國立中山大學111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【材光聯合：材光系碩士班選考、材料前瞻應材碩士班選考】

—作答注意事項—

考試時間：100分鐘

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國立中山大學111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【材光聯合：材光系碩士班選考、材料前瞻應材碩士班選考】題號：488001

※本科目依簡章規定「不可以」使用計算機(問答申論題)

1. (10%) Please find out the particular solution of u (x,y) of the following ODE
$(e^{x+y} + ye^{y})dx + (xe^{y} - 1)dy = 0,\ y(0) = -1$

2. (10%) Find out the particular solution of the ODE
$y' + xy = xy^{-1},\ y(0) = 3$

3. (10%) Find out the general solution of the ODE
$y'' - 16y = 9.6e^{4x} + 30e^{x}$

4. (10%) Find out the particular solutions of y_1 and y_2
$y_1' = y_1 + 2y_2$
$y_2' = 2y_1 + y_2$
$y_1(0) = 0.25, \quad y_2(0) = -0.25$

5. (10%) Use the Laplace transform to solve the following ODE
$y'' - 6y' + 5y = 29\cos 2t, \quad y(0) = 3.2, \quad y'(0) = 6.2$

6. (10%) Let

$$A = \begin{bmatrix} 4 & -2 & 3 \\ -2 & 1 & 6 \\ 1 & 2 & 2 \end{bmatrix},\ B = \begin{bmatrix} -1 & 3 & 0 \\ -3 & 1 & 0 \\ 0 & 0 & 2 \end{bmatrix},\ a = [1 \quad -2 \quad 0].$$

Showing all intermediate results, calculate the following expressions or give reasons why they are undefined:

(a) B^TA; **(b)** $(3A - 2B)^T$; **(c)** aBa^T; **(d)** $3A^T - 2B^T$

7. (15%) Use the idea of matrix to solve the following system of linear equations:

$$\begin{cases} x_1 + 2x_2 + x_3 + x_4 + x_5 = 0 \\ -x_1 + x_3 + x_4 + 2x_5 = 0 \\ x_2 + 3x_3 + 4x_5 = 0 \\ -3x_1 + x_2 + 4x_5 = 0 \end{cases}$$

8. (10%) $\frac{\partial u}{\partial x} + x\frac{\partial u}{\partial t} = 0$, where $u(x,0) = 0, u(0,t) = 4t$.

9. (15%) Find the general solution of the following differential equations:

$y'' + 2y' + y = -3e^{-x} + 8xe^{-x} + 1$, where $y' = \frac{dy}{dx}$, $y'' = \frac{d^2y}{dx^2}$.

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國立中山大學111學年度碩士班暨碩士在職專班招生考試試題

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※本科目依簡章規定「不可以」使用計算機(混合題)

單一選擇題 （1-5題，每題5分，共25分）

1. Which one of the following reaction mechanisms ***is not*** included in the three absorption mechanisms in nonmetallic materials: (A) electronic polarization, (B) electron transitions, (C) diffraction, (D) scattering. (5 points)

2. Which one of the following descriptions about a ferromagnetic material at total saturation ***is not*** correct: (A) Flux density reaches a maximum value. (B) The material is composed of numerous magnetic domains. (C) Magnetization is aligned with the field direction, (D) Permeability decreases with further increasing the magnetic field. (5 points)

3. Which one of the following descriptions about the thermal properties of solid materials ***is not*** correct: (A) Heat can be transported by dislocations. (B) Heat can be transported by vibrational lattice waves. (C) Heat can be transported by free electrons. (D) In excess of the Debye temperature, the heat capacity at constant volume reaches a constant value of approximately $3R$. (5 points)

4. Which one of the following descriptions about the electrical properties of solid materials ***is not*** correct: (A) Electric current can be resulted from the motion of free electrons. (B) Electric current can be resulted from the motion of ions. (C) Charge carrier type can be determined by using a Hall-effect experiment. (D) Electrical resistivity increases with temperature, impurity content and plastic deformation. (5 points)

5. Which one of the following descriptions about the mechanical properties of solid materials ***is not*** correct: (A) A measurement of toughness is the elongation attended during the fracture. (B) Ductility is a measure of the degree to which a material plastically deforms by the time fracture occurs. (C) Yielding occurs at the onset of plastic or permanent deformation. (D) The volume of a material decreases on elastic deformation. (5 points)

問答題 （6-14題，共75分）

6. A hypothetical A-B alloy of composition 65 wt% A-35 wt% B at some temperature is found to consist of mass fractions of 0.5 for both alpha and beta phases. If the composition of the alpha phase is 90 wt% A -10 wt% B, what is the composition of the beta phase? (6 points)

7. According to the homogeneous nucleation model, the critical radius r^* of stable nuclei in a solidification transformation is given by $r^* = \frac{2\gamma_{SL}}{\Delta G_v}$ where γ_{SL} is the solid/liquid interfacial free energy and ΔG_v the volume free energy change from a liquid phase to a solid one. Interestingly, the critical radius r^* of stable nuclei for heterogeneous nucleation in solidification is expressed in the same form, *i.e.* $r^* = \frac{2\gamma_{SL}}{\Delta G_v}$. Please explain why the heterogeneous nucleation can occur more readily (quickly and easily) than the homogeneous one though both mechanisms require the same critical radius of stable nuclei. (9 points)

8. Fig. 1 shows the potential energies versus interatomic separation for solid Al, Cu and W. Please write down the elastic moduli of the three metals in order from small to large, and explain your answer. (8 points)

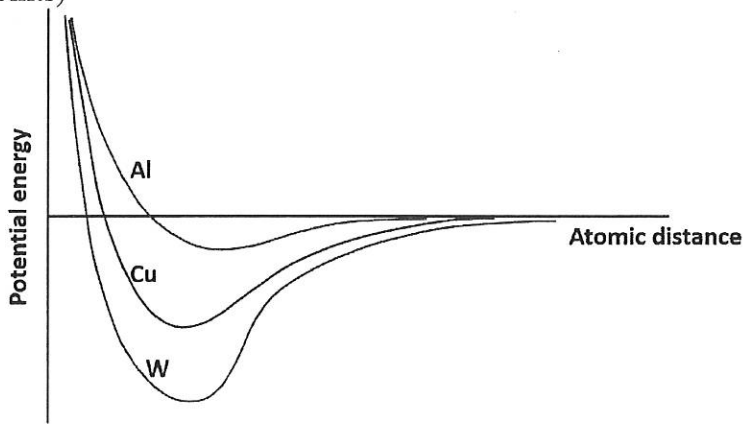

Fig. 1

9. In an experiment carried out by Kirkendall, a block of alpha-brass (Cu-30% Zn) was wound with molybdenum wires and encapsulated in a block of pure Cu as shown in Fig. 2. After annealing at a high temperature it was found that the separation of the Mo markers (W) has decreased. What is the cause of the decrease of W? Explain it. (8 points)

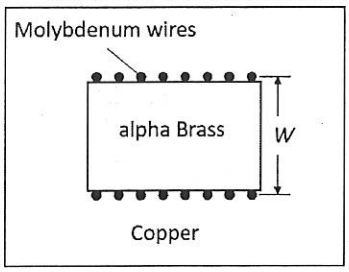

Fig. 2

10. What type(s) of bonding would be expected for each of the following materials: stainless steel, silicon carbide, solid CO_2, and polyethylene? (8 points)

11. Write down the Miller indices of the first three diffraction peaks, in order of 2-theta angles from low to high, which will be present in the diffraction patterns acquired from X-ray diffraction experiments for Aluminum (FCC, a=0.405 nm), Chromium, (BCC, a=0.291 nm) and Cu_2O (simple cubic, a=0.427 nm) powders, respectively, using a monochromatic x-ray radiation having a wavelength of 0.154 nm. (9 points)

12. (a) Determine the Miller indices for the plane and direction shown in Fig. 3a of an orthorhombic unit cell. (5 points)
(b) Determine the Miller-Bravais indices for the plane and direction shown in Fig. 3b of a hexagonal unit cell. (5 points)

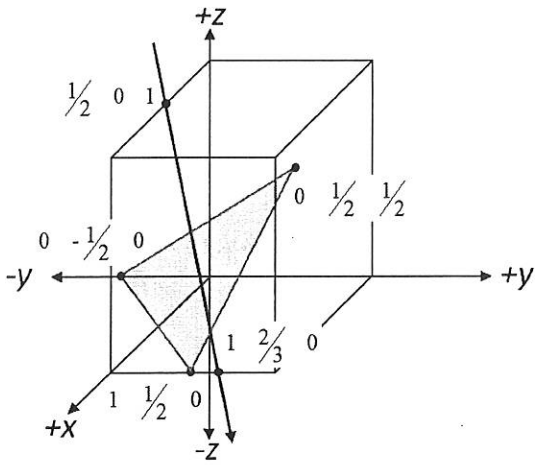

Fig 3a

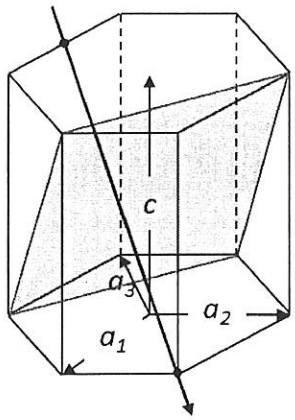

Fig. 3b

13. (a) Derive the plane density, in atoms/nm^2, of (110) planes of copper which has an FCC crystal structure with a = 0.36 nm. (5 points)
(b) Estimate the surface energy, in J/m^2, of the (110) surface plane according to the broken bond approximation if the heat of sublimation of copper is 360 kJ/mole. (5 points)

14. Explain why the mobile dislocations in a crystal usually possess a Burgers vector parallel to one of the close-packed directions of the crystal. (7 points)

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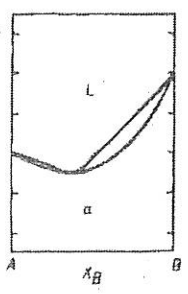
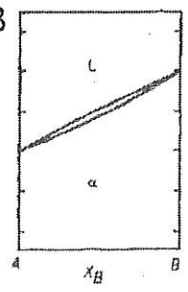
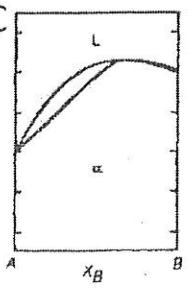
Part 1: Multiple choice questions, one answer per question. (Total 40% at 4% per question)

1. Which of the following is NOT one of the major laws of thermodynamics?
   A. If two systems are simultaneously equilibrated with a third system, all three systems are in equilibrium.
   B. A closed system's change in energy is equal to the heat supplied to the system and the work done by the system on its system.
   C. A reaction with negative change in free energy is spontaneous.
   D. Any system's disorder approaches a constant as its temperature approaches 0K.
2. Under which of the following scenario must the change in enthalpy exactly equal to the change in internal energy?
   A. When the system expanding in vacuum while decreasing in temperature.
   B. When the only work done is a change of volume at constant pressure.
   C. When the system undergoes a chemical reaction.
   D. When the systems undergo a simultaneous process.
3. Of the following, what is a correct relation between temperature (T), heat (Q), work(W), enthalpy (H), entropy(S), Helmholtz free energy (F), Gibbs free energy (G), and internal energy (U)?
   A. $F = U - TS$
   B. $G = H + TS$
   C. $U = Q + W + (G - F)$
   D. $U = Q + G + F$
4. Regarding Maxwell relations, which one of the following statements is true
   A. Thermodynamic models provide spontaneity and direction of a process, but they do not provide the rates of processes.
   B. Helmholtz free energy equations and Gibbs free energy equations provide spontaneity, direction, and rates for a chemical process.
   C. Temperature, pressure, volume, and entropy may be related to each other using the Maxwell equations.
   D. None of the above
5. What is the correct condition for changes in enthalpy, entropy, or free energy to be considered as state functions?
   A. The three quantities are always state properties, so they do not need additional conditions.
   B. The thermodynamic quantities must be reported as relative values to a common base value.
   C. The thermodynamic quantities must be applied to large sample populations, such as moles of chemicals.
   D. The three quantities are always scalars without directionalities, so they must be treated as state functions.

6. The partial molar vapor pressure of a substance in a binary liquid mixture deviates upward from Raoult's law behaviors. According to Henry's law, which of the following is true.
   A. The two components have strong intermolecular bonds such as hydrogen bonds and dipole-dipole interactions. Therefore, they prefer interacting with other components over self-interactions.
   B. The two components are able to interact strongly with itself, so the two components prefer self-interaction over interacting with other components.
   C. The two components have multiple intermolecular interaction mechanisms that result in strong total interaction between the two species. Therefore, they prefer self-interactions over interacting with other components.
   D. The two components in the mixture have strong shared intermolecular interactions, so they prefer self-interaction over interacting with the other component.
7. Two scientists proposed a new heat engine with hot end at 500°C and cold end at 100°C. What is the efficiency of this heat engine?
   A. 80.0%
   B. 75.6%
   C. 51.7%
   D. 32.2%
8. Why is it difficult to distil water and ethanol mixtures into individual pure components?
   A. Water and ethanol have hydrogen bonds, so their mixtures have higher boiling points.
   B. Water and ethanol binary phase diagrams indicate that they do not follow Raoult's law.
   C. Water and ethanol form azeotrope.
   D. Water and ethanol have hydrogen bonds, so their mixtures have unusually high heat capacities for mixtures.
9. Which of the following is a correct estimation of the Debye temperature of most metals, such as gold, combined with the correct reasoning?
   A. 100K to 400K, Debye temperature is the highest temperature at which a crystal's vibrations can be described with a single normal frequency.
   B. 1000-2000K, Debye temperature is the temperature at which bonds in a material starts to break apart. This is also known as the melting temperature.
   C. 100K to 3000K, Debye temperature is the temperature at which the rate of change for molar specific heat capacity increases.
   D. Debye cannot be estimated.
10. Among the following 3 diagrams of temperature VS X_B, which one correctly illustrate the phase transformation of a two-component mixture with a more stable solid phase?

A 

B 

C 

D. None of the above

Part 2: Long Answers (60% total)

1. Use the following information to answer the questions below about nitric acid synthesis.

$4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$	ΔH = ????
$N_2 + O_2 \rightarrow 2\ NO$	ΔH = - 180.5 kJ
$2\ NH_3 + 2CO_2 \rightarrow 2HCN + 2H_2O_2$	ΔH = - 80.0 kJ
$N_2 + 3\ H_2 \rightarrow 2\ NH_3$	ΔH = - 91.8 kJ
$2\ H_2O + C \rightarrow 2\ H_2 + CO_2$	ΔH = 280.0 kJ
$2\ H_2 + O_2 \rightarrow 2\ H_2O$	ΔH = - 483.6 kJ

   a. What is the change in enthalpy of the synthesis of nitric oxide (NO)? (5%)
   b. Is the synthesis of nitric oxide spontaneous? (5%)
   c. Can you provide information on the rate of reaction for the synthesis of nitric oxide? (5%)

2. A curious scientist discovered a gaseous compound, and he calls it "Cubicon". This newly discovered gas does not follow ideal gas behaviors, so the scientist must use the Van der Waals equation to describe its physical behaviors. Answer the following questions regarding this scenario.
   a. What is the Van der Waals equation and how does it differ from the ideal gas law in dealing with pressure of gases? (8%)
   b. Cubicon has a gas constant A of 0.5 L/mol and gas constant B of 3.64 $L^{2*}atm/mol^2$. It has an apparent volume of 200L at 25°C, what is the expected pressure of cubicon at 25°C? (7%)

3. An ideal gas is trapped in a closed system. From heat exchanges, the gas can generate work in a 4-steps cycle. Answer the following questions using the 4 steps listed below;
   Step 1 - Starting from 300K and 1,013,250 Pascal, the gas expands in a vacuum in double its original size.
   Step 2 - The gas is heated reversibly to 400K at constant volume.
   Step 3 - The gas is expanded reversibly at constant temperature until its volume doubles again.
   Step 4 - The gas is then reversibly cooled to 300K.
   a. What are total changes in internal energy (U) and entropy (S)? (10%)
   b. What is the net amount of work accomplished by one cycle of this gas? (5%)

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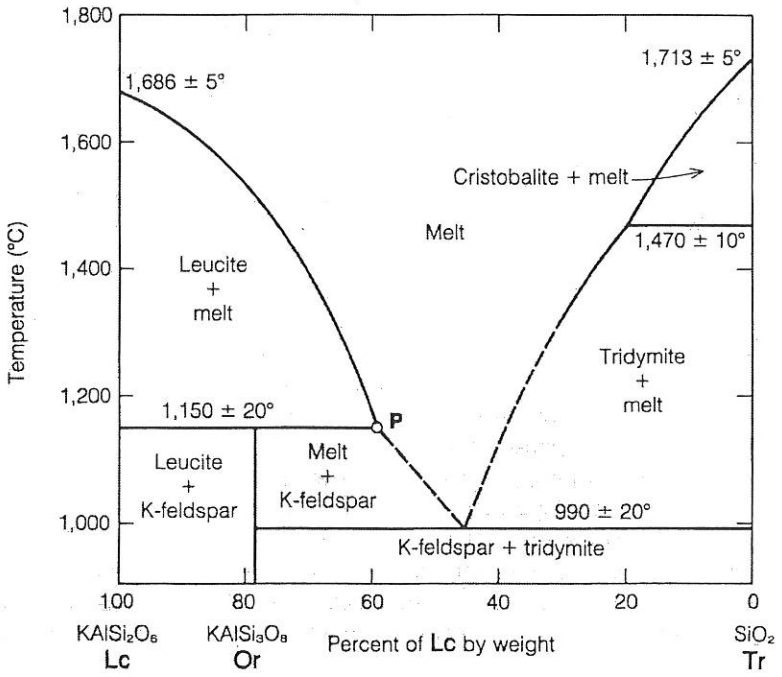
4. Using the following phase diagram, answer the following questions;
   a. A solution of K-feldspar and Tridymite was heated slowly from room temperature. What is the temperature that the melt phase may first appear? (2%)
   b. A melt sample of 80% Lc was cooled slowing from 2000°C to form a solid sample. At what temperature does the last solid phase solidify? What is the composition of in the final solid sample? (3%)
   c. Sketch the Gibbs free energy of mixing diagram for this sample between the range of 50 wt% to 30 wt% Lc? (10%)



試題請隨卷繳回，請留意背面是否有題

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科目名稱：普通化學【材光聯合：材光系碩士班選考、材料前瞻應材碩士班選考】

—作答注意事項—

考試時間：100分鐘

- **考試開始鈴響前不得翻閱試題，並不得書寫、劃記、作答。**請先檢查答案卷（卡）之應考證號碼、桌角號碼、應試科目是否正確，如有不同立即請監試人員處理。
- **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)。
- 答案卡請以2B鉛筆劃記，不可使用修正液（帶）塗改，未使用2B鉛筆、劃記太輕或污損致光學閱讀機無法辨識答案者，後果由考生自負。
- 答案卷（卡）應保持清潔完整，不得折疊、破壞或塗改應考證號碼及條碼，亦不得書寫考生姓名、應考證號碼或與答案無關之任何文字或符號。
- 可否使用計算機請依試題資訊內標註為準，如「可以」使用，廠牌、功能不拘，唯不得攜帶具有通訊、記憶或收發等功能或其他有礙試場安寧、考試公平之各類器材、物品（如鬧鈴、行動電話、電子字典等）入場。
- **試題及答案卷（卡）請務必繳回，未繳回者該科成績以零分計算。**
- **試題採雙面列印，考生應注意試題頁數確實作答。**
- **違規者依本校招生考試試場規則及違規處理辦法處理。**

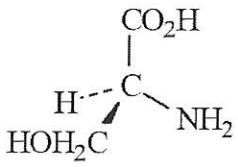
國立中山大學111學年度碩士班暨碩士在職專班招生考試試題

科目名稱：普通化學【材光聯合：材光系碩士班選考、材料前瞻應材碩士班選考】題號：488004

※本科目依簡章規定「可以」使用計算機（廠牌、功能不拘）（混合題）

I. **Multiple choice questions (4 points for each question, 60 points in total)**

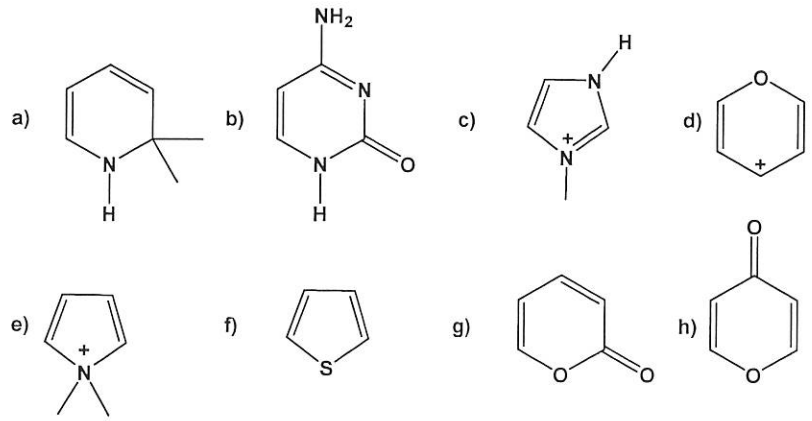
1- (*S*)-(–)-Serine:



(*S*)-(-)-Serine

(A) is dextrorotatory
(B) rotates plane-polarized light in a counterclockwise direction
(C) rotates plane-polarized light in a clockwise direction
(D) is racemic

2- All the following are aromatic EXCEPT



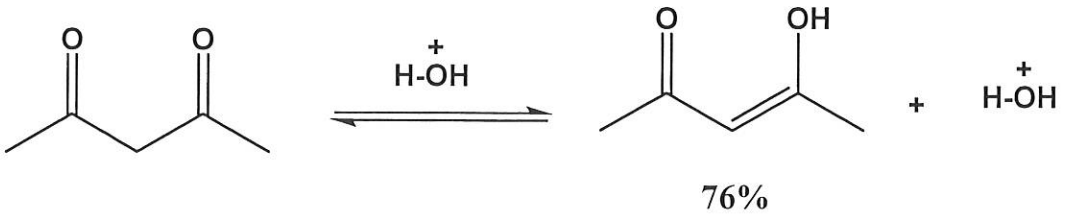
(A) b,e,h (B) a,c,h (C) d,f,g (D) b,c,e

3- Which of the following represents the correct relative energy?
(A) microwaves > infrared radiation > visible light > ultraviolet light > radio waves
(B) ultraviolet light > visible light > infrared radiation > microwaves > radio waves
(C) infrared radiation > visible light > ultraviolet light > microwaves > radio waves
(D) visible light > ultraviolet light > infrared radiation > microwaves > radio waves
(E) infrared radiation > ultraviolet light > visible light > microwaves > radio waves

4- Which of the following is the strongest interaction between polymer molecules?
(A) Ionic (B) Hydrogen bonding (C) Dipole-Dipole (D) Dispersion force

5- Which of the following statements concerning corrosion is(are) TRUE?
(A) Corrosion is an example of an electrolytic process.
(B) Corrosion of steel involves the reduction of iron coupled with the oxidation of oxygen.
(C) Steel rusts more easily in the dry (arid) Southwest states than in the humid Midwest states.
(D) Salting roads in the winter has the added benefit of hindering the corrosion of steel.
(E) The key to cathodic protection is to connect via a wire a metal more easily oxidized than iron to the steel surface to be protected.

6- The structures show the step-wise bond making and bond breaking in this reaction. the Gibbs free energy change ΔG° for the reaction equals



76%

(A) –2.86 KJ/mol. (B) +2.86 KJ/mol. (C) –2.68 KJ/mol. (D) –3.17 KJ/mol.

7- An electrochemical cell consists of a standard hydrogen electrode and a copper metal electrode. If the copper electrode is placed in a solution of 0.10 M NaOH that is saturated with $Cu(OH)_2$, what is the cell potential at 25 °C? [For $Cu(OH)_2$, $Ksp = 1.6 \times 10^{-19}$.]

(A) 0.16 V. (B) 1.0 V. (C) 2.0 V. (D) 0.14 V.

8- 4.0 mL of 0.35 M methylamine is titrated with 0.28 M hydrogen chloride until the end point is reached. Calculate the pH of the solution at the end point? (pKa of methylamine is 3.301)

(A) 5.74 (B) 7.54. (C) 11.42. (D) 9.65.

9- A 1.60 g sample of a mixture of naphthalene ($C_{10}H_8$) and anthracene ($C_{14}H_{10}$) is dissolved in 20.0 g benzene (C_6H_6). The freezing point of the solution is 2.81 °C. What is the composition as mass percent of the sample mixture? The freezing point of benzene is 5.51 °C and K_f is 5.12 °C • kg/mol.

(A) 44% naphthalene, 56% anthracene.
(B) 56%naphthalene, 44% anthracene.
(C) 50% naphthalene, 50% anthracene.
(D) 40% naphthalene, 60% anthracene.

10- Based on the position in the periodic table, which one of the following atoms would you expect to be the most electronegative?

(A) Cl (B) Ge (C) P (D)Se (E) Sn

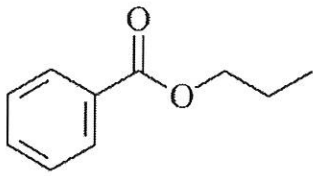
11- Which statement below would NOT ensure greater conductivity of an electric current?
(A) There must be charged particles or ions present in the solution.
(B) Particles must move freely through the solution.
(C) There must be fewer ions present in solution.
(D) There must be a lower volume of solvent in which the ions are dissolved.

12- Which of the following macromolecules would yield only one type of monomer after complete hydrolysis?
(A) DNA.
(B) Glycogen.
(C) Lipoprotein.
(D) RNA.
(E) Triacylglycerol.

13- A radioactive isotope, which is used in diagnostic imaging, has a half-life of 6.0 hours. If a quantity of this isotope has an activity of 150 μCi when it is delivered to a hospital, how much activity will remain 24 hours after delivery? (μCi = microcuries)

(A) 150 μCi (B) 38 μCi (C) 19 μCi (D) 9.4 μCi (E) 4.7 μCi

14- According to IUPAC rules, what is the name of the molecule shown below?



(A) Benzyl propanoate.
(B) Phenyl propanoate.
(C) Phenyl butanoate.
(D) Propanonyl benzene.
(E) Propyl benzoate.

15- Many enzyme reactions follow the Michaelis-Menten rate law shown below, where V and K_m are constants and [S] is the concentration of substrate that is undergoing a catalyzed reaction. When [S] >> K_m, what is the apparent order of the reaction?

$$\text{Rate} = \frac{V[S]}{K_m + [S]}$$

(A) Zero order.
(B) One-half order.
(C) First order.
(D) Second order.
(E) Third order.

II. Non-choice questions (10 points for each question, 40 points in total)

16- Complete the following equations:

(A) $CH_3\text{-}CH_2\text{-}CH_2\text{-}COOH \xrightarrow[2.\ H_3O^+]{1.\ NaBH_4}$ ----------

(B)  $\xrightarrow[H_2SO_4]{HNO_3}$ ---------- $\xrightarrow[AlCl_3]{CH_3Cl}$ ----------

(C) ---------- $\xleftarrow[2.\ H_3O^+]{1.\ CH_3MgBr}$ $CH_3\text{-}CH_2\text{-}\overset{\overset{O}{\|}}{C}\text{-}CH_3$ $\xrightarrow[2.\ H_3O^+]{1.\ NaBH_4}$ ----------

17- Consider a sample of a hydrocarbon (a compound consisting of only carbon and hydrogen) at 0.959 atm and 298 K. Upon combusting the entire sample in oxygen, you collect a mixture of gaseous carbon dioxide and water vapor at 1.51 atm and 375 K. This mixture has a density of 1.391 g/L and occupies a volume four times as large as that of the pure hydrocarbon. Determine the molecular formula of the hydrocarbon.

18- Calculate the temperature at which 20 mol of helium would exert a pressure of 120 atm in a 10 dm^3 cylinder. a = 0.034 dm^6 atm mol^{-2} and b = 0.024 dm^3 mol^{-1} using both the ideal gas equation and the van der Waals equation. (R = 0.08206 dm^3 atm K^{-1} mol^{-1}).

19- Choose one of the following terms to match the description given in statements (1)–(10).

A. Lipid bilayers
B. Globular proteins
C. waxes
D. Phosphoglycerides
E. Hormones
F. fats and oils
G. Ligases
H. cysteine
I. Fibrous proteins
J. Prostaglandins

(1) Proteins that are tough and insoluble in water.
(2) Enzymes that catalyze the breaking away of a small molecule such as from a substrate.
(3) Enzymes that catalyze the bonding together of two substrates.
(4) Lipids that major components of cell membranes.
(5) Lipids that a group of C_{20} and contain a five-membered ring with two long side chains.
(6) Lipids that form the cell membranes and form an effective barrier to the passage of ions and other components into and out of the cell.
(7) Steroids that exist in humans and are responsible for the most steroids function.
(8) These are triacylglycerols, triesters of glycerol with three long-chain carboxylic acids.
(9) Amino acid responsible for permanent wave in hair.
(10) Mixtures of esters of long-chain carboxylic acids with long-chain alcohols.

國立中山大學 111 學年度

碩士班暨碩士在職專班招生考試試題

科目名稱：普通物理【材光聯合：材光系碩士班選考、材料前瞻應材碩士班選考】

－作答注意事項－

考試時間：100 分鐘

- **考試開始鈴響前不得翻閱試題，並不得書寫、劃記、作答。**請先檢查答案卷（卡）之應考證號碼、桌角號碼、應試科目是否正確，如有不同立即請監試人員處理。
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- **違規者依本校招生考試試場規則及違規處理辦法處理。**

國立中山大學111學年度碩士暨碩士專班招生考試試題

科目名稱：普通物理【材光聯合：材光系碩士班選考、材料前瞻應材碩士班選考】 題號：488005
※ 本科目依簡章規定「不可以」使用計算機（問答申論題） 共 2頁第 1 頁

Problem 1. [Mechanics: 40 points]

A particle with mass m is attached to a spring with the elastic constant k. This particle is displaced from the equilibrium position $x = 0$ to x.

(a) [5 points] If the restoring force is F, write down the Hooke's law (with the correct sign).

(b) [10 points] Using Hooke's law and $F = ma$, where a is the acceleration, solve the equation of motion to obtain the vibrational angular frequency ω of the particle (express your answer ω with m, and k).

(c) [5 points] If the particle with mass m is now attached to two different springs with the elastic constants k_1 and k_2, as shown in Fig. 1(a). What is the vibrational angular frequency ω of the particle (express your answer ω with m, and k).

(d) [5 points] If the particle with mass m is now attached to two different springs with the elastic constants k_1 and k_2, as shown in Fig. 1(b). What is the vibrational angular frequency ω of the particle (express your answer ω with m, and k).

(e) [15 points] If two particles with mass m, are linked with two springs with the same elastic constant k, as shown in Fig. 1(c). Solve the equation of motion to obtain the vibrational angular frequencies of this coupled system (express your answer ω with m, M, and k).

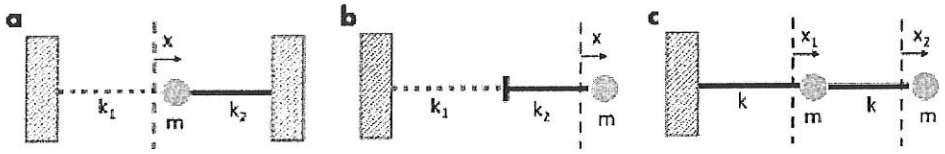

Figure 1

Problem 2. [Electromagnetism: 40 points]

Electromagnetic fields are the dominant forces in materials science. They are also directly related to optoelectronic applications. The electric field at a distance $\boldsymbol{r}$ from a point charge Q is:

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

where $\hat{\boldsymbol{r}}$ is the unit vector along the vector $\boldsymbol{r}$. Consider the following questions in the vacuum, and **use the units in the above formula**.

(a) [5 points] Write down (i) the electric potential $V(\mathbf{r})$ of a point charge Q, (ii) how to calculate $\mathbf{E}(\mathbf{r})$ using $V(\mathbf{r})$?

(b) [5 points] If there is one point charge $+q$ fixed at the origin, what is the work to bring the other point charge $-q$ from $(\infty, 0, 0)$ to $(r, 0, 0)$?

(c) [10 points] If the two point charges are now separated with a distance d: $-q$ at $(d, 0, 0)$ and q at $(0, 0, 0)$, the magnitude of the dipole moment p of these two point charges is then $p = qd$. Use the approximation $(1 + \delta)^\alpha \approx 1 + \alpha\delta$ if $\delta \ll 1$ to find (i) the magnitude (express your answer with s

and p) and (ii) the direction of the electric field at the point $(s, 0, 0)$, where $s \gg d$ (hint: try to use $\delta = \frac{d}{s}$).

(d) [5 points] If now the negative charge $-q$ with a mass m is orbiting the positive charge $+q$ fixed at the origin with a radius r, what is the velocity v of the negative charge?

(e) [5 points] Following the above question, what is the period T of the circular motion of the negative charge?

(f) [10 points] Following the above question, the orbiting negative charge is equivalent to a current in the circular orbit. Assume the $-q$ charge moves very fast such that the current I can be approximated as a stationary and uniform current: $I \equiv \Delta Q/\Delta t = -q/T$. Find the magnitude of the magnetic field **B** at the point $(0, 0, s)$.

Problem 3. [Thermodynamics: 15 points]

(a) [10 points] Considering an ideal gas of atoms at equilibrium, the probability of the particles with the energy E to $E + dE$ follows the Maxwell-Boltzmann energy distribution:

$$P(E) \propto e^{-\frac{E}{k_B T}},$$

where k_B is the Boltzmann's constant, and T is the temperature. Calculate the average energy:

$$\langle E \rangle \equiv \frac{\int_0^\infty EP(E)dE}{\int_0^\infty P(E)dE}.$$

(b) [5 points] Using the result of (a), what is the specific heat of the ideal gas? (hint: $C_v = d\langle E \rangle/dT$)

Problem 4. [Waves/Optics/Modern physics: 5 points]

If a propagating wave along the x direction has the form $cos(kx - \omega t + \phi)$, where x is the position, t is the time, and ϕ is an extra phase. (i) What is the period T? (ii) What is the wave length λ? (Express your answer with k, ω, and ϕ)