T-1 1	Name: ____________ Student code: ____________	5 pts	
		marks	
		25	75

1-1.

The mass of a water droplet:

$m = V\rho = [(4/3)\pi r^3]\rho = (4/3)\pi (0.5\times10^{-6}\text{ m})^3 (1.0\text{ g/cm}^3)$

$= 5.2\times10^{-16}$ kg ⇒ **10 marks**

Average kinetic energy at 27°C:

$KE = mv^2/2 = (5.2\times10^{-16}\text{ kg})(0.51\times10^{-2}\text{ m/s})^2/2$

$= 6.9\times10^{-21}\text{ kg m}^2/\text{s}^2$ = **<u>6.9×10^{-21} J</u>** ⇒ **15 marks**

1-2.

The average kinetic energy of an argon atom is the same as that of a water droplet.

KE becomes zero at –273 °C.

From the linear relationship in the figure, KE = aT (absolute temperature)

where a is the increase in kinetic energy of an argon atom per degree.

$a = KE/T = 6.9\times10^{-21}\text{ J}/(27+273\text{K}) = 2.3\times10^{-23}$ J/K ⇒ **25 marks**

S: specific heat of argon N: number of atoms in 1g of argon

S = 0.31 J/g K = a x N

$N = S/a = (0.31\text{ J/g K}) / (2.3\times10^{-23}\text{ J/K})$

$= 1.4\times10^{22}$ ⇒ **30 marks**

Avogadro's number (N_A) : Number of argon atoms in 40 g of argon

$N_A = (40)(1.4\times10^{22})$

= **<u>5.6×10^{23}</u>** ⇒ **20 marks**

T-2[1]	Name: ______________________ Student code: ____________	5 pts				
		marks				
		30	30	10	20	10

2-1. ⇒ **30 marks**

mass of a typical star = $(4/3)(3.1)(7\times10^{8}\ m)^{3}(1.4\ g/10^{-6}\ m^{3}) = 2\times10^{33}$ g
mass of protons of a typical star = $(2\times10^{33}\ g)(3/4 + 1/8) = 1.8\times10^{33}$ g
number of protons of a typical star = $(1.8\times10^{33}\ g)(6\times10^{23}/g) = 1\times10^{57}$
number of stellar protons in the universe = $(1\times10^{57})(10^{23})$ = **1×10^{80}**

Partial credits on principles:

Volume = $(4/3)(3.14)\text{radius}^{3}\times$density; 4 marks

1 mole = 6×10^{23}; 4 marks

Total number of protons in the universe = number of protons in a star $\times10^{23}$; 2 marks

Mass fraction of protons from hydrogen = (3/4)(1/1); 5 marks

Mass fraction of protons from helium = (1/4)(2/4); 10 marks

2-2. ⇒ **30 marks**

$\Delta E(2\to3) = C(1/4 - 1/9) = 0.1389\ C$ $\lambda(2\to3) = 656.3$ nm
$\Delta E(1\to2) = C(1/1 - 1/4) = 0.75\ C$
$\lambda(1\to2) = (656.3)(0.1389/0.75) = 121.5$ nm

No penalty for using Rydberg constant from memory.

15 marks penalty if answered in a different unit (Hz, etc.)

2-3.

$T = (2.9\times10^{-3}\ m\ K)/1.215\times10^{-7}\ m = 2.4\times10^{4}\ K$ ⇒ **10 marks**

2-4. . ⇒ **20 marks**

$\lambda = 3\times10^{8}\ m/1.42\times10^{9} = 0.21\ m$

$T = (2.9\times10^{-3}\ m\ K)/0.21\ m = 0.014\ K$

2-5. ⇒ **10 marks**

$^{14}N + {}^{4}He \to$ (**^{17}O**) $+ {}^{1}H$

O-17, $^{17}_{8}O$ acceptable

T-31	**Name:** ______________________ **Student code:** ____________	**5 pts** **marks** **30 | 30 | 25 | 15**

3-1.

$k_{des} = A \exp(-E_{des}/RT)$

$= (1\times10^{12}\ s^{-1})(5\times10^{-32}) = 5\times10^{-20}\ s^{-1}$ at T = 20 K ⇒ **10 marks**

surface residence time, $\tau_{residence} = 1 / k_{des} = 2\times10^{19}$ s = <u>6×10^{11} yr</u> ⇒ **20 marks**

(full credit for $\tau_{half\text{-}life} = \ln2 / k_{des} = 1\times10^{19}$ s = 4×10^{11} yr)

residence time = 2×10^{19} s

3-2.

The distance to be traveled by a molecule: $x = \pi r$ = 300 nm.

$k_{mig} = A \exp(-E_{mig}/RT)$

$= (1\times10^{12}\ s^{-1})(2\times10^{-16}) = 2\times10^{-4}\ s^{-1}$ at T = 20 K ⇒ **5 marks**

average time between migratory jumps, $\tau = 1 / k_{mig} = 5\times10^{3}$ s

the time needed to move 300 nm

= (300 nm/0.3 nm) jumps x (5×10^{3} s/jump) = 5×10^{6} s = <u>50 days</u> ⇒ **15 marks**

(Full credit for the calculation using a random-walk model. In this case:

$t = \tau\,(x/d)^2 = 5 \times 10^{9}$ s = 160 yr. The answer is still (b).)

(a) <u>**(b)**</u> (c) (d) (e) **10 marks**

3-3.

$k(20\ K) / k(300\ K) = \exp[(E/R)\,(1/T_1 - 1/T_2)]$

$= e^{-112} = \sim 10^{-49}$ for the given reaction).) ⇒ **15 marks**

The rate of formaldehyde production at 20 K

$= \sim 10^{-49}$ molecule/site/s = $\sim 10^{-42}$ molecule/site/ yr

⇒ **10 marks**

(The reaction will not occur at all during the age of the universe (1×10^{10} yr).)

rate = 10^{-42} molecules/site/yr

3-4. circle one

(a) (b) (c) (a, b) (a, c) <u>**(b, c)**</u> (a, b, c)

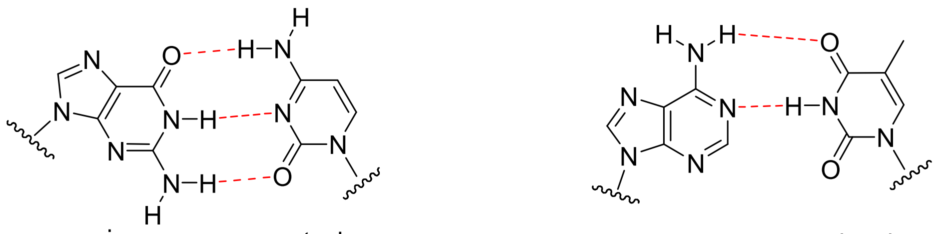
(15 marks, all or nothing)

T-4₁	Name: _______________ Student code: _______________	5 pts			
		marks			
		20	20	20	20

4-1.

	H	P		
Number of atoms	(**11.3**)	1	⇒	**10 marks**
Theoretical wt %	(**3.43**)		⇒	**10 marks**

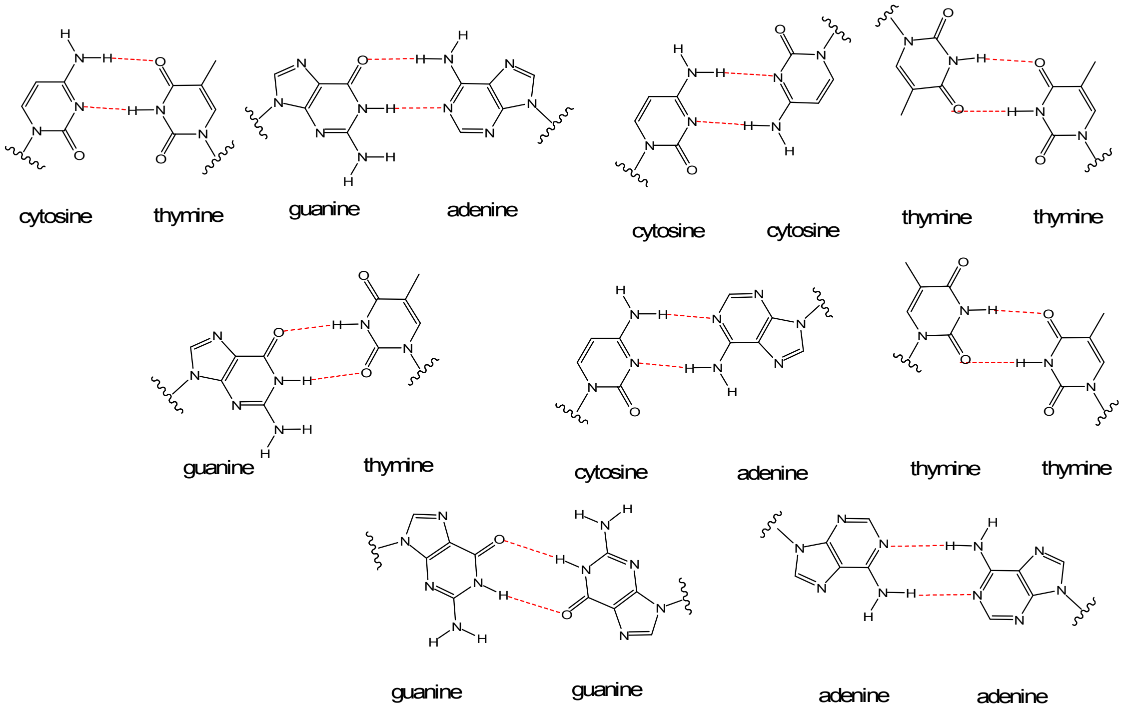
4-2.



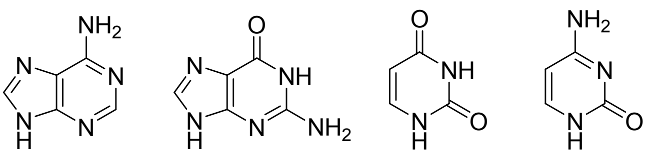
guanine　　cytosine　　　　adenine　　thymine

(10 marks on each)

4-3. **7 marks each, 20 marks for three**



4-4. **2.5 marks for each bracket**



	adenine	guanine	Uracil	cytosine
HCN	(**5**)	(**5**)	(**4**)	(**4**)
H_2O	(**0**)	(**1**)	(**2**)	(**1**)

T-5₁	Name: ____________ Student code: ____________	5 pts		
		marks		
		20	20	20

5-1. (20 marks)

1st ionization is complete: $H_2SO_4 \rightarrow H^+ + HSO_4^-$

$[H_2SO_4] = 0$

2nd ionization: $[H^+][SO_4^{2-}]/[HSO_4^-] = K_2 = 1.2 \times 10^{-2}$ (1)

Mass balance: $[H_2SO_4] + [HSO_4^-] + [SO_4^{2-}] = 1.0 \times 10^{-7}$ (2)

Charge balance: $[H^+] = [HSO_4^-] + 2[SO_4^{2-}] + [OH^-]$ (3)

Degree of ionization is increased upon dilution.

$[H_2SO_4] = 0$

Assume $[H^+]_{H2SO4} = 2 \times 10^{-7}$

From (1), $[SO_4^{2-}]/[HSO_4^-] = 6 \times 10^4$ (2nd ionization is almost complete)

$[HSO_4^-] = 0$

From (2), $[SO_4^{2-}] = 1.0 \times 10^{-7}$ [5 marks]

From (3), $[H^+] = (2 \times 10^{-7}) + 10^{-14}/[H^+]$

$[H^+] = 2.4 \times 10^{-7}$ (pH = 6.6) [8 marks]

$[OH^-] = 10^{-14}/(2.4 \times 10^{-7}) = 4.1 \times 10^{-8}$ [2 marks]

From (1), $[HSO_4^-] = [H^+][SO_4^{2-}]/K_2$

$= (2.4 \times 10^{-7})(1.0 \times 10^{-7})/(1.2 \times 10^{-2}) = 2.0 \times 10^{-12}$ [5 marks]

Check charge balance:

$2.4 \times 10^{-7} \approx (2.0 \times 10^{-12}) + 2(1.0 \times 10^{-7}) + (4.1 \times 10^{-8})$

Check mass balance:

$0 + 2.0 \times 10^{-12} + 1.0 \times 10^{-7} \approx 1.0 \times 10^{-7}$

Species	**Concentration**
HSO_4^-	2.0×10^{-12}
SO_4^{2-}	1.0×10^{-7}
H^+	2.4×10^{-7}
OH^-	4.1×10^{-8}

T-5$_2$	**Name:** ______________________ **Student code:** ______________________

5-2. (20 marks)

mmol H_3PO_4 = 0.85 × 3.48 mL × 1.69g/mL × 1 mol/98.00 g × 1000 = 51.0 [5 marks]

The desired pH is above pK_2.

A 1:1 mixture of $H_2PO_4^-$ and HPO_4^{2-} would have pH = pK_2 = 7.20.

If the pH is to be 7.40, there must be more HPO_4^{2-} than $H_2PO_4^-$.

We need to add NaOH to convert H_3PO_4 to $H_2PO_4^-$ and to convert to the right amount of $H_2PO_4^-$ to HPO_4^{2-}.

$$H_3PO_4 + OH^- \rightarrow H_2PO_4^- + H_2O$$

$$H_2PO_4^- + OH^- \rightarrow HPO_4^{2-} + H_2O$$

The volume of 0.80 NaOH needed to react with to to convert H_3PO_4 to $H_2PO_4^-$ is:

51.0 mmol / 0.80M = 63.75 mL [5 marks]

To get pH of 7.40 we need:

	$H_2PO_4^-$	+ OH^-	→ HPO_4^{2-}
Initial mmol	51.0	x	0
Final mmol	51.0-x	0	x

pH = pK_2 + log [HPO_4^{2-}] / [$H_2PO_4^-$]

7.40 = 7.20 + log {x / (51.0-x)}; x = 31.27 mmol [5 marks]

The volume of NaOH needed to convert 31.27 mmol is :

31.27 mmol / 0.80 M = 39.09 mL

The total volume of NaOH = 63.75 + 39.09 = 102.84 mL , 103 mL [5 marks]

Total volume of 0.80 M NaOH (mL)	**103 mL**

T-5[3]	Name: ______________________ Student code: ______________________

5-3. (20 marks)

pK = 3.52

pH = pK_a + log ([A^-]/[HA])

[A^-]/[HA] = $10^{(pH-pKa)}$ [5 marks]

In blood, pH =7.40, [A^-]/[HA] = $10^{(7.40-3.52)}$ = 7586

Total ASA = 7586 +1 = 7587   [5 marks]

In stomach, pH = 2.00, [A^-]/[HA] = $10^{(2.00-3.52)}$ = $3.02x10^{-2}$

Total ASA = 1+ $3.02x10^{-2}$ = 1.03   [5 marks]

Ratio of total aspirin in blood to that in stomach = 7587/1.03 = 7400   [5 marks]

Ratio of total aspirin in blood to that in stomach	**7.4×10^3**

T-6 1	**Name:** ____________________ **Student code:** ________	**5 pts**
		marks: 5 · 5 · 5 · 20 · 15 · 15 · 10 · 10

6-1. (5 marks)

$4\ H_2O + 4\ e^- \rightarrow 2\ H_2(g) + 4\ OH^-$ (or $2\ H_2O + 2\ e^- \rightarrow H_2(g) + 2\ OH^-$)

6-2. (5 marks)

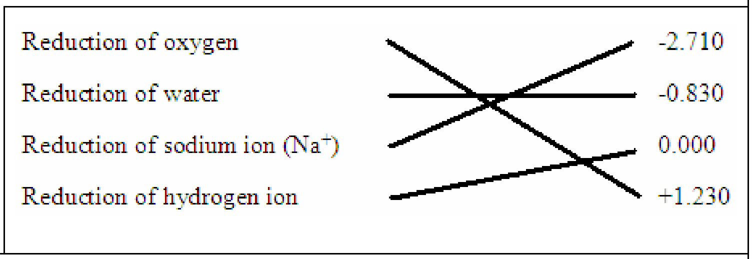
$2\ H_2O \rightarrow O_2 + 4\ H^+ + 4\ e^-$ (or $H_2O \rightarrow 1/2\ O_2 + 2\ H^+ + 2\ e^-$)

6-3. (5 marks)

$Cu \rightarrow Cu^{2+} + 2e^-$

6-4. (20 marks)

Reduction of sodium ion seldom takes place.
It has a highly negative reduction potential of –2.710 V.
Reduction potential for water to hydrogen is negative (water is very stable).
But, it is not as negative as that for sodium ion. It is –0.830 V.
Reduction of both copper ion and oxygen takes place readily and the reduction potentials for both are positive.
In the present system, the reverse reaction (oxidation) takes place at the positive terminal. Copper is oxidized before water.
Reduction potential for hydrogen ion is defined as 0.000 V.



6-5. (15 marks)

pOH = 14.00 – 4.84 = 9.16

$[OH^-] = 6.92 \times 10^{-10}$

$K_{sp} = [Cu^{2+}][OH^-]^2 = 0.100 \times (6.92 \times 10^{-10}) = 4.79 \times 10^{-20}$

6-6.

$E = E^o_{Cu2+/Cu} + (0.0592/2) \log [Cu^{2+}]$

$= +0.340 + (0.0592/2) \log [Cu^{2+}]$

$= +0.340 + (0.0592/2) \log (K_{sp} / [OH^-]^2)$

$= +0.340 + (0.0592/2) \log (K_{sp}) - (0.0592/2) \log [OH^-]^2$

$= +0.340 + (0.0592/2) \log (K_{sp}) - 0.0592 \log [OH^-]$, **3 marks**

By definition, the standard potential for $Cu(OH)_2(s) + 2e^- \rightarrow Cu(s) + 2OH^-$ is the potential where $[OH^-] = 1.00$.

$E = E^o_{Cu(OH)2/Cu} = +0.340 + (0.0592/2) \log (K_{sp})$
$= +0.340 + (0.0592/2) \log (4.79 \times 10^{-20})$
$= +0.340 - 0.572$ **2 marks**

$= -0.232$ V **10 marks**

One may solve this problem as following.

Eqn 1: $Cu(OH)_2(s) + 2e^- \rightarrow Cu + 2OH^-$
$E_+^o = E^o_{Cu(OH)2/Cu} = ?$

Eqn 2: $Cu(OH)_2(s) \rightarrow Cu^{2+} + 2OH^-$
$E^o = (0.05916/n) \log K_{sp}$
$= (0.05916/2) \log(4.79 \times 10^{-20})$
$= -0.5715$ V **3 marks**

Eqn 1 – Eqn 2 : $Cu^{2+} + 2e^- \rightarrow Cu$
$E_-^o = E_+^o - E^o = E^o_{Cu2+/Cu} = 0.34$ V

Therefore, $E_+^o = E_-^o + E^o = + 0.34 + (-0.5715)$ **2 marks**

$= -0.232$ V **10 marks**

-0.232 V

6-7.

Below pH = 4.84, there is no effect of $Cu(OH)_2$ because of no precipitation.

Therefore,

$E = E_{Cu2+/Cu} = +0.340 + (0.0592/2) \log [Cu^{2+}]$

$= +0.340 + (0.0592/2) \log 0.100$ **3 marks**

$= +0.340 – 0.0296 = +0.310$ V **7 marks**

0.310 V

T-6$_3$	**Name:** ____________________ **Student code:** ____________________

6-8.

1.00 g graphite = 0.0833 mol carbon

6 mol carbon to 1 mol lithium; 1 g graphite can hold 0.0139 mol lithium

To insert 1 mol lithium, 96487 coulombs are needed.

Therefore, 1 g graphite can charge 96487 × 0.0139 = 1340 coulombs. **5 marks**

1340 coulombs / g = 1340 A sec / g = 1340 x 1000 mA × (1 / 3600) h = 372 mA h / g

5 marks

372 mA h / g

T-7 1	Name: ____________ Student code: ________	4 pts		
		marks		
		10	20	50

7-1. (10 marks)

n/V = P/RT = $(80 \times 10^6 / 1.013 \times 10^5$ atm)/[(0.082 atm L/mol/K)(298K)] = 32 mol/L **5 marks**

density = mass/volume = d = 32 x 2 g/L = 64 kg/m^3 **5 marks**

64 kg/m^3

7-2.

$H_2(g) + 1/2\ O_2(g) \rightarrow H_2O(l)$; $\Delta H_{rexn\text{-}1} = \Delta H_f[H_2O(l)]$ = -286 kJ/mol = -143 kJ/g **7 marks**

$C(s) + O_2(g) \rightarrow CO_2(g)$; $\Delta H_{rexn\text{-}2} = \Delta H_f[CO_2(g)]$ = -394 kJ/mol = -33 kJ/g **7 marks**

$(-\Delta H_{rexn\text{-}1}) / (-\Delta H_{rexn\text{-}2}) = 4.3$ or $(-\Delta H_{rexn\text{-}2}) / (-\Delta H_{rexn\text{-}1}) = 0.23$ **6 marks**

4.3 or 0.23

7-3.

$H_2(g) + 1/2\ O_2(g) \rightarrow H_2O(l)$

ΔH_c = -286 kJ/mol = -143 kJ/g = -143×10^3 kJ/kg **5 marks**

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

ΔS_c = 70 – 131 – 205/2 = -163.5 J/K/mol **5 marks**

ΔG_c = -286 kJ/mol + 298K x 163.5 J/K/mol = -237 kJ/mol = -1.2×10^5 kJ/kg **5 marks**

(a) electric motor $W_{max} = \Delta G_c \times 1$ kg = -1.2×10^5 kJ **5 marks**
(b) heat engine W_{max} = efficiency x ΔH_c **5 marks**
= (1 – 298/573) x (-143×10^3 kJ) = -6.9×10^4 kJ **5 marks**

119×10^3 kJ = 1 W x t(sec)

t = 1.2×10^8 sec = 3.3×10^4 hr = 1.4×10^3 days = 46 month = 3.8 yr **5 marks**

$\Delta G = -nFE$ n = # of electrons involved in the reaction
F = 96.5 kC/mol

$H_2(g) + 1/2\ O_2(g) \rightarrow H_2O(l)$ n = 2 **5 marks**

E = - ΔG/nF = 237 kJ/mol / 2 / 96.5 kC/mol = 1.23 V **5 marks**

I = W/E = 0.81 A **5 marks**

(a) (-)1.2×10^5 kJ,
(b) (-)6.9×10^4 kJ

1.2×10^8 sec or 3.3×10^4 hr or 1.4×10^3 days
or 46 month or 3.8 yr

I = 0.81 A

T-8₁	Name: ____________ Student code: ____________	5 pts				
		marks				
		15	25	20	20	20

8-1-1. (5 marks on each)

① C	② C	③ CO

8-1-2.

③ $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$ **5 marks**

① $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H_{①}^{\circ} = -393.51$ kJ $= \Delta H_f^{\circ}(CO_2(g))$

② $CO_2(g) + C(s) \rightarrow 2CO(g)$ $\Delta H_{②}^{\circ} = 172.46$ kJ

From ① and ②,

$\Delta H_f^{\circ}(CO(g)) = (1/2)\{172.46 + (-393.51)\} = -110.525$ kJ

$\Delta H_f^{\circ}(Fe_2O_3) = -824.2$ kJ

$\Delta H_{③}^{\circ} = 3 \times \Delta H_f^{\circ}(CO_2(g)) - \Delta H_f^{\circ}(Fe_2O_3) - 3 \times \Delta H_f^{\circ}(CO(g))$

$= 3 \times (-393.51) - (-824.2) - 3 \times (-110.525) = -24.8$ kJ **7 marks**

$\Delta S_{③}° = 2 \times 27.28 + 3 \times 213.74 - 87.4 - 3 \times 197.674 = 15.36$ J/K **3 marks**

$\Delta G_{③}° = \Delta H° - T\Delta S° = -24.8 kJ - 15.36 J/K \times 1 kJ/1000 J \times 1473.15 K = -47.43$ kJ

5 marks

$K = e^{(-\Delta G°/RT)} = e^{(47430 J/(8.314 J/K \times 1473.15 K))} = 48$ **5 marks**

Balanced equation of ③: $Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$	K = 48

8-2-1. (20 marks)

One AB_2O_4 unit has available 4 (= 1 + (1/4) × 12) octahedral sites.

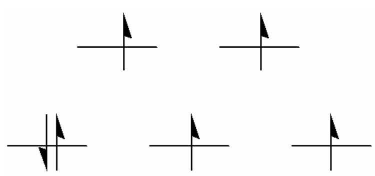
4

8-2-2. (20 marks)

Since one face-centered cube in AB_2O_4 represents one Fe_3O_4 unit in this case, it has 8 available tetrahedral sites. In one Fe_3O_4 unit, 1 tetrahedral site should be occupied by either one Fe^{2+} (normal-spinel) or one Fe^{3+} (inverse-spinel). Therefore, in both cases, the calculation gives (1/8) × 100% = 12.5% occupancy in available tetrahedral sites.

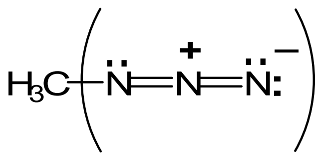
12.5%

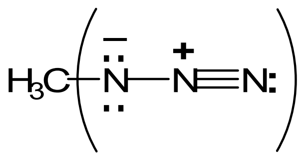
8-2-3. (10 marks for d-orbital splitting, 10 marks for elec. distribution)



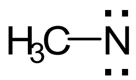
T-9[1]	Name: ______________	5 pts						
	Student code: ______________	marks						
		15	10	20	15	10	40	10

9-1-1. **1 answer for 8 marks, two for 15 marks**

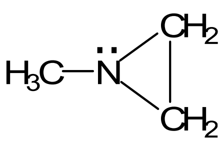




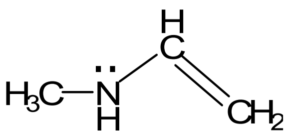
9-1-2. **(10 marks)**



9-1-3.

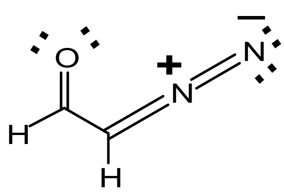


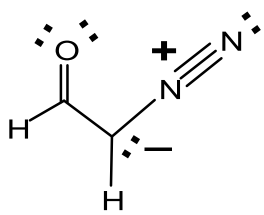
(10 marks)

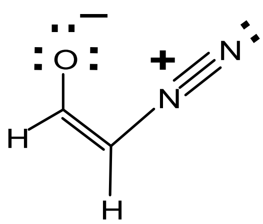


(10 marks)

9-2-1. **5 marks each**

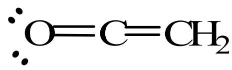




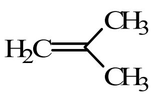


T-9$_2$	**Name:** ____________________ **Student code:** ____________________

9-2-2. **(10 marks)**



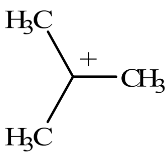
9-3-1. **(40 marks)**



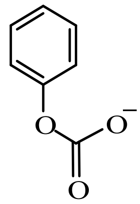
B

CO_2

C

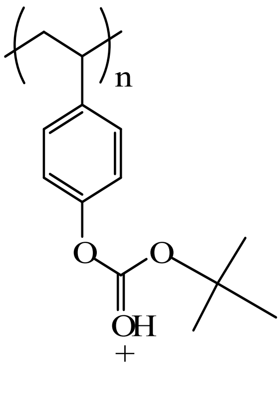


D



E

9-3-2. **(10 marks)**

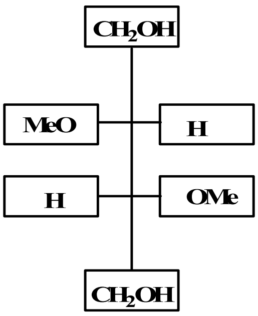


F

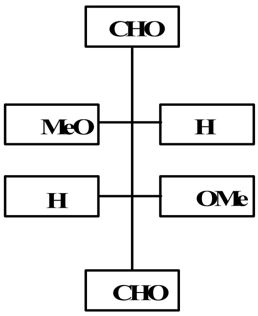
T-10₁	Name: ____________________ Student code: __________	9 pts
		marks
		30 | 20 | 20 | 10 | 30 | 20

10-1. **10 marks each**

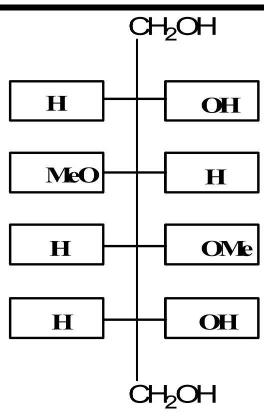
N



M



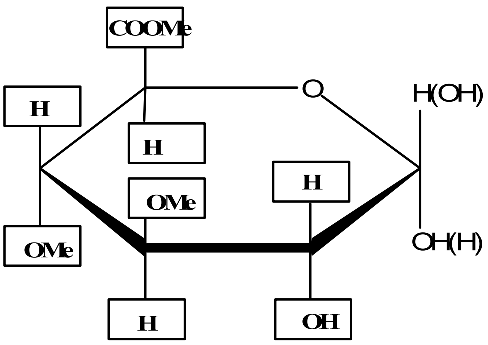
L



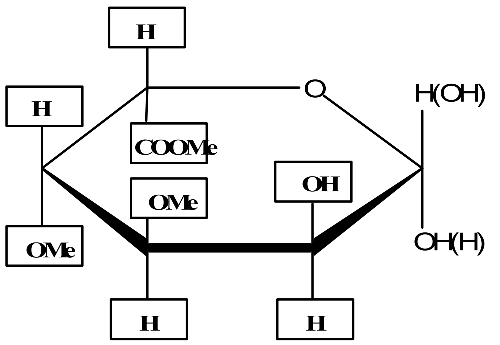
10-2. **8 marks each for correct structures**

Number of possible structures	2	4 marks

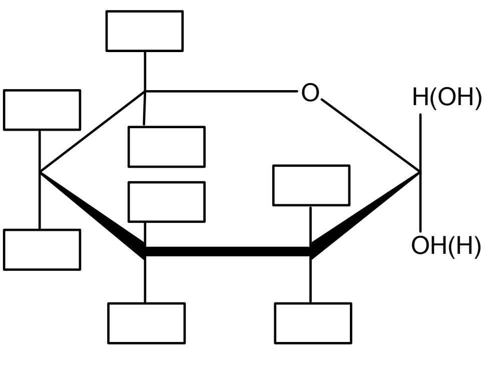
1



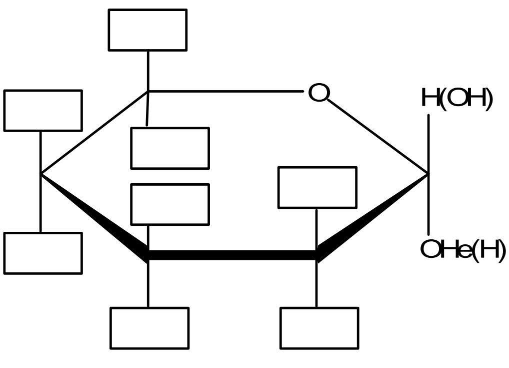
2



3



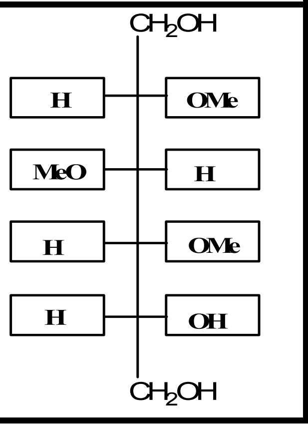
4



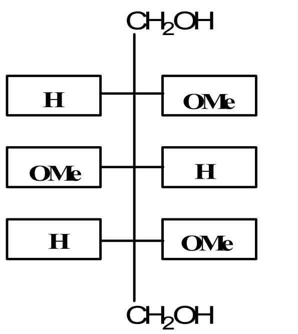
T-10$_2$	Name: ______________________ Student code: ______________

10-3. 10 marks each

G



I

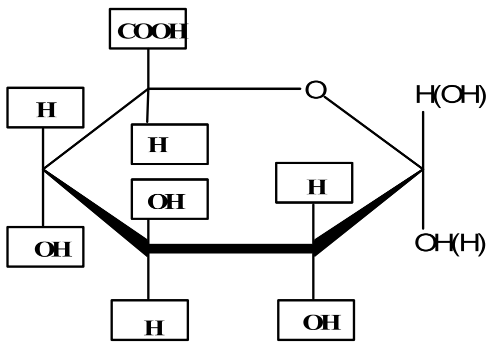


10-4. 10 marks

Number of the correct structure for **C** from 10-2
1

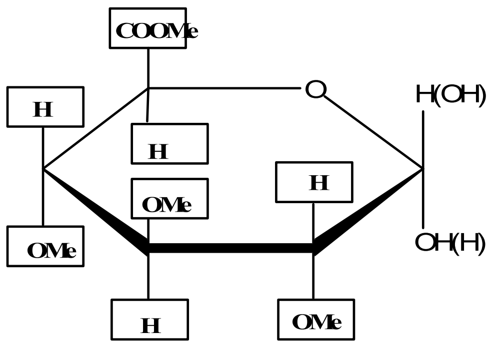
10-5.

B

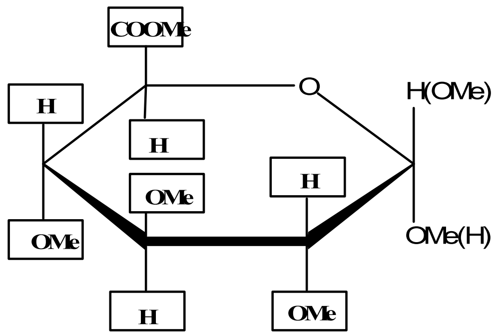


10 marks each

D



J

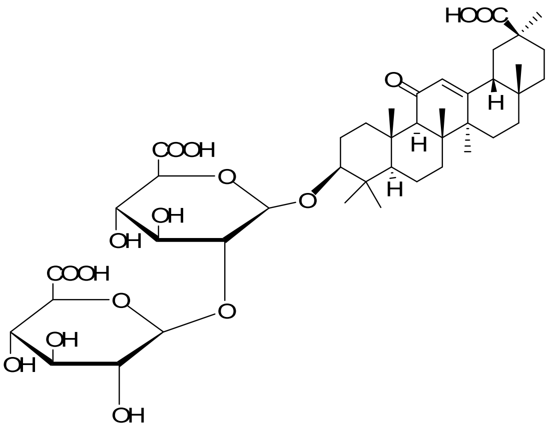


T-10₃

Name: ______________________________

Student code: ______________________

10-6. 20 marks

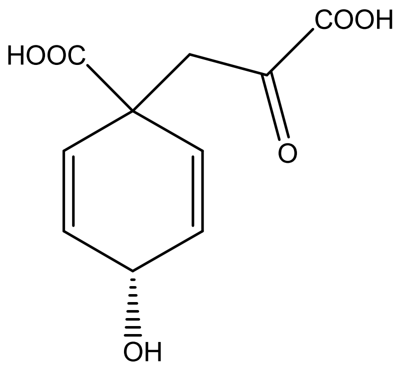


T-11[1]	Name: ________________ Student code: ______________	7pts marks
		10 | 30 | 10 | 20 | 30

11-1. **10 marks**

3

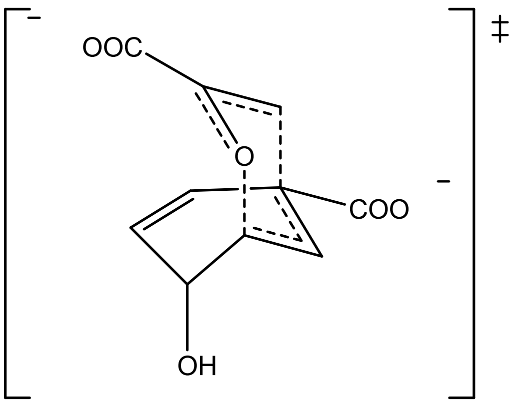
11-2. **30 marks**



11-3. **2.5 marks each**

a, c, d

11-4 **30 marks**



Transition State

T-11₂

Name: ______________________

Student code: ______________________

11-5.

For the enzyme-catalyzed reaction, Arrehnius equation could be applied.

k_{cat}/k_{uncat} = A exp ($-E_{a,\ cat}$ / RT) / A exp ($-E_{a,\ uncat}$ / RT)

= exp [$-\Delta E_{a,\ cat\text{-}uncat}$ / RT]

= exp [$-\Delta E_{a,\ cat\text{-}uncat}$ (J/mol) / (2,480 J/mol)] = 10^6

Therefore, $-\Delta E_{a,\ cat\text{-}uncat}$ = 34,300 J/mol 15 marks

$k_{uncat,\ T}/k_{uncat,\ 298}$ = exp ($-\Delta H^{\neq}_{uncat}$ / RT) / exp ($-\Delta H^{\neq}_{uncat}$ / 298R)

= exp [($-\Delta H^{\neq}_{uncat}$ /R)(1/T-1/298)]

ln($k_{uncat,\ T}/k_{uncat,\ 298}$) = 13.8 = [(-86900/8.32)(1/T-1/298)]

Therefore, T = 491 K, or 218°C 15 marks

$-E_{a,\ cat\text{-}uncat}$ = 34,300 J/mol

T = 491 K, or 218°C