ersity CHEM 206

r. C. Rogers, Section 52

F15

206

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FIRST NAME:	answer key
STUDENT ID:	

Chem 206 - GENERAL CHEMISTRY II

MIDTERM EXAMINATION

INSTRUCTIONS: ***PLEASE READ THIS PAGE WHILE WAITING TO START YOUR EXAM.***

- This test includes 4 pages (both sides). Read over the whole test quickly before starting.
- Write answers in the space provided; fill in MCQ answers on the scan sheet <u>in pencil</u>.
- Calculators are permitted; cell phones and other electronic devices are not allowed.
- Potentially useful information is given on back of the (removable) periodic table.
- To earn full points, calculations must include units & explanatory comments.
- You have 70 min to complete the test.
- **GOOD LUCK!**

* Nearly ALL students need to work on EXPLAINING phenomena. * See the highlighted MCQs — most errors were made in conceptual questions, fewer errors made in calculations. PRACTICE the END-OF-CHAPTER conceptual + summary questions, NOT JUST PROBLEMS.

<u>Mark breakdown</u>:

Page 2.	15.7	/ 16	/30
Page 3.		/ 14	
Page 4.	8.8	/ 12	
Page 5.	5.2	/ 10	

TOTAL: 29.6 / 50 (max. = 52)

PERCENT: 59.2 %

EARNED toward FINAL GRADE: / 15

* IMFs responsible for:
- pure solvent's bp
- solubility of solute

BUT NOT responsible for:
- colligative properties like mp ↓, Pvap ↓, bp ↑

Remember, colligative properties are INDEPENDENT of solute identity (which affects IMFs), just depend on CONCENTRATION of solute particles! Thus, it is a statistical/probability/rate effect.

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PART A: MCQs - MULTIPLE-CHOICE QUESTIONS (2 marks each)

Each question has one correct answer. Put answers in pencil on scan sheet; circle here as a back-up.

(ANSWER POPULARITY IN RED = % OF CLASS WHO CHOSE ANS.) ⊛ PROBLEMS FOR MANY

Questions #1 – 8 are all independent of each other.

#1. Which of the following phase changes is exothermic?

A

47% [✓ a)] condensation

31% b) evaporation

9% c) sublimation

14% d) fusion

releases heat, due to net formation of IMFs (molecules come closer together)

#2. Which halogen (F_2, Cl_2, Br_2, I_2) should have the strongest intermolecular forces with water, and why?

D

56% a) F_2, because fluorine is highly electronegative. → not relevant here since in a NONPOLAR molecul

0 b) Cl_2, because chlorine is a strong oxidizing agent.

0 c) Br_2, because bromine is liquid at room temperature.

44% [✓ d)] I_2, because iodine is highly polarizable.

all nonpolar... so dispersion forces + d-id forces with water

#3. Which statement shows how to find the heat flow involved in warming a 15 g ice cube from -8 to 6°C? must me

A

67% [✓ a)] $q_{sys} = [(2.06\ J{\cdot}g^{-1}{\cdot}K^{-1})(15\ g)(8\ K)] + [(6020\ J{\cdot}mol^{-1})(15\ g/18.02\ g{\cdot}mol^{-1})] + \underbrace{[(4.18\ J{\cdot}g^{-1}{\cdot}K^{-1})(15\ g)(6\ K)]}_{\text{warming melted ice from } 0 \to 6\,°C}$

13% b) $q_{sys} = [(4.18\ J{\cdot}g^{-1}{\cdot}K^{-1})(15\ g)(14\ K)] + [(6020\ J{\cdot}mol^{-1})(15\ g/18.02\ g{\cdot}mol^{-1})]$

8% c) $q_{sys} = [(2.06\ J{\cdot}g^{-1}{\cdot}K^{-1})(15\ g)(14\ K)] + \underbrace{[(6020\ J{\cdot}mol^{-1})(15\ g/18.02\ g{\cdot}mol^{-1})]}_{\text{melting ice}}$

12% ✗ d) $q_{sys} = [(4.18\ J{\cdot}g^{-1}{\cdot}K^{-1})(15\ g)(14\ K)]$

#4. Which one of the following statements about thermodynamics is INCORRECT?

B

10% T a) Two touching objects reach thermal equilibrium when collisional heat transfer balances throughout.

59% F [✓ b)] A reaction with $\Delta S°_{universe} > 0$ should be product-favoured and proceed rapidly towards products.

8% T c) A system can exchange energy with its surroundings through heat flow and work.

23% T d) Spontaneous change occurs in the direction in which free energy is released.

#5. Which should have the higher osmotic pressure and why: 1 M $NH_4Cl(aq)$ or 1 M $NH_3(aq)$?

A

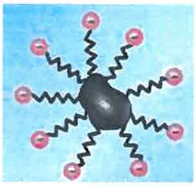
63% [✓ a)] the NH_4Cl solution, because higher [solute] means water flows faster into than out of the solution

13% ✗ b) the NH_3 solution, because higher [solute] means water flows faster into than out of the solution

13% ✗ c) the NH_3 solution, because strong hydrogen bond interactions pull water into the solution

13% ✗ d) the NH_4Cl solution, because strong ion-dipole interactions pull water into the solution ✗

#6. Which one of the following statements about detergent micelles (right) is INCORRECT?



D

15% T a) The amphiphilic molecules become suspended in water as spherical micelles.

16% T b) Their hydrophilic heads are dissolved in the water via molecular-level contact.

16% T c) Their hydrophobic tails are excluded from direct contact with water molecules.

53% F [✓ d)] An emulsion results when polar molecules are enveloped in the micelle cores.

#7. Which of the following is a *state function*?

C

1% a) heat } path functions

15% b) work

64% [✓ c)] enthalpy

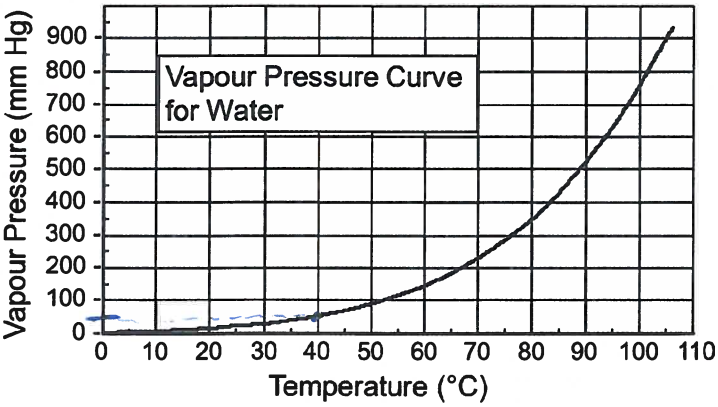
20% d) temperature

#8. Rubbing alcohol, 2-propanol $(CH_3)_2CHOH$, has a vapour pressure of 100 mm Hg at 39.5°C. Considering the vapour pressure data provided for water (diagram at right), which substance has stronger intermolecular forces? = lower Pvap

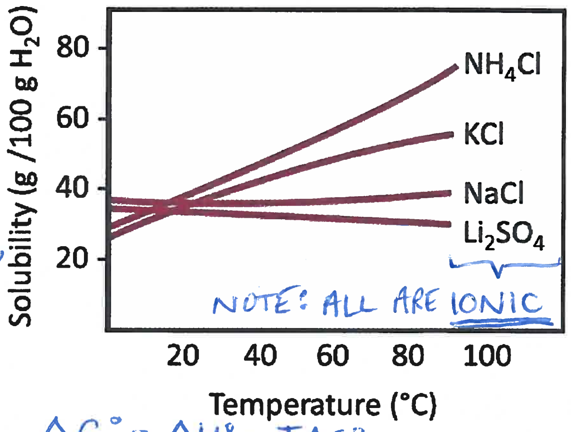
B

17% a) rubbing alcohol ≈ 100 mmHg at 40°C

83% [✓ b)] water — Pvap ≈ 50 mmHg at 40°C



16



Questions #9 – 11 are related to the solubility graph shown.

#9. Which is the strongest intermolecular force between water molecules and the solute particles in these solutions? → all ions here

D

- 22% a) dipole-dipole forces
- 33% b) hydrogen bonding
- 10% c) dispersion forces
- 34% [✓ d)] ion-dipole forces — this will usually be stronger than H-bonding, in any case, but that is not the question.

#10. Most solids are more soluble at higher temperatures. One substance shown on the graph, Li_2SO_4, has lower solubility at higher temperature. What must be causing this?

C

- 23% a) Its dissolving process is thermodynamically unfavourable.
- 26% b) Its dissolving process is enthalpically unfavourable.
- 51% [✓ c)] Its dissolving process is entropically unfavourable.

$\Delta G° = \Delta H° - T\Delta S°$ for dissolving

if −, then $-T\Delta S$ is + so lower T results in larger $-\Delta G$ for dissolving

#11. To which real-world phenomenon discussed in class is this graph and topic related?

A

- 33% [✓ a)] It relates to why deposits of hard-water minerals build up in coffee-makers.
- 11% b) It relates to why cloudy liquids should be called suspensions, not solutions.
- 5% c) It relates to why diamond should, but doesn't, convert into graphite.
- 51% d) It relates to why salt can be used to melt ice on roads in the winter.

Questions #12 - 15 are based on the following scenario: $C_2H_5OH(\ell) + \underbrace{3\ O_2(g) \rightarrow 2\ CO_2(g)}_{\Delta n\ gases\ =\ -1} + 3\ H_2O(\ell)$

You perform a bomb calorimetry experiment to study the combustion of ethanol (reaction above). The bomb had a heat capacity of 550 J/K, and the calorimeter's water tank contained 650 g of water. Burning 4.20 g of ethanol resulted in a temperature increase from 18.5 to 22.3°C. ← at this T, the product H_2O is (ℓ) not (g)

#12. During this experiment, what quantity of heat was absorbed by the bomb itself?

C

- 7% a) 4600 J
- 20% b) 2500 J
- 65% [✓ c)] 2100 J
- 7% d) 380 J

$\Delta T = +3.8°C$

$\therefore \Delta T = +3.8 K$

$q_{bomb} = C_{bomb} \Delta T_{bomb}$

$= (550 \frac{J}{K})(3.8 K)$

$= 2090$ J to 2SF...

#13. Which would be a reasonable first-law statement to use to find the heat released by this reaction?

C

- 5% ✗ a) $0 = q_{bomb} + q_{water} + \overset{?}{q_{evaporation}} + q_{rxn}$
- 1% b) $q_{bomb} = -(q_{rxn} + q_{bomb})$
- 75% [✓ c)] $q_{rxn} = -(q_{bomb} + q_{water})$
- 19% ✗ d) $q_{water} = -q_{bomb}$ no q_{rxn}?

$-q_{rxn} = \underbrace{(q_{bomb} + q_{water\ in\ tank})}$

OR, $q_{rxn} = -q_{calorimeter}$

#14. Can this experiment provide the enthalpy of combustion of ethanol? Why or why not? bomb calorimeter = constant-volume

B

- 11% ✗ a) No (at constant pressure, heat flow is not caused solely by bonding changes) ← F
- 28% [✓ b)] No - at constant volume, heat flow is not caused solely by bonding changes ← $\Delta n_{gases} \neq 0$ so $q_v \neq q_p$
- 38% ✗ c) Yes ✗ at constant pressure, heat flow is caused solely by bonding changes. ← true but does not apply here!
- 22% d) Yes (at constant volume, heat flow is caused solely by bonding changes) ← FALSE IF trapped/missing gas? ONLY TRUE IF P IS CONSTANT

#15. If this reaction was done in a cylinder with a movable piston, how would you describe the work involved?

A

- 18% [✓ a)] Work done by surroundings: the system would gain energy by being compressed by the surroundings.
- 6% b) Work done by surroundings: the system would expend energy by pushing away the surroundings.
- 6% ✗ c) Work done by system: the system would gain energy by being compressed by the surroundings.
- 68% ✗ d) Work done by system: the system would expend energy by pushing away the surroundings.

- means constant pressure, free to expand/contract if $\Delta n_{gases} \neq 0$.
- Here $\Delta n_{gases} = -1$, so volume will DECREASE. (as if compressed by surroundings)

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PART B: SHORT-ANSWER QUESTIONS & CALCULATIONS

Always show full calculations with units and brief comments to clarify the science behind the math.

#16. (12 marks) Consider the reaction of nitrogen monoxide with chlorine to produce NOCl (see reaction equation in data table).

$2\,NO(g) + Cl_2(g) \rightarrow 2\,NOCl(g)$

Thermodynamic data (at 298 K)

Substance	ΔH°_f (kJ·mol^{-1})	S°_f (J·mol^{-1}·K^{-1})	
R NO(g)	90.2$\underline{9}$	210.7$\underline{6}$	×2
R Cl_2(g)	0	223.0$\underline{8}$	×1
P NOCl(g)	51.7$\underline{1}$	261.$\underline{8}$	×2

different # decimal places – watch out for SF... (last SF is underlined)

a) **(6 marks)** Calculate the Gibbs' free energy change for this reaction at 298 K (show complete work). Is the reaction spontaneous?

$\Delta G^\circ_{rxn} = \Delta H^\circ_{rxn} - T\Delta S^\circ_{rxn}$ if $\Delta G^\circ_{rxn} < 0 \Rightarrow$ spontaneous

2

$\Delta H^\circ_{rxn} = [2\,mol(51.71\,\frac{kJ}{mol})] - [2\,mol(90.29\,\frac{kJ}{mol}) + 1\,mol\,(0)]$

$= 103.4\underline{2}\ kJ - 180.5\underline{8}\ kJ$

$= -77.1\underline{6}\ kJ$ contributes favourably towards spontaneity

2

$\Delta S^\circ_{rxn} = [2\,mol\,(\overset{261.8}{\cancel{210.76}}\ \frac{J}{mol\cdot K})] - [2\,mol\,(210.76\ \frac{J}{mol\cdot K}) + 1\,mol\,(223.08\ \frac{J}{mol\cdot K})]$

$= 523.\underline{6}\ J/K - 644.6\underline{0}\ J/K$

$= -121.\underline{0}\ J/K$ contributes against spontaneity

2

$\Delta G^\circ_{rxn} = -77.16\,kJ - (298\,K)(-121.0\ J/K)(\frac{1\,kJ}{1000\,J})$

$= -77.1\underline{6}\ kJ + 36.0\underline{5}8\ kJ$

$= -41.1\underline{0}\ kJ$ for the rxn as written (i.e. kJ/mol·rxn)

−0.5 units
−0.5 SF
−0.5 math errors

Spontaneous because $\Delta G^\circ_{rxn} < 0$, i.e. thermodynamically favoured overall ∴ PRODUCT FAVOURED at this temp.

b) **(4 marks)** Based on the data and your answer to part (a), circle the words that describe this reaction.

4

- Which is more stable? pure reactants or [✓ pure products] ∵ $\Delta G^\circ < 0$
- Does the system…? [✓ release heat] or absorb heat ∵ $\Delta H^\circ < 0$
- Does the bonding become…? weaker or [✓ stronger] ∵ $\Delta H^\circ < 0$
- Does the surroundings become…? [✓ more disordered] or more organized ∵ $\Delta H^\circ < 0$

c) **(2 marks)** Do you expect this reaction to yield *more products* or *less products* at a higher temperature? Explain your choice in a few words (no calculations, please).

2

The reaction is entropically unfavourable ($\Delta S^\circ_{rxn} < 0$), so we expect LESS PRODUCT at higher temperatures.

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

We get more product if ΔG is more negative.

This term is positive (works against forming product) and becomes a larger positive number at higher T.

12

ID #: answer key

#17. (10 marks) Imagine you make some automotive antifreeze by adding some liquid ethylene glycol ($HOCH_2CH_2OH$, mp -13°C, bp 197°C, *d* 1.113 g/mL) to 5.0 kg of water in your car's cooling system.

a) **(6 marks)** If the freezing point of the water-glycol mixture is -15.0°C, what mass of $HOCH_2CH_2OH$ must have been added? *See data sheet for physical properties of water.*

- $HOCH_2CH_2OH$ is a molecular solute that is a NON-ELECTROLYTE ✓, so $i = 1$. ✓

- $\Delta T_f = i m K_f$ ✓ where $i = 1$ (# solute particles per formula unit)

  $\boxed{m = \frac{\text{moles solute}}{\text{kg solvent}}}$ ✓

  $K_f = 1.86\ °C \cdot kg \cdot mol^{-1}$ = how solvent's (H2O) m.p. is affected by presence of solute

  15.0 degrees below m.p. of pure water ✓

  $15.0° = (1)(m)(1.86\ °C \cdot kg \cdot mol^{-1})$ ✓

  $\Rightarrow m = 8.065\ \frac{\text{mol glycol}}{\text{kg } H_2O}$ ✓ ✓ units

- For 5.0 kg of water, this means need $\underset{(kg\,H_2O)}{5.0} \times \underset{\left(\frac{mol\,gly.}{kg\,H_2O}\right)}{8.065} = 40.32$ mol ethylene glycol ✓ ✓

- Mass of ethylene glycol $= n \times MM$

  $= (40.32\ mol)(62.068\ g/mol)$ ✓

  $= 2502.6\ g$ ✓

  $\Rightarrow m \doteq 2.5$ kg ethylene glycol ($\boxed{2\ SF}$ limited by 5.0 kg SF)

  −0.5 for SF errors

6

NOTE: IMFs are relevant to why solute dissolves but NOT to why solvent bp ↑.

b) **(4 marks)** Car antifreeze also plays an important role as "coolant" for dissipating engine heat. Luckily, solutions have higher boiling points than water, so water-glycol mixtures resist overheating even better than pure water. Explain, *in detail*, the molecular-level cause of "elevation of the boiling point".

max. 4

- b.p. = temperature at which solvent's vapour pressure is same as the external pressure ("normally" 1 atm) ✓

- solute particles interfere with evaporation ✓, but not with condensation ✓, so solute particles decrease the vapour ✓ pressure of the solvent.

  How? BY LOWERING ✓ THE MOLE FRACTION OF ✓ WATER (SOLVENT) since not all molecules at the liquid surface will actually be volatile solvent, the rate of ✓ evaporation of solvent is lower than in a sample of pure solvent, so P_{vap} ↓.

  Raoult's law: ✓ $P_{soln} = \chi_{solv} P^o_{solv}$

- Since P_{vap} is lower for the solution ✓ at any temperature, it means a higher temperature is ✓ required for the P_{vap} to increase until it equals the external P ⇒ b.p. is HIGHER.

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