

國立中山大學 112 學年度

碩士班暨碩士在職專班招生考試試題

科目名稱：工程數學【材光系碩士班選考、材料前瞻應材碩士班選考、材光聯合碩士班選考】

— 作答注意事項 —

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共 1 頁 第 1 頁

1. (10%) Find out the particular solution of the ODE
 $y' + (\tan x)y = \sin 2x$, $y(0) = 1$
2. (10%) Find out the particular solution of the ODE
 $y' + y = -\frac{x}{y}$, $y(0) = 1$
3. (10%) Find out the particular solution of the ODE
 $xy' + 4y = 8x^4$, $y(1) = 2$
4. (10%) Find out the general solution of the ODE
 $x^3y''' + 3x^2y'' - 6xy' - 6y = 0$
5. (20%) Find out the particular solution of the ODE (Please use the undetermined coefficient method)
 $y'' - 3y' + 2y = 3e^{2x} + 2x^2 - 7$, $y(0) = 1$, $y'(0) = 0$
6. (10%) Find out the particular solutions of y_1 and y_2
 $y_1' = -y_1 - y_2$, $y_1(0) = 1$, $y_2(0) = 0$
 $y_2' = y_1 - y_2$
7. (10%, each one has 5%) Find out the inverse Laplace transforms of the following equations
(a) $\frac{2}{s^4} - \frac{48}{s^6}$ (b) $\frac{6s + 7}{2s^2 + 4s + 10}$
8. (10%) Use the Laplace transform to solve the following ODE
 $y'' - \frac{1}{4}y = 0$, $y(0) = 12$, $y'(0) = 0$
9. (10%) Use the Laplace transform to solve the following ODE
 $y'' + 2y' - 3y = 0$, $y(2) = -3$, $y'(2) = -5$

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共 3 頁第 1 頁

第一部分：單選題，每題 5 分，無倒扣

1. Which one *is not* included in the three interactions when a visible light beam proceeds from air into a solid: (A) absorption, (B) reflection, (C) diffraction, (D) transmission? (5 points)
2. Which one of the following descriptions is correct? (5 points)
(A) The net magnetic moment for an atom is the sum of the contributions of each of its electrons.
(B) Diamagnetism results from changes in electron spin motion that are induced by an external field.
(C) Paramagnetism materials are those having permanent atomic dipoles, which are coupled and mutually aligned with moments of adjacent atoms.
(D) Below its Curie temperature, a ferromagnetic material is composed of domains in which all net dipole moments are acted on individually.
3. Which one of the following descriptions of electric polarization *is not* correct? (5 points)
(A) Polarization mechanisms include electronic, ionic, and orientation polarizations.
(B) Dielectric materials are electrical conductors that can be polarized when an electric field is present.
(C) Ferroelectric materials exhibit spontaneous polarization.
(D) The polarization phenomenon accounts for the ability of the dielectrics to increase the charge-storing capability of capacitors.
4. Various possible band structures in solid at 0 K are demonstrated schematically in **Figure 1** shown below. Which one of the following correspondences correctly describes the band structures and the electrical conduction characteristics of materials? (5 points)
(A) i: insulator, ii: semiconductor, iii: conductor, iv: semiconductor.
(B) i: semiconductor, ii: conductor, iii: insulator, iv: semiconductor.
(C) i: conductor, ii: conductor, iii: insulator, iv: semiconductor.
(D) i: insulator, ii: conductor, iii: semiconductor, iv: conductor.

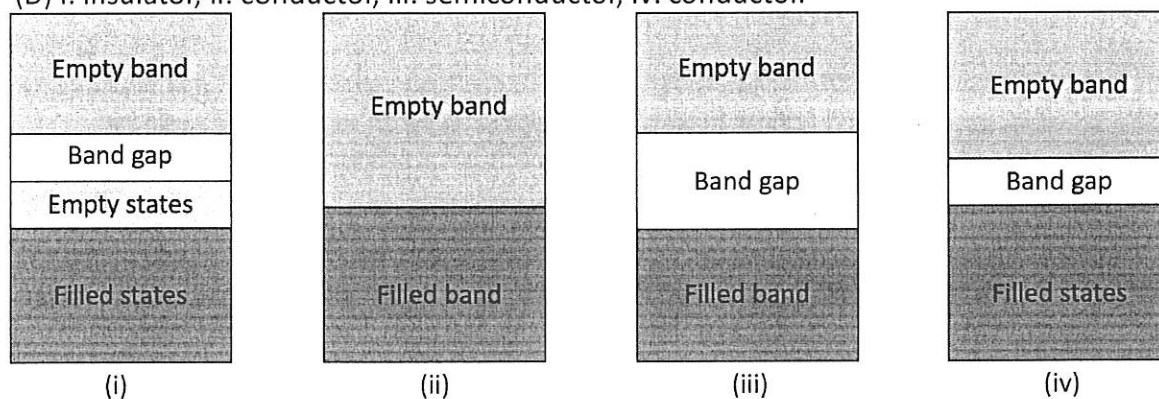


Figure 1

5. Which one of the following descriptions for atomic diffusion *is not* correct? (5 points)
(A) For a given host metal, substitutional atoms generally diffuse more rapidly than the interstitial ones.
(B) Both host solvent atoms and substitutional solute atoms diffuse via the exchange of an atom with an adjacent vacancy.
(C) The diffusion condition for which the flux is independent of time is known as steady state.
(D) The driving force of atomic diffusion is indeed the gradient of chemical potential instead of the

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共 3 頁第 2 頁

concentration gradient.

第二部分：問答計算題

6. Figure 2 shows a unit cell for a hypothetical metal whose structure belongs to one of the 14 Bravais lattices. Please give the name of this crystal structure in English and determine the Miller indices for the shaded plane. (8 points)

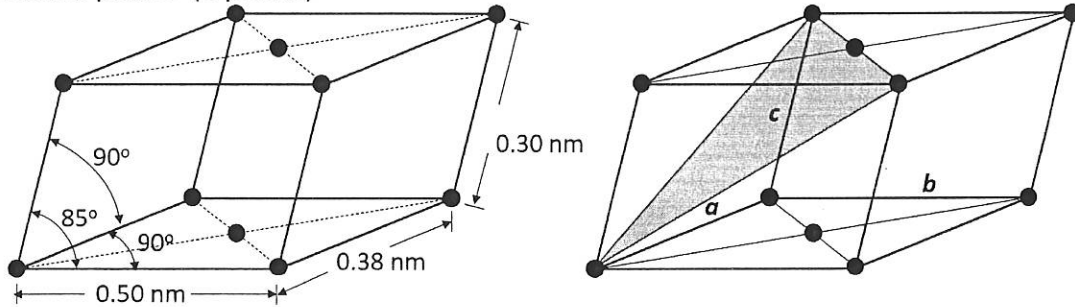


Figure 2

7. For a hypothetical metal, the equilibrium number of vacancies is $N_v(1)$ at temperature T_1 and $N_v(2)$ at temperature T_2 , respectively. Estimate the energy for vacancy formation in terms of $N_v(1)$, T_1 , $N_v(2)$, and T_2 . (7 points)
8. For a $K^+ - F^-$ ion pair, the attractive and repulsive energies E_A and E_R between ions can be expressed as functions of the distance between the ions r as $E_A = -\frac{A}{r}$, $E_R = \frac{B}{r^n}$, respectively. Based on this, derive the equilibrium spacing r_0 in terms of A, B and n. (7 points)
9. Arrange the following four types of surface/interfaces based on their energy from the lowest to the highest: (i) an external surface, (ii) a coherent twin boundary, (iii) a subgrain boundary with a misorientation angle of 8 degrees, and (iv) a high-angle grain boundary. (7 points)
10. A single crystal of α -Fe having a body-centered cubic structure is oriented such that a tensile stress σ of 10 MPa is applied in the [010] direction. Compute the resolved shear stress in the [1-11] direction on each of the {110} planes. Which slip system(s) is (are) most favorably oriented for slip? (Note: it is known that $\sqrt{2} = 1.41$, $\sqrt{3} = 1.73$, $\sqrt{5} = 2.24$, $\sqrt{6} = 2.45$, $\sqrt{7} = 2.65$) (8 points)
11. It is known that the {400} diffraction peak acquired from a (100) silicon wafer in a $\theta - 2\theta$ x-ray diffraction scan has an intensity of several orders of magnitude higher than that of the {400} one acquired from a polycrystalline Si sample of the same size. Please explain the phenomenon. (7 points)
12. Please derive the structure factor of the {111} planes of Cu having a face-centered cubic structure in terms of the atomic scattering factor. (8 points)
13. Figure 3 shows a Mn-Ni phase diagram. Please answer the following questions. (15%)
- How many two-phase regions are present in the phase diagram?
 - List all the three-phase reactions in the phase diagram including the reaction type.
 - Give the phases that are present for a 40 mole% Mg alloy at 1200 K and their molar fractions in

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equilibrium.

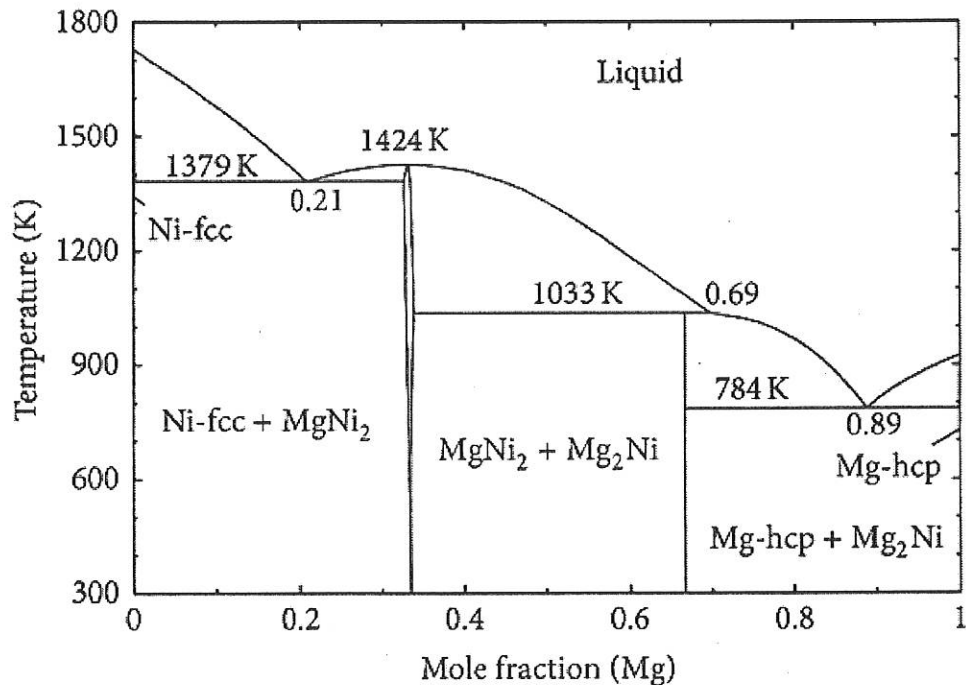


Figure 3

14. Silicon to which $1 \times 10^{15} \text{ cm}^{-3}$ phosphorus atoms have been doped is an extrinsic semiconductor at room temperature by assuming that all the P atoms are ionized. (a) Is this material *n*-type or *p*-type? (b) Calculate the electrical conductivity of this material, assuming that both electron and hole mobilities are $800 \text{ cm}^2/\text{V}\cdot\text{s}$. (Note: the atomic concentration in Si is $5 \times 10^{22} \text{ cm}^{-3}$ and the intrinsic concentration n_i is $1.0 \times 10^{10} \text{ cm}^{-3}$.) (8 points)

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共 4 頁第 1 頁

Multiple choice questions, one answer per question. (8 questions at 7pt each)

1. A material with perfect crystallinity was cooled to near 0 K. Can the entropy of the material be estimated?
 - a. Yes, the entropy of a single crystal material approaches 0 as it approaches 0 K.
 - b. No, entropy of any material depends on their chemistry and cannot be estimated.
 - c. Yes, the entropy of a material does not vary with temperature, so entropy is constant.
 - d. No, the entropy of materials does not show any predictable trend.
2. Which of the following scenario can Helmholtz free energy be used to predict spontaneity?
 - a. A chemical reaction between two dissolved metal salts in an open beaker held constant at room temperature.
 - b. A physical process happening on the leaves of a tree turning water into water vapor.
 - c. A chemical reaction happening in a tightly sealed water bottle turning sugar into alcohol.
 - d. None of the above.
3. A cup of water is suspended in a larger bowl of water. The outer bowl of water is heated to boiling. What would happen to the inner cup of water?
 - a. The inner cup of water would reach 100 °C and it would boil vigorously.
 - b. The inner cup of water would reach a temperature that is just below 100 °C.
 - c. The inner cup of water would reach a temperature that is just below 100 °C, and the water would evaporate quickly.
 - d. The inner cup of water would reach 100 °C, but it does not boil.
4. When 100 mL of sample A and 50 mL of sample B are carefully mixed together, the combined homogeneous solution measures 140 mL. If no chemical reactions occurred, which of the following must be true.
 - a. Dissimilar molecules have stronger intermolecular interactions than those found in the pure samples.
 - b. Dissimilar molecules have weaker intermolecular interactions than those found in the pure samples.
 - c. Dissimilar molecules do not interact with each other.
 - d. This phenomenon disobeys the conservation of mass, so some of the material must have been lost during the transferring process. There is no other plausible explanation.
5. A new refrigerator is being showcased at an exhibition. This refrigerator uses new materials to achieve reverse Carnot cycle based cooling from 25 °C to 4 °C. The presenter argued that they achieved a maximum COP of 110%, which seem impressive. However, this number doesn't seem to be correctly presented. Based on what you know about Carnot cycles, which of the following is the most suitable explanation?
 - a. The optimal COP is over 10, which would indicate the exhibited refrigerator is not efficient.
 - b. The maximum COP is 100%, which would make the exhibited value incorrect.
 - c. The optimal COP is 160%, so the exhibited value is competitive with the ideal performance of 70% efficiency for most Carnot cycles.
 - d. The exhibitors are correct, no correction needed.

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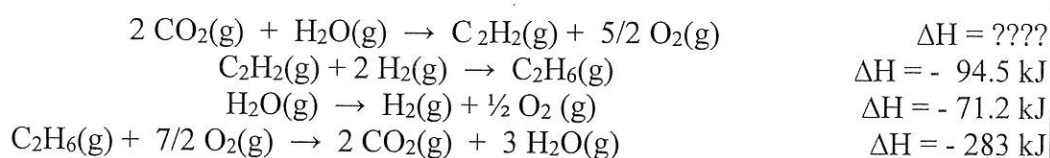
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6. Separation of water and ethanol solution using distillation is difficult. Knowing that the two chemicals have significantly different boiling points for distillation processes to differentiate them. Which of the following is the most direct reasoning explaining the difficulty for water and ethanol to separate?
- Water and ethanol have hydrogen bonds, so their molecules repel each other.
 - Water and ethanol have hydrogen bonds, so their mixtures have higher boiling points.
 - Water and ethanol had hydrogen bonds, so they form stable complexes.
 - Water and ethanol have hydrogen bonds, so their mixtures have unusually high heat capacities for mixtures.
7. When a liquid undergoes a phase transformation from gas to liquid, there's often an intermediate vapor form. This form is most evident in the presence of a vapor dome in the P-V diagram. Which of the following is true about the vapor?
- The vapor has a constant composition of gas and liquid.
 - The vapor follows the lever rule, which can help evaluate the amount of liquid and gas in the vapor.
 - The vapor can be considered as a condensed gas, so it can be considered as a low pressure liquid. However, its properties are more closely related to gas.
 - The Vapor is a chaotic phase, so there aren't any predictable properties.
8. Henry's law and Raoult's law are both laws to predict the properties of liquid mixtures. However, neither of the laws are perfectly accurately. Which of the following provides a proper explanation for the differences?
- Molecular interactions vary significantly with concentration of components, so the solution properties would undergo complex changes.
 - Henry's law and Raoult's law only consider the solution, but the two laws fail to consider the contributions from the gas above the solution.
 - Molecules in a solution are mobile and do not form permanent intermolecular bonds. Therefore, solutions are unpredictable.
 - None of the above.

Long Answers (4 questions at 11pt each)

9. Hess's law can be used to evaluate complex chemical reactions' enthalpy. Consider the following set of chemical reactions and answer the follow up questions.



- (7%) What is the change in enthalpy of the synthesis of ethyne?
- (4%) Can you estimate the time it would take to produce 10 moles of ethyne at 50°C? (you can assume mixing of different chemicals occurs instantly)

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共 4 頁第 3 頁

10. On a universe far far away, a curious scientist discovered a gaseous compound that he names “Spherigon”. Somehow, this newly discovered gas exactly follows ideal gas behaviors and adheres to the assumptions. Answer the following questions regarding this scenario. (Please use less than 7 words per answer)
- (3%) Because Spherigon exactly follows ideal gas behavior, what is the expected shape of this gas molecule?
 - (5%) Van der Waals equation is an improved variation of ideal gas law. For Spherigon, what would be the gas constants A and gas constant B when modeled using the Van der Waals equation?
 - (3%) By understanding that Spherigon exactly follows ideal gas behavior, what is the only type of intermolecular interaction that can occur in a sample of Spherigon?
11. Mixing can be considered as a thermodynamic process. While some chemicals readily mix together, others do not. Using Gibbs free energy of mixing, answer the following true and false questions;
- (3%) (True / False) Mixed states always have greater entropy.
 - (3%) (True / False) Mixing of chemicals relies on the intermolecular interactions of the components.
 - (3%) (True / False) Stable homogeneous solutions are always at an energy minimum or local minimum.
 - (2%) (True / False) When a combination of materials form a mixture at any condition, then the solution is miscible at all conditions.

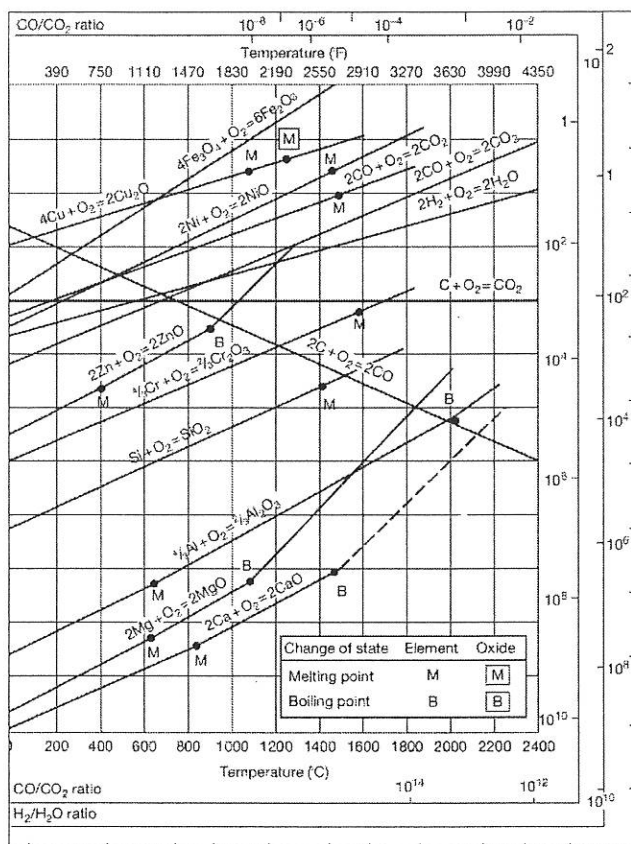
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12. Below is a typical Ellingham diagram, it illustrates the Gibbs free energy of various metal oxidation reactions. Using the diagram, answer the following questions;

- a. (4%) In a group of metals between nickel, iron, chromium, silicon, and magnesium, which one of the metals is the most likely to oxidize at 600 °C
- b. (4%) What is the minimum temperature for carbon dioxide to corrode nickel?
- c. (3%) Is it realistic to use a calcium coating to protect nickel against oxidation at temperatures above 3200 °F? why or why not?



Ellingham Diagram for question 12.

國立中山大學 112 學年度

碩士班暨碩士在職專班招生考試試題

科目名稱：普通化學【材光系碩士班選考、材料前瞻應材碩士班選考、材光聯合碩士班選考】

— 作答注意事項 —

考試時間：100 分鐘

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- 答案卷限用藍、黑色筆(含鉛筆)書寫、繪圖或標示，可攜帶橡皮擦、無色透明無文字墊板、尺規、修正液（帶）、手錶(未附計算器者)。每人每節限使用一份答案卷，請衡酌作答(不得另攜帶紙張，亦不得使用應考證空白處作為計算紙使用)。
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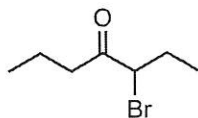
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※本科目依簡章規定「可以」使用計算機（廠牌、功能不拘）（混合題）

共 4 頁第 1 頁

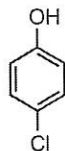
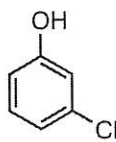
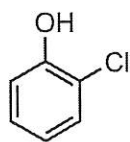
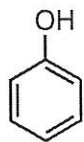
Multiple choice, single answer questions (10 questions at 4 pt each)

1. Which one of the following is the correct IUPAC name of the following molecule?



- 4-bromo-3-heptanone
- 5-bromo-4-heptanone
- 4-carbonyl-3-bromoheptane
- 3-bromo-4-heptanone

2. Which one of the following molecules is the most acidic?



- Phenol
 - o*-Chlorophenol
 - m*-Chlorophenol
 - p*-Chlorophenol
3. In a typical chemical reaction between 2 dissolved non-charged molecules, heating the experiment would often accelerate then reaction. Which of the following statement is correct reason to justify heating organic reactions?
- Heating the reaction lowers the activation energy for the reaction.
 - Heating the reaction makes it more likely for each collision to be in the right conformation.
 - Heating the reaction causes the molecules to vibrate more energetically.
 - Heating the reaction causes the molecules to move faster and collide with more energy.
4. Different light, electromagnetic wave, and radiation have different characteristic wavelengths. Which of the following relations list the correct relative magnitudes of these waves?
- Longest:** Visible light > microwave > X-ray > infrared > radio: **Shortest**
 - Longest:** radio wave > microwave > infrared > Visible light > X-ray: **Shortest**
 - Longest:** microwave > X-ray > visible light > radio > infrared: **Shortest**
 - Longest:** X-ray > microwave > infrared > radio > visible light: **Shortest**
5. Which one of the following statements is true regarding reaction order and reaction formula
- Reaction order must be equal to the number of reacting species.
 - Reaction order must be equal to the number of reacting molecules.
 - Reaction order must be equal to the number of chemical species in a reaction vessel at any instant.
 - Reaction cannot be obtained from reaction formula alone.

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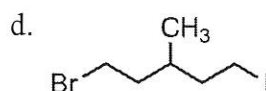
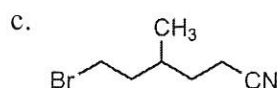
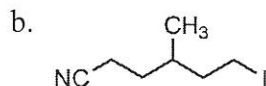
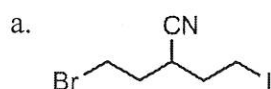
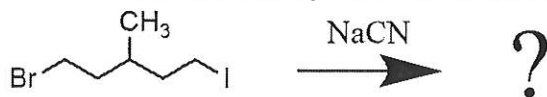
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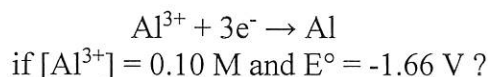
共 4 頁第 2 頁

6. Byproducts are key parts of chemical reactions. Typically, reactions are designed for byproducts to help accelerate a chemical reaction. Which one of the following is not a suitable target for byproducts during reaction design?
- Byproducts should be easily removable from the reaction vessel to promote the reaction.
 - Byproducts must be large molecules, so you can easily see the difference from the final product.
 - Byproducts should be small in size to increase entropy.
 - Byproducts should have different properties, so they can be easily removed during purification.

7. What is the most likely outcome of the following reaction?



8. A typical redox reaction using an electrochemical cell consists of two half cells with cathode and anode. Which one of the following statement is true regarding the electrochemical reaction?
- Reduction must occur at the cathode because electrons flow toward the cathode.
 - Oxidation must occur at the anode because salt ions flow toward the cathode.
 - Reduction must occur at the cathode because electrons flow toward the anode
 - Oxidation and reduction can occur at either anode or cathode because every reaction is different.
9. Consider the following electrochemical reaction, what is the reduction potential for the half-reaction at 25°C:



- 1.84 V
- 1.60 V
- 1.68 V
- 1.66 V

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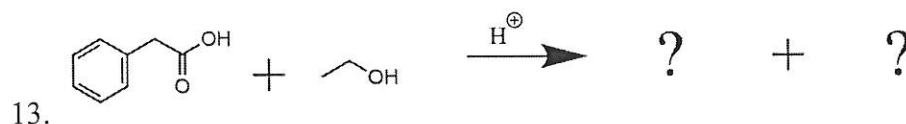
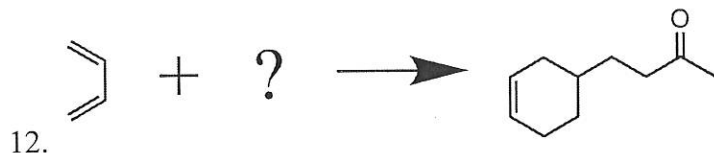
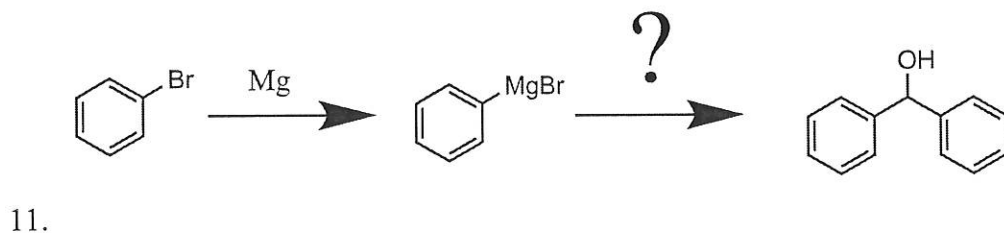
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10. An enzyme and reactant reaction follows the Michaelis-Menten equation. If the concentration of the reacting species far exceeds the concentration of enzymes, what is the reaction order this system? And the correct reasoning?

- 1st order because only the excess reacting reactant is reacting.
- 2nd order because there are two reacting species.
- 1st order because the excess reactant concentration is effectively constant.
- 2nd order because the enzyme must follow 2 steps to bind and release the reactants.

Long Answers questions (6 questions at 10 pt each)

For questions 11-13, replace the question mark with the correct chemical to complete the chemical reaction.



For questions 14 and 15, you will be given a scenario with which you will need to respond to a prompt marked in bold.

- At a hot pot restaurant, a propane tank is used to fuel a stove and heat up the hot pot. The combustion reaction can be imagined as a simple oxidation reaction, and **what is the chemical reaction equation for the combustion?**
- Julianne is on a cruise trip with her family to the North pole. While inside the cruise ship, she got a helium balloon from an entertainer. The balloon floated innocently within the comfortable interior of the ship maintained at 25 °C. When Julianne took the balloon outside to -40 °C, the balloon sank to the ground. **What happened?**

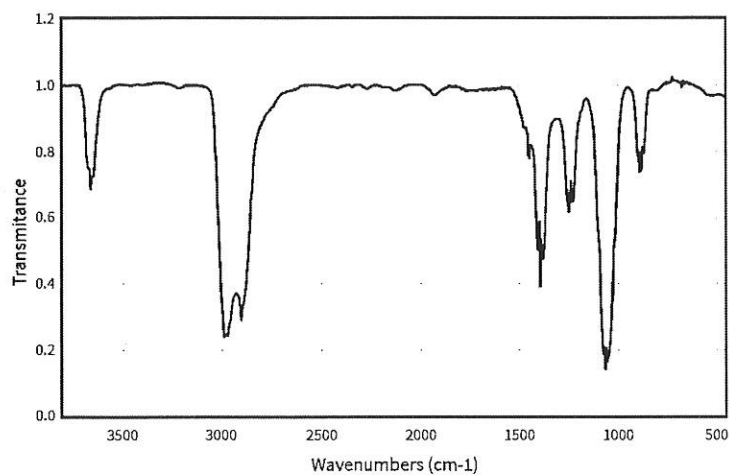
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共 4 頁第 4 頁

16. A police officer is investigating the compositions of a chemical that has caused several individuals to become lethargic and even unresponsive. Unfortunately, he only has the following FT-IR spectrum on hand. **What is this chemical?**
(Hints: There is only one chemical. The chemical is made from C, H, O atoms. There are 9 atoms in the structure.)



Above: FT-IR spectrum used by the police officer to identify the unknown chemical.

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共 2 頁第 1 頁

Problem 1. [Mechanics: 40 points]

In the following, we consider particles only move in x -direction.

(a) [5 points] There are two springs, one with the elastic constant k_1 , and the other with elastic constant k_2 . If the two springs are in series, what is the effective elastic constant k_{eff} ?

(b) [5 points] Consider 2 identical atoms with mass m , connected by a chemical bond modeled as a spring with elastic constant k_σ (a sigma bond). The center of mass is stationary (not moving). Solve the angular frequency of the vibration motion of the 2 atoms. (hint: it might be easier if using the result of (a))

(c) [5 points] There are two springs, one with the elastic constant k_1 , and the other with elastic constant k_2 . If the two springs are in parallel, what is the effective elastic constant k_{eff} ?

(d) [5 points] Consider 2 identical atoms with mass m , connected by 2 chemical bonds (that is, a double bond) modeled as 2 springs with elastic constant k_σ and k_π . The center of mass is stationary (not moving). Solve the angular frequency of the vibration motion of the 2 atoms. (hint: use the result of (c))

(e) [10 points] Consider 2 non-identical atoms with mass M and m (such as a carbon and an oxygen atom), connected by a chemical bond modeled as a spring with elastic constant k_σ (a sigma bond). The center of mass is stationary (not moving). Solve the angular frequency of the vibration motion of the 2 atoms.

(f) [5 points] Consider 2 non-identical atoms with mass M and m (such as a carbon and an oxygen atom), connected by 3 chemical bonds modeled as 3 springs with the same elastic constant k_σ (a sigma bond). (i) solve the angular frequency of the vibration motion of the 2 atoms, and (ii) compare the obtained frequency with the single bond case above.

(g) [5 points] Carbon dioxide CO_2 can be modeled as one carbon atom and two oxygen atoms linked by springs (double bonds). How many are the vibrational modes? Please give a proper argument, not just giving the answer.

Problem 2. [Electromagnetism: 35 points]

The electric field at a distance r from a point charge Q is:

$$\mathbf{E} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{\mathbf{r}},$$

where $\hat{\mathbf{r}}$ is the unit vector along the vector \mathbf{r} . The electric potential is:

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

Consider the following questions in the vacuum, and **use the units in the above formula.**

(a) [5 points] If there are two point charges $-q$ and q , separated by a distance d , as shown in the figure below. The magnitude of the dipole moment p of these two point charges is then $p = qd$. Write down the electric potential at \mathbf{r} (the origin is at the middle of the two charges), using those quantities given in the figure.

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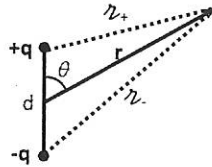


Figure 1

(b) [5 points] Prove $r_{\pm}^2 = r^2 \left(1 \mp \frac{d}{r} \cos \theta + \frac{d^2}{4r^2} \right)$.

(c) [5 points] Use the approximation $(1 + \delta)^\alpha \approx 1 + \alpha\delta$ if $\delta \ll 1$ to show: when $r \ll d$ (measuring the potential far away from the dipole), $\frac{1}{r_{\pm}} \approx \frac{1}{r} \left(1 \pm \frac{d}{2r} \cos \theta \right)$.

(d) [10 points] When $r \ll d$ (measuring the potential far away from the dipole), show the electric potential $V = \frac{1}{4\pi\epsilon_0} \frac{p \cos \theta}{r^2}$.

(e) [10 points] From the above result, calculate the electric field far away from the dipole using:

$$\mathbf{E} = -\nabla V = -\left(\frac{\partial V}{\partial r} \hat{r} + \frac{1}{r} \frac{\partial V}{\partial \theta} \hat{\theta} + \frac{1}{r \sin \theta} \frac{\partial V}{\partial \phi} \hat{\phi} \right).$$

Problem 3. [Thermodynamics: 10 points]

(a) [5 points] A gas is enclosed in a cylinder with a moveable piston, and follows the equation:

$$P^3 V^5 = \text{constant},$$

where P is the pressure, and V is the volume of the gas. Find the work done when the volume is compressed from V_A to V_B , with a known initial pressure P_A (the final pressure P_B is not known).

(b) [5 points] The Maxwell-Boltzmann distribution of the speed v of the particle is:

$$f(v) = \left(\frac{m}{2\pi k_B T} \right)^{3/2} 4\pi v^2 e^{-\frac{mv^2}{2k_B T}},$$

where m is the mass of the particle, k_B is the Boltzmann constant, and T is the temperature. Calculate the most probable speed v_p , which corresponds to the maximum value of $f(v)$.

Problem 4. [Waves/Optics/Modern physics: 15 points]

If a propagating wave along the x direction has the form $f(x, t) = A e^{i(kx - \omega t + \phi)}$, where x is the position, t is the time, A is a constant amplitude and ϕ is a constant phase.

(a) [5 points] (i) Show that this wave function satisfies the wave equation

$$\frac{\partial^2 f}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 f}{\partial t^2}$$

(ii) express the velocity v using A , k , ω , or ϕ .

(b) [5 points] The wave is a periodic function of the time, so $f(x, t_0) = f(x, t_0 + T)$ for arbitrary t_0 (where T is the period). Use this relation, express the period T with A , k , ω , and ϕ .

(c) [5 points] The wave is a periodic function of the position, so $f(x_0, t) = f(x_0 + \lambda, t)$ for arbitrary x_0 (where λ is the wave length). Use this relation, express the wave length λ with A , k , ω , and ϕ .