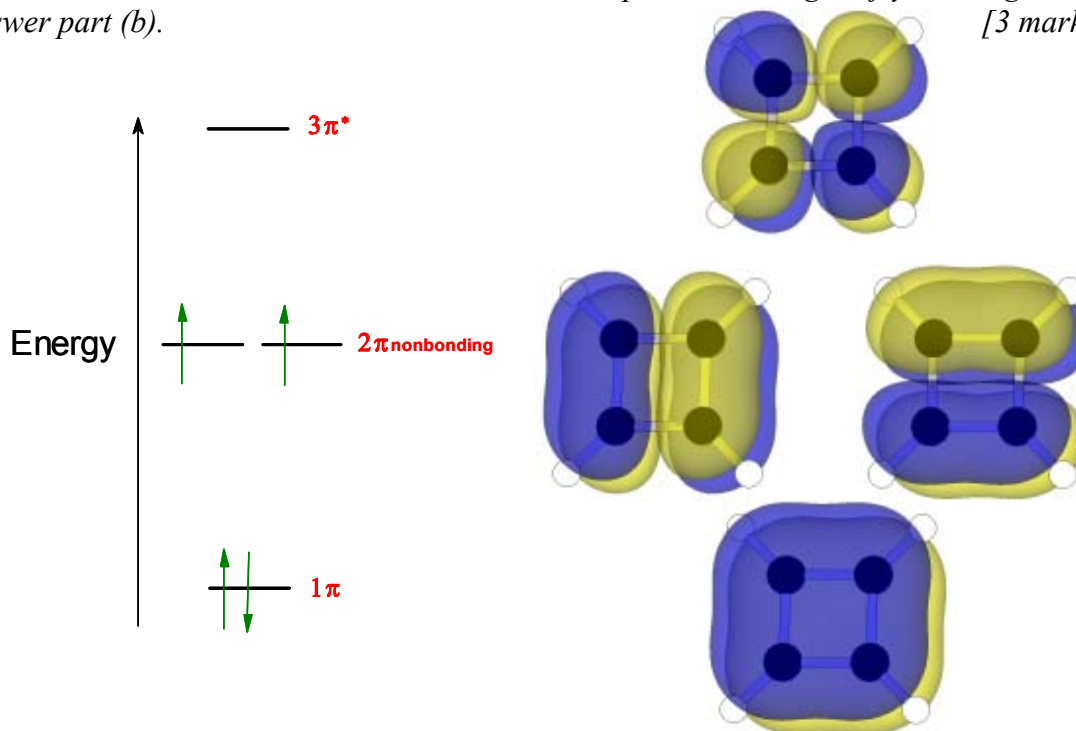
An extrinsic semiconductor is a substance which has been doped with another element, introducing an additional band which gives the substance some conductivity. There are two types of extrinsic semiconductors: n-type in which an additional donor band (full of electrons) has been introduced between the valence and conduction bands, and p-type in which an additional acceptor band (empty – or full of holes) has been introduced between the valence and conduction bands.

15. The diagram below shows one resonance structure of 1,3-cyclobutadiene:



[7 marks]

- (a) Draw a **valence pi** molecular orbital diagram for 1,3-cyclobutadiene. Do not include atomic orbitals on your diagram – just molecular orbitals. Label all molecular orbitals and include electrons. Leave space to the right of your diagram to answer part (b). [3 marks]



- (b) To the right of the diagram, draw a sketch of each molecular orbital. Make sure that phases are clearly shown. [2 marks]

see pictures above

- (c) What is the average C-C bond order for 1,3-cyclobutadiene? [1 mark]

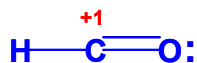
1.5

- (d) This molecule is not particularly stable when compared to other molecules with similar structures (e.g. benzene). Looking at your valence pi molecular orbital diagram, can you suggest why this might be? [1 mark]

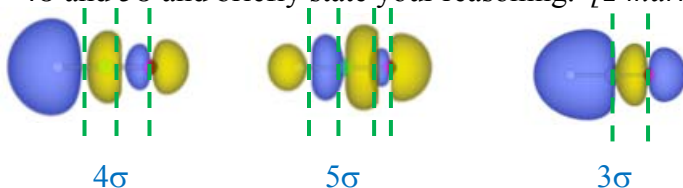
The MO diagram shows that this molecule has two unpaired electrons. Unpaired electrons generally make a substance reactive.

16. On this page is the MO diagram and the MOs for the HCO^+ cation, also known as the acylium cation. Carbon is the central atom. The MOs beside the diagram are shown in their proper energy order. [11 marks]

- (a) Draw the Lewis structure for this species. [1 mark]



- (b) Three of the MOs are shown below. Label them as 3σ , 4σ and 5σ and briefly state your reasoning. [2 marks]



An MO with more perpendicular nodes will be higher in energy than one with fewer perpendicular nodes. Here, 3σ has two such nodes, 4σ has three such nodes and 5σ has four such nodes. *see diagrams above for nodes*

- (c) Indicate which atomic orbitals on H, C and O were combined to form the three MOs in part (b). [1 mark]

These MOs (along with the 2σ MO) were made from: $1s$ on H, $2s$ and $2p_z$ on C and $2p_z$ on O.

- (d) Label all MOs on this page as B, A or NB for bonding, antibonding or nonbonding respectively. [3 marks]

see diagram

- (e) There is only one nonbonding orbital for this molecule. Explain why you labeled it as NB. [1 mark]

The 1σ MO is nonbonding because it was only made from one atomic orbital ($2s$ on O) and therefore has the same energy as that atomic orbital.

- (f) Add the correct number of electrons to this MO diagram. [1 mark]

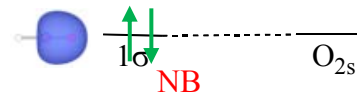
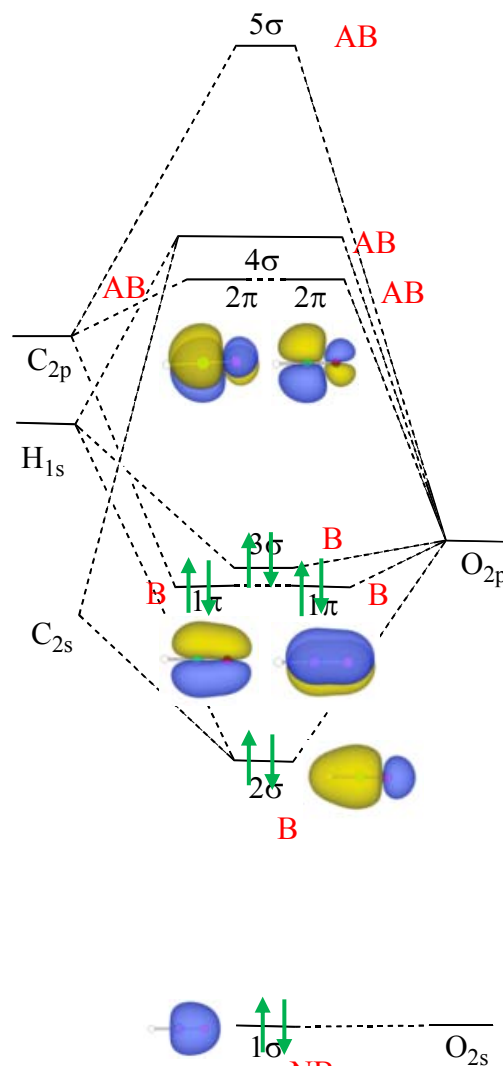
see diagram; there are 10 valence electrons

- (g) What is the average sigma bond order for this species based on the MO diagram?

1 (4 σ bonding electrons over two bonds; no σ^* electrons) [1 mark]

- (h) What is the C-O pi bond order for this molecule based on the MO diagram? [1 mark]

2 (4 π bonding electrons over one C-O bond; no π^* electrons)



17. Certain groups argue that life cannot have originated without help from a higher being. One of their arguments is as follows:

“In order for large biological molecules to form from smaller molecules (like CH_4 , H_2O and CO_2), you must violate the second law of thermodynamics. This is a universal law of decay and states that no process can create order from chaos.”

This argument misrepresents the second law of thermodynamics. State the real Second Law of Thermodynamics, and explain why this argument is flawed. **[3 marks]**

Your personal opinion on the origin of life is not relevant to this question. Please focus on this particular argument only.

The Second Law of Thermodynamics states that “the entropy of the universe increases in any spontaneous process”.

The argument is flawed because it only addresses the entropy of the system and ignores the entropy of the surroundings. Reactions/processes in which the entropy of the system decreases are still allowed as long as the increase in the entropy of the surroundings increases by a greater amount.

This argument implies that water should never freeze; however, we know that this is not the case. While the water molecules become more ordered as the water freezes in a freezer, heat is given off into the surroundings, increasing the energy of the molecules in the air and therefore increasing the number of different ways in which that energy could be distributed between the air molecules. This is a net increase in the entropy of the universe despite being a decrease in the entropy of the system (the water/ice).

18. What was the most interesting and/or useful thing you learned in CHEM 2000? **[1 mark]**

**...AND THAT'S ALL FOR CHEM 2000.
HAVE A GREAT SUMMER!**

DATA SHEET

Some Useful Constants and Formulae

Fundamental Constants and Conversion Factors

Atomic mass unit (u)	1.6605×10^{-27} kg	Kelvin temperature scale	0 K = -273.15 °C
Avogadro's number (N_A)	6.02214×10^{23} mol ⁻¹	K_w (for standard state)	10^{-14}
Boltzmann constant (k_B)	1.38065×10^{-23} J·K ⁻¹	Planck's constant (h)	6.626×10^{-34} J·Hz ⁻¹
Charge of electron	$-1.602176 \times 10^{-19}$ C	Speed of light in vacuum (c)	2.9979×10^8 m·s ⁻¹
Faraday's constant (F)	96485 C·mol ⁻¹	Volume conversion	1000 L = 1 m ³
Ideal gas constant (R)	8.3145 J·mol ⁻¹ ·K ⁻¹	Pressure conversions	1 bar = 100 kPa
	8.3145 m ³ ·Pa·mol ⁻¹ ·K ⁻¹		1 atm = 1.01325 bar

Formulae

$$\bar{K} = \frac{1}{2} m \overline{v^2} = \frac{3}{2} RT \quad v_{rms} = \sqrt{\overline{v^2}} = \sqrt{\frac{3RT}{M}} \quad PV = nRT \quad \left(P + a \frac{n^2}{V^2}\right)(V - nb) = nRT$$

$$\bar{x^2} = 2Dt \quad D = \frac{k_B T}{6\pi r \eta} \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$S = k_B \ln \Omega \quad \Delta S = \frac{q_{rev}}{T} \quad \Delta_r G = \Delta_r H - T \Delta_r S$$

$$\Delta_r G = \Delta_r G^\circ + RT \ln Q \quad \Delta_r G^\circ = -RT \ln K \quad \ln \left(\frac{K_2}{K_1}\right) = \frac{\Delta_r H_m^\circ}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

$$P_A = X_A P_A^\circ \quad [A] = k_H P_A \quad X = \frac{n}{\sum n} \quad \Delta_r G = -\nu_e F E \quad E = E^\circ - \frac{RT}{\nu_e F} \ln Q$$

$$pH = -\log a_{H^+} \quad pK_a = -\log K_a \quad pK_b = -\log K_b \quad K_w = K_a \cdot K_b \quad pH = pK_a + \log \left(\frac{a_{A^-}}{a_{HA}}\right)$$

Activities

Solid	$a = 1$
Pure liquid	$a = 1$
Ideal Solvent	$a = X$
Ideal Solute	$a = \frac{c}{c^\circ}$
Ideal Gas	$a = \frac{P}{P^\circ}$

Functional Group Suffixes

Functional Group	Suffix
Carboxylic acid	-oic acid
Aldehyde	-al
Ketone	-one
Alcohol	-ol
Amine	-amine
Alkene	-ene
Alkyne	-yne
Alkane	-ane

DATA SHEET

Chem 2000 Standard Periodic Table

1 1.0079 H 1											13	14	15	16	17	18 4.0026 He 2	
2 6.941 Li 3	4 9.0122 Be 4											5 10.811 B 5	6 12.011 C 6	7 14.0067 N 7	8 15.9994 O 8	9 18.9984 F 9	10 20.1797 Ne 10
11 22.9898 Na 11	12 24.3050 Mg 12	3	4	5	6	7	8	9	10	11	12	13 26.9815 Al 13	14 28.0855 Si 14	15 30.9738 P 15	16 32.066 S 16	17 35.4527 Cl 17	18 39.948 Ar 18
19 39.0983 K 19	20 40.078 Ca 20	21 44.9559 Sc 21	22 47.88 Ti 22	23 50.9415 V 23	24 51.9961 Cr 24	25 54.9380 Mn 25	26 55.847 Fe 26	27 58.9332 Co 27	28 58.693 Ni 28	29 63.546 Cu 29	30 65.39 Zn 30	31 69.723 Ga 31	32 72.61 Ge 32	33 74.9216 As 33	34 78.96 Se 34	35 79.904 Br 35	36 83.80 Kr 36
37 85.4678 Rb 37	38 87.62 Sr 38	39 88.9059 Y 39	40 91.224 Zr 40	41 92.9064 Nb 41	42 95.94 Mo 42	43 (98) Tc 43	44 101.07 Ru 44	45 102.906 Rh 45	46 106.42 Pd 46	47 107.868 Ag 47	48 112.411 Cd 48	49 114.82 In 49	50 118.710 Sn 50	51 121.757 Sb 51	52 127.60 Te 52	53 126.905 I 53	54 131.29 Xe 54
55 132.905 Cs 55	56 137.327 Ba 56	La-Lu	72 178.49 Hf 72	73 180.948 Ta 73	74 183.85 W 74	75 186.207 Re 75	76 190.2 Os 76	77 192.22 Ir 77	78 195.08 Pt 78	79 196.967 Au 79	80 200.59 Hg 80	81 204.383 Tl 81	82 207.19 Pb 82	83 208.980 Bi 83	84 (210) Po 84	85 (210) At 85	86 (222) Rn 86
87 (223) Fr 87	88 226.025 Ra 88	Ac-Lr	104 (261) Rf 104	105 (262) Db 105	106 (263) Sg 106	107 (262) Bh 107	108 (265) Hs 108	109 (266) Mt 109	110 (281) Dt 110	111 (283) Rg 111							

57 138.906 La 57	58 140.115 Ce 58	59 140.908 Pr 59	60 144.24 Nd 60	61 (145) Pm 61	62 150.36 Sm 62	63 151.965 Eu 63	64 157.25 Gd 64	65 158.925 Tb 65	66 162.50 Dy 66	67 164.930 Ho 67	68 167.26 Er 68	69 168.934 Tm 69	70 173.04 Yb 70	71 174.967 Lu 71
89 227.028 Ac 89	90 232.038 Th 90	91 231.036 Pa 91	92 238.029 U 92	93 237.048 Np 93	94 (240) Pu 94	95 (243) Am 95	96 (247) Cm 96	97 (247) Bk 97	98 (251) Cf 98	99 (252) Es 99	100 (257) Fm 100	101 (258) Md 101	102 (259) No 102	103 (260) Lr 103

Developed by Prof. R. T. Boeré

Thermodynamic Data (All Data In This Section Corresponds to the Standard State of 25 °C and 1 bar)

	$\Delta_f H^\circ \left(\frac{kJ}{mol} \right)$	$\Delta_f G^\circ \left(\frac{kJ}{mol} \right)$
H ₂ O _(g)	-241.8	-228.6
H ₂ O _(l)	-285.8	-237.1