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並不得書寫、畫記、作答。

國立清華大學 115學年度學士後醫學系單招試題

系所班組別：學士後醫學系

科目代碼：0103

考試科目：化學與物理

—作答注意事項—

1. 請核對答案卡上之准考證號、科目名稱是否正確。
2. 作答中如有發現試題印刷不清，得舉手請監試人員處理，但不得要求解釋題意。
3. 答案卡限用 2B 鉛筆畫記；如畫記不清（含未依範例畫記）致光學閱讀機無法辨識答案者，其後果一律由考生自行負責。
4. 其他應考規則、違規處理及扣分方式，請自行詳閱簡章附錄上「**國立清華大學試場規則及違規處理辦法**」，無法因本試題封面作答注意事項中未列明而稱未知悉。

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共 19 頁， 第 1 頁 *請在【答案卡】作答

Choose one best answer for the following questions

【單選題】每題 2.5 分，共計 150 分，答錯一題倒扣 0.625 分，未作答，不給分亦不扣分。1~30 題為化學，31~60 題為物理。

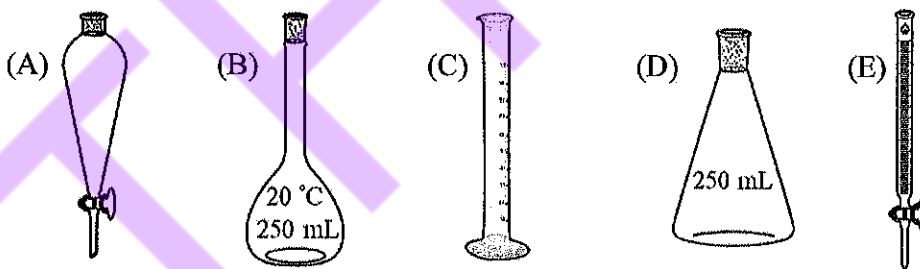
1. Compound A has the molecular formula C_5H_{10} , and all of its hydrogen atoms are chemically equivalent. Upon chlorination, A forms a dichlorinated product with the formula $C_5H_8Cl_2$. Ignoring optical isomers, how many distinct isomers of $C_5H_8Cl_2$ are possible?

(A) 3 (B) 4 (C) 5 (D) 6 (E) 7

2. The main procedures for determining the H_2SO_4 content in concentrated sulfuric acid include:

- ① Measuring a certain volume of concentrated sulfuric acid and diluting it;
- ② Transferring the solution to a volumetric flask and diluting to a fixed volume;
- ③ Pipetting 20.00 mL of the solution to be tested and titrating it with 0.10 M NaOH solution.

Which of the following pieces of apparatus is NOT required for the above procedures?



3. Arrange the following compounds in order of decreasing normal boiling point:

- ① neopentane ② 1-pentanol ③ *n*-pentane ④ 3-chloropentane
⑤ pentanoic acid

- (A) ⑤ > ④ > ② > ③
(B) ② > ⑤ > ① > ③
(C) ⑤ > ② > ① > ④
(D) ⑤ > ④ > ① > ③
(E) ② > ④ > ③ > ①

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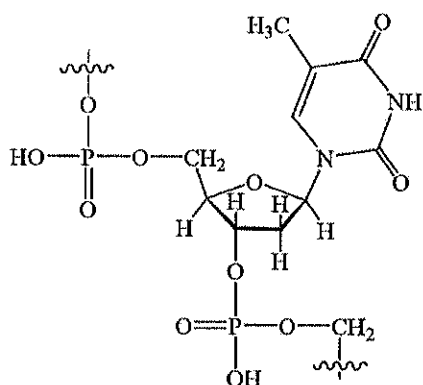
Questions 4 and 5 are based on the following information.

4. Gallium-68 has been used for Positron Emission Tomography (PET) through a beta plus decay to generate a positron (β^+), which annihilate with an ordinary electron to generate two gamma rays are emitted in opposite directions. Which of the following is the product for the β^+ decay of the Gallium-68?

		B	C	N
		Al	Si	P
Cu	Zn	Ga	Ge	As
Ag	Cd	In	Sn	Sb
Au	Hg	Tl	Pb	Bi

- (A) Zn-68 (B) Ga-67 (C) Ge-69 (D) Zn-67 (E) Ge-68
5. Gallium-68 has a half-life of 68 min for positron decay. The recommended amount of Gallium-68 radioactivity to be administered for positron emission tomography (PET) imaging is 2 MBq/kg at the time of injection. If a freshly prepared Gallium-68 tracer solution has 64 MBq/mL, and it takes 3.5 hours to transport and ready for injection to patient. What volume of Gallium-68 solution is required for PET scan on a 70-kg patient?
- (A) 5.6 mL (B) 7.5 mL (C) 11.6 mL (D) 14.2 mL (E) 17.5 mL

6. The basic building blocks of nucleic acids are nucleotides. The figure on the right shows a fragment of a nucleic acid structure. Which of the following statements is NOT correct?



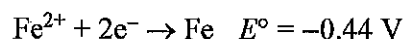
- (A) DNA (deoxyribonucleic acid) and RNA (ribonucleic acid) contain the same nitrogenous bases, but their five-carbon sugars are different.
- (B) A nitrogenous base condenses with a five-carbon sugar to form a nucleoside; a nucleoside condenses with phosphoric acid to form a nucleotide; nucleotides undergo condensation polymerization to form a nucleic acid.
- (C) Under certain conditions, a nucleotide can react with both acids and bases.
- (D) In nucleic acid molecules, bases undergo complementary pairing through hydrogen bonding.
- (E) This nucleic acid fragment contains three chiral centers.

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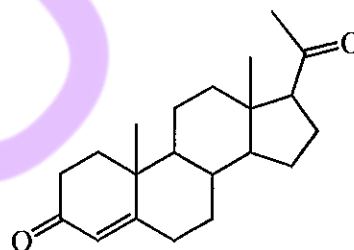
7. A galvanic cell is constructed based on the following standard reduction potentials at 25 °C:



Which of the following statements is correct? (Faraday constant is 96500 C/mol.)

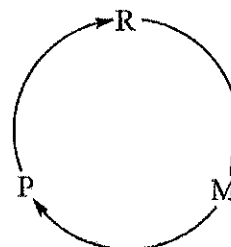
- (A) The cell potential with all components in their standard state is 3.42 V.
 (B) The cathode compartment would be composed of La^{3+}/La .
 (C) Three electrons are transferred per unit of cell reaction.
 (D) When $[\text{Fe}^{2+}] = 2.00 \times 10^{-4} \text{ M}$ and $[\text{La}^{3+}] = 2.00 \times 10^{-3} \text{ M}$, the cell potential is > 1.93 V.
 (E) The ΔG° for this cell is -1117.5 kJ.

8. Progesterone is a key female hormone with the structure on the right. Which of the following statements about this structure is correct?



- (A) It has two π -bonds.
 (B) It has six chiral carbon atoms.
 (C) Three carbon atoms are sp^2 hybridized.
 (D) Both oxygen atoms are sp hybridized.
 (E) It has two lone pairs of electrons in the Lewis structure.

9. Which of the substances listed below can be transformed in nature according to the pathway shown in the diagram on the right, and for which substance R can react directly with water to form M?



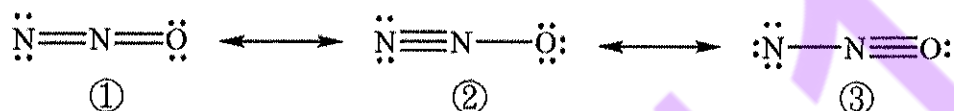
Options	R	M	P
(A)	Cl_2	NaClO	NaCl
(B)	SO_2	H_2SO_4	CaSO_4
(C)	Fe_2O_3	$\text{Fe}(\text{OH})_3$	FeCl_3
(D)	ATP	ADP	$\text{Mg}(\text{HPO}_3)_2$
(E)	CO_2	H_2CO_3	$\text{Ca}(\text{HCO}_3)_2$

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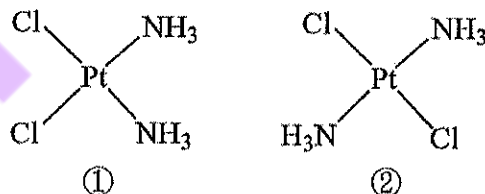
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10. Three possible Lewis structures (①, ② and ③) can be drawn for nitrous oxide (N_2O). Which of the following statements regarding N_2O and its Lewis structures is correct?



- (A) The oxidation state of nitrogen in N_2O is +2.
 (B) The formal charge on the oxygen atom is the same in all three Lewis structures.
 (C) Based on formal-charge considerations, ① is the most favorable.
 (D) Based on formal-charge considerations, ② is the most favorable.
 (E) The terminal nitrogen atom in ③ is sp -hybridized.
11. $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ has two isomers, ① and ②, as shown in the figure below. Compound ① is called *cisplatin*, and compound ② is called *transplatin*. One of them is an anticancer drug, and one is inactive. The anticancer drug works by its chloride ions undergoing a substitution reaction with nitrogen atoms in DNA that are close together, forming a N-Pt-N angle of about 90° . Which of the following statements regarding the structures and properties of isomers ① and ② is correct?



- (A) The types of chemical bonds present in $\text{Pt}(\text{NH}_3)_2\text{Cl}_2$ are coordinate (dative) bonds and ionic bonds.
 (B) The d -orbital splitting patterns of the metal center in ① and ② are identical.
 (C) Compound ② is the anticancer drug.
 (D) ① and ② have identical polarity.
 (E) IR spectroscopy can be used to distinguish between ① and ②.
12. A solution saturated with a salt of the type M_2X has an osmotic pressure of 3.69×10^{-2} atm at 300 K. Assuming ideal behavior, what is the K_{sp} value for the salt? ($R = 0.082 \text{ atm}\cdot\text{L}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$)
 (A) 5.6×10^{-5} (B) 2.3×10^{-6} (C) 2.5×10^{-7} (D) 1.4×10^{-8} (E) 5.0×10^{-10}

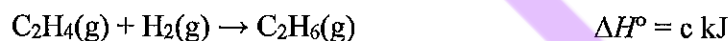
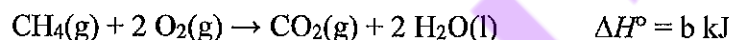
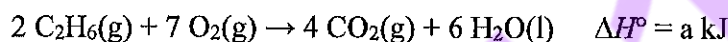
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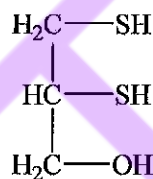
13. At 25 °C, a solution is formed by mixing 50.0 mL of 0.200 M HNO₃, 25.0 mL of 0.200 M HCOOH, 25.0 mL of 0.200 M NaOH, 25.0 mL of 0.100 M Ba(OH)₂, and 20.0 mL of 0.100 M KOH. Assuming the volume change during the mixing can be ignored. What is the pH of this solution? ($K_a = 1.8 \times 10^{-4}$ for HCOOH, $\log 2 = 0.301$, $\log 3 = 0.477$)
- (A) 6.90 (B) 5.58 (C) 4.91 (D) 3.92 (E) 3.57

14. Given the thermochemical data:

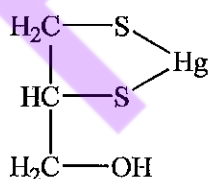


What is the ΔH° for the reaction: $2 \text{CH}_4 \rightarrow \text{C}_2\text{H}_4 + 2 \text{H}_2$?

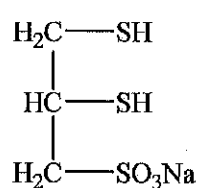
- (A) $a/2 - d + b/2$ (B) $-a + b + 2c + d/2$ (C) $2b - d/2 - a/2 - c$
 (D) $a - b + 2c + d$ (E) $b + d - a - 2c$
15. Many organic compounds containing thiol groups (-SH) are antidotes for the heavy metal element mercury poisoning. For example, the antidote compound I produces compound II with mercuric oxide as shown below.



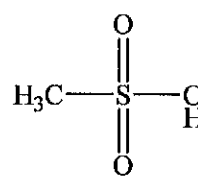
I



II



III



IV

Compound III is also a mercury detoxifier. Compound IV is a strong acid. Which of the following statements is correct?

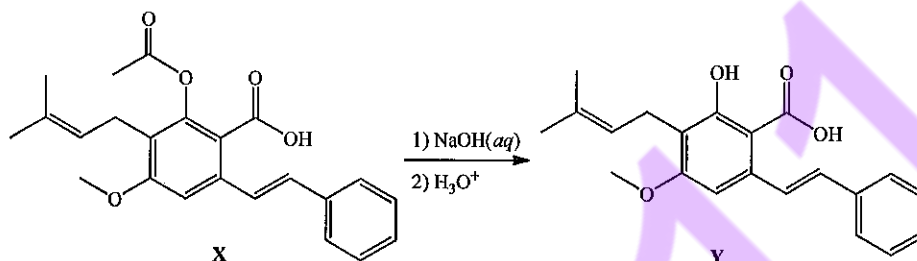
- (A) In compound I, the S atoms take on sp hybridization.
 (B) The electronegativity of the S element is the greatest in compound II.
 (C) the C-C-C bond angle is 180° in compound III.
 (D) There are ionic and covalent bonds in compound III.
 (E) The bond energies of the sulfur-oxygen bonds are equal in compound IV.

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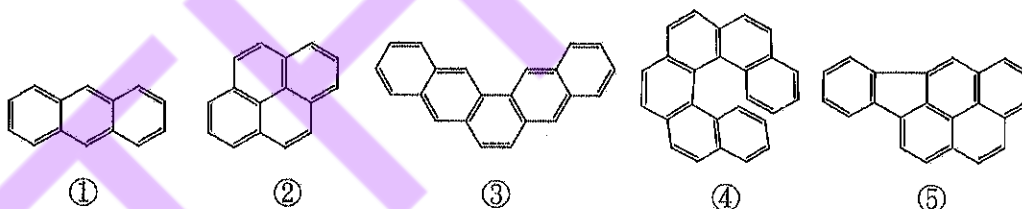
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16. Compound Y has antimicrobial and anti-inflammatory properties and can be produced from X.



Which of the following statements about compounds X and Y is correct?

- (A) 1 mol of X reacts with a maximum of 2 mol of NaOH.
 (B) X can be obtained by esterification of Y with ethanol.
 (C) X and Y both react with acidic KMnO_4 solution.
 (D) At room temperature, X and Y react with sufficient amounts of Br_2 to produce products containing different numbers of chiral centers.
 (E) All C and O atoms in both X and Y are coplanar.
17. Which of the following is a chiral compound?

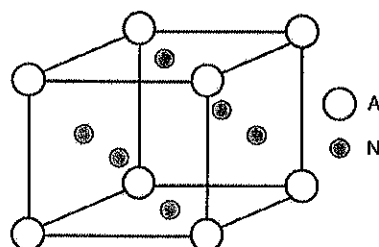


- (A) ① (B) ② (C) ③ (D) ④ (E) ⑤

18. A compound formed by Ni and Al may form a structure with the unit cell shown on the right.

Based on the provided information, which of the following statements is incorrect?

- (A) This compound is an ionic solid.
 (B) Each Ni atom is surrounded by 4 Al atoms.
 (C) Each Al atom is surrounded by 12 Ni atoms.
 (D) Each unit cell contains 1 Al atom.
 (E) This compound has a higher melting point than aluminum metal

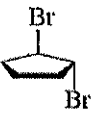
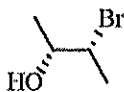
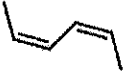


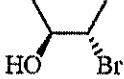




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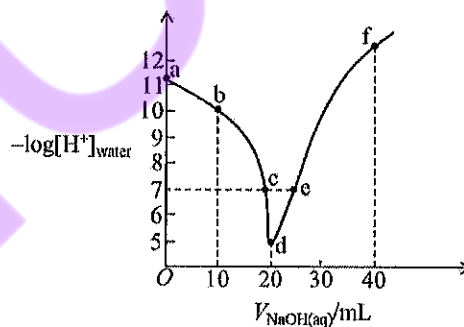
19. Which of the following pairs of compounds have identical normal boiling point?

(A)	(B)	(C)	(D)	(E)
H ₂ O				
D ₂ O				

20. What is the approximate lifting power of 16 g of helium in the atmosphere at 1 atm and 25 °C?

- (A) 13 g (B) 40 g (C) 80 g (D) 100 g (E) 120 g

21. At room temperature, 0.10 M NaOH solution is added dropwise to 20 mL of 0.10 M CH₃COOH solution. The relationship between the negative logarithm of the H⁺ concentration originating from the autoionization of water, $-\log[H^+]_{\text{water}}$, and the volume of NaOH solution added is shown in the graph on the right. Assuming that the volume change upon mixing can be neglected, which of the following statements is correct?



- (A) At point b, $[CH_3COO^-] < [CH_3COOH]$.
 (B) At points c and e, the solutions are both neutral.
 (C) At point d, the concentration of CH_3COO^- is greater than that at point e.
 (D) At point d, $[CH_3COO^-] + [CH_3COOH] = 0.05 \text{ M}$.
 (E) At point f, $[Na^+] > [CH_3COO^-] > [OH^-] > [H^+]$.

22. A 0.10 M solution of the salt BHA has a pH of 6.5 at 25 °C, where B is a weak base and A⁻ is the conjugated base of the weak acid HA. Given that the K_b value for B is 1.0×10^{-6} , what is the K_a value for HA?

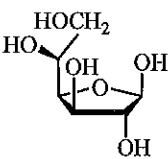
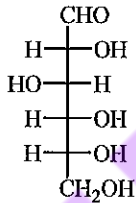
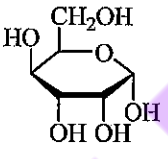
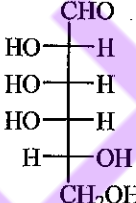
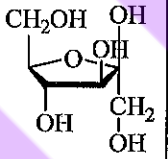
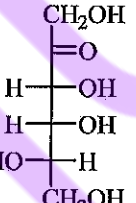
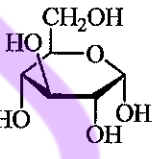
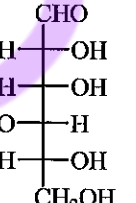
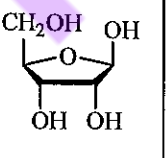
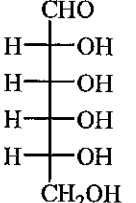
- (A) 1.0×10^{-6} (B) 2.0×10^{-6} (C) 1.0×10^{-8} (D) 1.0×10^{-5} (E) 2.0×10^{-5}

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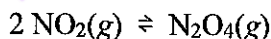
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23. The nuclide ${}^{38}_{17}\text{Cl}$ decays by β -emission with a half-life of 37.2 min. A sample of 0.80 mol of H^{38}Cl is placed in a 11.0 L closed container at 300 K, where one of the decay products is $\text{H}_2(\text{g})$. What is the pressure (atm) in the container after 74.4 min? ($R = 0.082 \text{ atm}\cdot\text{L}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$)
 (A) 1.23 (B) 1.79 (C) 2.24 (D) 2.46 (E) 3.13
24. Monosaccharides can be presented in both Haworth and Fischer projection. Which of the following pairs represents the same monosaccharide?

(A)	(B)	(C)	(D)	(E)
 	 	 	 	 

25. The standard molar free energies of formation (ΔG_f°) of $\text{NO}_2(\text{g})$ and $\text{N}_2\text{O}_4(\text{g})$ at 25 °C are 52 and 97 kJ/mol, respectively. Consider the equilibrium at 25 °C:



Which of the following statements is correct?

- (A) The reaction is endothermic at 25 °C.
 (B) ΔS° for this reaction is positive at 25 °C.
 (C) The equilibrium constant (K) is less than 1 at 25 °C.
 (D) Decreasing the temperature increases the ratio $[\text{N}_2\text{O}_4]/[\text{NO}_2]$.
 (E) The reaction is spontaneous at all temperatures.

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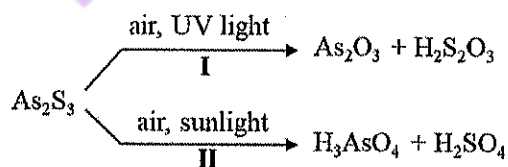
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26. The rate law for the reaction $2 \text{H}_2(\text{g}) + 2 \text{NO}(\text{g}) \rightarrow 2 \text{H}_2\text{O}(\text{g}) + \text{N}_2(\text{g})$ is $\text{rate} = k[\text{H}_2]^\alpha[\text{NO}]^\beta$, and the rates of the reaction under different conditions are as follows.

temperature	$[\text{H}_2]/\text{mol}\cdot\text{L}^{-1}$	$[\text{NO}]/\text{mol}\cdot\text{L}^{-1}$	reaction rate
T_1	0.1	0.1	r
T_1	0.2	0.2	$8r$
T_1	0.3	0.2	$12r$
T_2	0.3	0.2	$16r$

Which of the following statements is correct?

- (A) $T_2 < T_1$
 (B) $\alpha = 2, \beta = 1$
 (C) When all other conditions are held constant and only the concentrations of the four substances in the reaction system are varied, only the change in the concentration of the reactants has an effect on rate, and the effect of $[\text{NO}]$ is greater.
 (D) At T_2 , $[\text{NO}] = 0.1 \text{ mol}\cdot\text{L}^{-1}$, the reaction rate is $8r$, then $[\text{H}_2] = 0.3 \text{ mol}\cdot\text{L}^{-1}$
 (E) According to the varied reaction rates above, this is an endothermic reaction.
27. Oil painting typically involves a variety of inorganic pigments. Studies have found that under different humidity and light conditions in air, the fading of the pigment orpiment (As_2S_3) is mainly due to the following two chemical reactions (I and II):



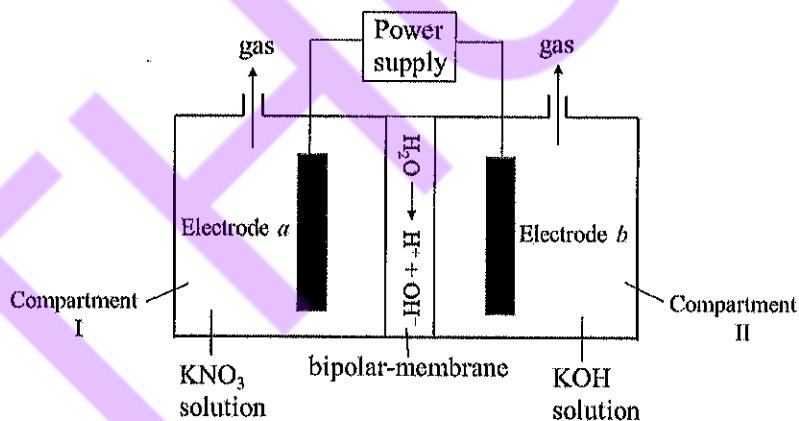
- (A) The structures of $\text{S}_2\text{O}_3^{2-}$ and SO_4^{2-} are both tetrahedral.
 (B) In both reactions I and II, the elements As and S are oxidized.
 (C) In reactions I and II, the amount of $\frac{n(\text{O}_2)}{n(\text{H}_2\text{O})}$ participating in the reaction satisfies: $\text{I} < \text{II}$.
 (D) In reactions I and II, the ratio of the number of electrons transferred when 1 mole of As_2S_3 is oxidized is 3 : 7.
 (E) The energy required for reaction I is lower than that for reaction II.

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28. A 150 g mixture of methanol and ethylene glycol is dissolved in 1.0 kg of water, producing a solution with freezing point of $-5.5\text{ }^{\circ}\text{C}$. Which of the following values is closest to the mole percent of methanol in the mixture? (K_f of water is $1.86\text{ }^{\circ}\text{C/m}$)
 (A) 10% (B) 25% (C) 30% (D) 40% (E) 55%
29. A bipolar-membrane electrolyzer is used to reduce KNO_3 to produce NH_3 , as shown in the figure below. The Faradaic efficiency for ammonia, $FE(\text{NH}_3)$, can reach 90% [Faradaic efficiency: $FE(\text{P}) = \frac{\text{electron required to form P}}{\text{electrons passed through the electrode}}$]. The Faradaic efficiency for producing other gas(es) is 50%. During operation, H_2O dissociates in the interfacial (middle) layer of the bipolar membrane to generate H^+ and OH^- , which migrate toward the two electrodes under the electric field. Which of the following statements is correct?



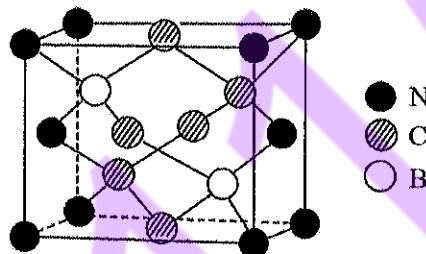
- (A) Electrode potential: the potential of electrode a is higher than that of electrode b .
 (B) The OH^- produced by water dissociation in the bipolar membrane migrates toward electrode a .
 (C) The overall reaction in compartment I is: $\text{NO}_3^- + 8\text{e}^- + 6\text{H}_2\text{O} \rightarrow \text{NH}_3 + 9\text{OH}^-$.
 (D) When 11.2 L of gas is produced at the anode (at standard conditions), 0.45 mol of NH_3 is produced at the cathode.
 (E) Hydrogen and oxygen gases are evolved from compartment II.

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30. A boron-carbon-nitrogen compound with a diamond cubic-like structure can be synthesized under high-temperature and high-pressure conditions. Its crystal structure was determined by X-ray crystallography and its unit-cell structure is shown in the figure on the right. The cubic unit-cell parameter is a pm, and N_A denotes Avogadro's constant. Which of the following statements is incorrect? (molar atomic mass (g/mol): B = 11, C = 12, N = 14)

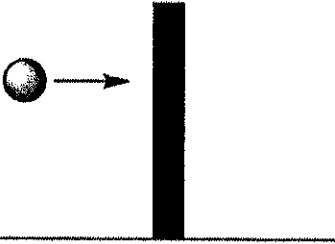


- (A) This material is a covalent compound with high hardness.
- (B) The number of boron atoms that are nearest neighbors to a given boron atom in the crystal and are at equal distances is 4.
- (C) The ratio of the number of C-C bonds to C-N bonds in the unit cell is 2:1.
- (D) The density of the unit cell is $\frac{98}{N_A \times (a \times 10^{-10})^3} \text{ g/cm}^3$.
- (E) The empirical formula of this compound is BC_2N .
31. A space probe is equipped with a large, perfectly reflecting solar sail. At the probe's location, the Sun provides an average energy flux (Poynting vector magnitude) of $S = 1500 \text{ W/m}^2$. The sail has an area $A = 1000 \text{ m}^2$, and sunlight strikes the sail at normal incidence. What is the total force exerted on the sail due to radiation pressure?
- (A) $1 \times 10^{-3} \text{ N}$ (B) $5 \times 10^{-3} \text{ N}$ (C) $1 \times 10^{-2} \text{ N}$
 (D) $3 \times 10^{-2} \text{ N}$ (E) $5 \times 10^{-2} \text{ N}$
32. A light ray enters a transparent tank filled with a liquid of refractive index $n_L = 1.5$. At the bottom of the tank lies a thick glass slab with refractive index $n_G = 1.8$. The ray enters the liquid from air ($n = 1.0$) at an angle of incidence $\theta = 60^\circ$. What is the range of the angle of refraction θ_r inside the glass slab?
- (A) $0^\circ < \theta_r < 15^\circ$ (B) $15^\circ < \theta_r < 30^\circ$ (C) $30^\circ < \theta_r < 45^\circ$
 (D) $45^\circ < \theta_r < 60^\circ$ (E) $60^\circ < \theta_r < 75^\circ$

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33. An engineer is calibrating an acoustic sensor on the surface of Mars. The Martian atmosphere is primarily composed of carbon dioxide, whereas Earth's atmosphere consists mainly of dinitrogen and dioxygen. Sound waves propagate as rapid compressions and rarefactions under conditions where heat transfer is negligible (i.e., adiabatic propagation). If the engineer compares a sample of Martian air with a sample of Earth air at the same temperature, which of the following is the dominant factor explaining why the speed of sound is lower on Mars?
- (A) CO_2 has a higher molar mass than N_2 or O_2 .
(B) CO_2 has a higher heat capacity ratio (C_P/C_V) due to more degrees of freedom.
(C) The Martian atmosphere is thinner, and the lower pressure P reduces the bulk modulus.
(D) The heat conduction of CO_2 is much poorer than that of N_2 or O_2 for the same temperature.
(E) The gravity on Mars is lower than that on Earth.
34. The depth of a dam is 200.0 m. What is the pressure (atm) at its bottom? ($1.01 \times 10^5 \text{ N/m}^2 = 1 \text{ atm}$.)
- (A) 2.6 (B) 9.8 (C) 20.4 (D) 200.0 (E) 19600.0
35. John is attempting to knock over a heavy wooden target that is hinged at its base. He is given two balls of equal mass. Ball A is made of sticky clay, and Ball B is made of highly elastic rubber. He throws both balls toward the target with the same initial speed v . Ball A: Strikes the target and sticks to it (does not bounce). Ball B: Strikes the target and rebounds with approximately the same speed v . Assuming the collision times are approximately equal, which ball is more likely to knock the target over, and why?
- 
- (A) Ball A, because it transfers all its kinetic energy to the target.
(B) Ball B, because it undergoes a larger change in momentum.
(C) Both are equally likely because they have the same mass and initial velocity.
(D) Ball A, because the collision time is shorter.
(E) Ball B, but only if the target is made of metal.

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36. A laboratory is testing a pneumatic actuator containing n moles of a monatomic ideal gas. The gas initially has state variables (P_0, V_0, T_0) . During a test cycle, the gas is compressed to exactly half its original volume. The engineers perform this compression using two different thermodynamic paths: (i) the isothermal process and (ii) an adiabatic process. Which of the following statements is correct?
- (A) The work done during the isothermal process is greater than the adiabatic process.
- (B) No work is done during the isothermal process.
- (C) The change in internal energy is zero for the isothermal process.
- (D) The temperature of the gas decreases during the adiabatic process.
- (E) The final temperature after the adiabatic compression is lower than after the isothermal compression.
37. A parallel-plate capacitor is connected to an ideal battery that maintains a constant voltage V . A dielectric slab initially completely fills the space between the plates. An engineer slowly pulls the slab out at constant speed while the battery remains connected. Which of the following correctly describes the work done by the engineer (W_{ext}) and the change in the electrostatic energy stored in the capacitor (ΔU)?
- (A) W_{ext} is positive and ΔU is positive.
- (B) W_{ext} is positive and ΔU is negative.
- (C) W_{ext} is negative and ΔU is positive.
- (D) $W_{\text{ext}} = 0$ and ΔU is negative.
- (E) $W_{\text{ext}} = 0$ and ΔU is positive.
38. X-ray imaging relies on the fact that different biological tissues have distinct attenuation coefficients (μ). An X-ray beam with an initial intensity I_0 passes through a bone of thickness x and attenuation coefficient μ , emerging with intensity $I = I_0 e^{-\mu x}$. If the same X-ray beam instead passes through another tissue of the same thickness but with half the attenuation coefficient ($\mu' = \mu/2$), what is the resulting intensity I' ?
- (A) $I' = I/2$ (B) $I' = I$ (C) $I' = I^2/I_0$
- (D) $I' = \sqrt{I \cdot I_0}$ (E) $I' = \sqrt{\frac{I}{I_0}}$

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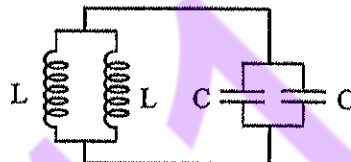
39. To visualize a virus with a diameter of approximately 20 nm, a researcher uses a transmission electron microscope. Electrons are accelerated from rest through a potential difference V , acquiring a non-relativistic kinetic energy $K = eV$. According to the de Broglie relation, how do the electron wavelength and the microscope's resolution change if the accelerating voltage is increased to four times its original value?
- (A) The wavelength doubles; resolution becomes worse.
(B) The wavelength is halved; resolution becomes better.
(C) The wavelength decreases by a factor of 4; resolution becomes better.
(D) The wavelength increases by a factor of $\sqrt{2}$; resolution becomes worse.
(E) The wavelength decreases by a factor of 2; the resolution decreases by a factor of 2.
40. A rigid container holds a mixture of two non-reacting ideal gases: 1.0 mole of He and 2.0 moles of N_2 . The temperature of the mixture is maintained at 27 °C. Let R denote the universal gas constant. What is the constant-volume molar specific heat C_V of the gas mixture? (Assume all degrees of freedom appropriate at room temperature are active.)
- (A) $3R/2$ (B) $13R/6$ (C) $5R/2$ (D) $3R$ (E) $7R/2$
41. A nonrelativistic charged particle (speed $\ll c$) with mass m and charge $+q$ moves with velocity \vec{v} in a uniform magnetic field \vec{B} . Which of the following statement is correct?
- (A) Regardless of the direction of \vec{v} , the magnetic field does no work on the charged particle.
(B) Regardless of the direction of \vec{v} , the magnetic force on the particle has magnitude qvB .
(C) If \vec{v} is parallel to \vec{B} , the particle experiences an acceleration due to the magnetic field.
(D) If \vec{v} is perpendicular to \vec{B} , the particle undergoes circular motion with radius $r = \frac{mv}{2qB}$.
(E) If \vec{v} is perpendicular to \vec{B} , the magnitude of \vec{v} changes due to the magnetic force.

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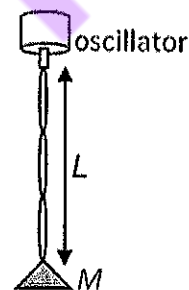
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42. A circuit consists of a single inductor L and a single capacitor C , with natural angular frequency ω_0 . A new circuit is constructed by connecting two identical inductors (each of inductance L) in parallel and two identical capacitors (each of capacitance C) in parallel, as shown on the right. What is the natural angular frequency of the new circuit?



- (A) $\frac{\omega_0}{\sqrt{2}}$ (B) ω_0 (C) $\sqrt{2}\omega_0$ (D) $2\omega_0$ (E) $4\omega_0$
43. A string of length $L = 0.75$ m is fixed at both ends and vibrates in a standing-wave pattern at a frequency of 100 Hz. A mass of 1.02 kg is attached to one end, providing the tension in the string. The standing-wave pattern shows three loops as shown on the right. Use $g = 9.8$ m/s². What is the linear mass density of the string?

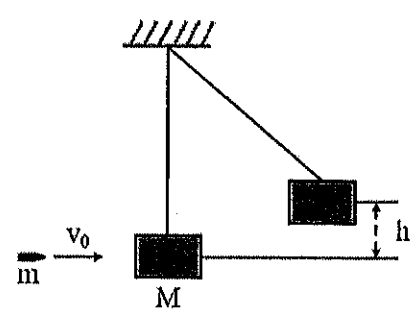


- (A) 8.0×10^{-4} kg/m (B) 1.6×10^{-3} kg/m
(C) 4.0×10^{-3} kg/m (D) 2.0×10^{-2} kg/m (E) 8.0×10^{-2} kg/m
44. In a single-slit diffraction experiment, monochromatic light of wavelength λ passes through a slit of width a , producing a diffraction pattern on a distant screen. Which of the following statements is correct?
- (A) If the width of the slit changes, the diffraction pattern does not change.
(B) If the wavelength of the light changes, the diffraction pattern does not change.
(C) The diffraction pattern is dark at the center of the screen.
(D) If the slit width is doubled and the wavelength is also doubled, the positions of the dark fringes remain the same.
(E) The width of the central maximum is proportional to the slit width a .
45. A particle moves along the x -axis under the influence of a potential energy function $U(x) = x^4 - 8x^2$. Which of the following values of x correspond to positions of stable equilibrium?
- (A) $x = 0$ (B) $x = +2$ (C) $x = -2$
(D) $x = +2$ and $x = -2$ (E) $x = 0$, $x = +2$, and $x = -2$

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46. A deuteron has the same charge as a proton ($q_d = q_p$), but twice the mass ($m_d = 2m_p$). Both particles move in circular paths in a plane perpendicular to a uniform magnetic field. The radius of the deuteron's circular path is twice that of the proton ($r_d = 2r_p$). Which of the following statements is correct?
- (A) The relation between their angular momentum L_d/L_p is 2.
 (B) The relation between their acceleration is a_d/a_p is 2.
 (C) The relation between their angular speed is $\omega_d/\omega_p = 2$.
 (D) The relation between their tangential speed is v_d/v_p is 2.
 (E) The relation between their period of the circular motion is T_d/T_p is 2.
47. A planet orbits a star in an elliptical path under a central gravitational force. The length of the major axis of the ellipse is 5 (in arbitrary units), and the length of the minor axis is 4. The star is located at one focus of the ellipse. What is the ratio of the planet's maximum speed to its minimum speed?
- (A) 1:1 (B) 2:1 (C) 3:1 (D) 4:1 (E) 5:1
48. A bullet of mass m moving horizontally with initial speed v_0 strikes a stationary block of mass M that is suspended from the ceiling by a light string, forming a pendulum. The bullet becomes embedded in the block immediately upon impact, and the combined object swings upward to a maximum vertical rise of h as shown on the right. Air resistance is negligible. Which of the following statements is correct?
- 
- (A) The collision between the bullet and the block is elastic.
 (B) The mechanical energy of the entire process is conserved.
 (C) The linear momentum of the block is conserved during the entire process.
 (D) The maximum height is $h = \frac{v_0^2}{2g}$.
 (E) The mechanical energy lost during the collision is $\frac{mM}{2(m+M)} v_0^2$.

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49. Estimate the typical (order-of-magnitude) speed of air molecules (eg. N_2 or O_2) under ambient conditions (approximately $20^\circ C$ and 1 atm).
(A) Nearly at rest
(B) A few micrometers per second
(C) Several meters per second
(D) A few hundred meters per second
(E) Several kilometers per second
50. A Carnot cycle is an ideal thermodynamic cycle that consists of two isothermal processes exchanging heat with reservoirs and two adiabatic processes. For the Carnot cycle, which of the following statements is true?
(A) The entropy of the reservoir does not change during the cycle.
(B) Work is performed only during the adiabatic processes.
(C) All of the heat absorbed from the hot reservoir is converted into work.
(D) The entropy of the universe increases during one complete cycle.
(E) The thermal efficiency does not depend on the volume of the Carnot engine.
51. Two people, A and B, each of mass 70 kg, are inside an elevator. Person A stands on the floor, while person B hangs from a light rope attached to the ceiling. Let \vec{F}_F be the force exerted on A by the floor, and \vec{F}_R be the force exerted on B by the rope. Which of the following statements is correct?
(A) $\vec{F}_F = \vec{F}_R$ (B) $\vec{F}_F = 2\vec{F}_R$ (C) $\vec{F}_F = -\vec{F}_R$
(D) $\vec{F}_F = -2\vec{F}_R$ (E) $\vec{F}_F > \vec{F}_R$
52. A particle of extremely small mass m is confined in a one-dimensional infinite potential well (box) of width L . Its quantum mechanical nature must be taken into account. Which of the following statements is correct?
(A) The ground state energy of the particle is zero.
(B) The allowed wavenumbers depend on the particle's mass.
(C) The allowed energy states of the particle are multiples of the ground state energy.
(D) The allowed wavelengths of the particle are multiples of the wavelength of the ground state.
(E) The allowed wavenumbers of the particle are multiples of the wavenumber of the

ground state.

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53. A cylindrical tube of length 17.0 cm is closed at one end and open at the other.

Assuming the speed of sound in air is $v = 340$ m/s, what are the lowest two resonance frequencies of the tube?

- (A) 250 Hz and 500 Hz (B) 250 Hz and 750 Hz (C) 500 Hz and 1000 Hz
(D) 500 Hz and 1500 Hz (E) 1000 Hz and 2000 Hz

54. A uniform rod of mass M and length L is pivoted at one end and allowed to swing freely under gravity. For small-angle oscillations, what is the period T of the motion? (Assume gravitational acceleration is g and neglect air resistance.)

- (A) $T = 2\pi\sqrt{\frac{2L}{g}}$ (B) $T = 2\pi\sqrt{\frac{3L}{2g}}$ (C) $T = 2\pi\sqrt{\frac{L}{g}}$
(D) $T = 2\pi\sqrt{\frac{2L}{3g}}$ (E) $T = 2\pi\sqrt{\frac{L}{3g}}$

55. Two copper wires are connected in parallel. Both wires have the same resistivity, $\rho \approx 2.0 \times 10^{-8} \Omega \cdot \text{m}$.

Wire A has length 200 m and cross-sectional area 1.0 mm^2 .

Wire B has length 300 m and cross-sectional area 0.5 mm^2 .

What is the equivalent resistance of the two-wire combination?

- (A) 2.0Ω (B) 3.0Ω (C) 4.0Ω (D) 8.0Ω (E) 12.0Ω

56. A soap film (refractive index of $n \approx 1.35$) is surrounded by air and illuminated by normally incident monochromatic light of wavelength 540 nm (in air). What is the minimum film thickness required to produce constructive interference in the reflected light?

- (A) 50 nm (B) 75 nm (C) 100 nm (D) 200 nm (E) 300 nm

57. An electric kettle with resistance 12Ω is connected to a 110 V (rms), 60 Hz AC power supply. The kettle is used to heat 1.0 L of water. Assuming all electrical energy is converted into heat, approximately how long will it take to raise the water temperature by 1°C ? The specific heat of water is about $4.2 \frac{\text{J}}{\text{g}^\circ\text{C}}$.

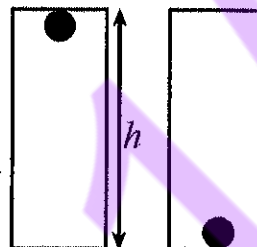
- (A) about 2 s (B) about 4 s (C) about 6 s (D) about 8 s (E) about 10 s

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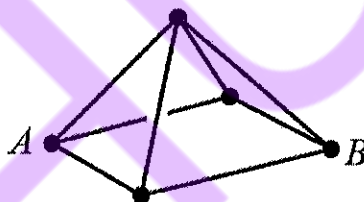
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58. An elevator starts from rest and accelerates upward with constant acceleration $a = 2g$. A small ball is released from rest relative to the elevator at a height h above the floor. The ball then falls and strikes the floor. What is the speed of the ball just before it hits the floor, as measured in the ground frame?



- (A) $\sqrt{\frac{2}{3}gh}$ (B) $\sqrt{2gh}$ (C) $\sqrt{3gh}$ (D) $\sqrt{6gh}$ (E) $3\sqrt{gh}$
59. Eight resistors of equal length, each of resistance R , are connected along the edges of a regular square pyramid: four resistors form the square base, and four resistors connect each base vertex to the apex as shown below. What is the equivalent resistance between point A and B of the square base?



- (A) $\frac{1}{3}R$ (B) $\frac{2}{3}R$ (C) R (D) $\frac{4}{3}R$ (E) $2R$
60. A microscope has an objective lens with an aperture diameter of 2.6 mm and a focal length of 5.0 mm. The sample is illuminated with monochromatic light of wavelength 520 nm. Considering the diffraction limit, which of the following is closest to the minimum resolvable distance between two points?
- (A) 0.4 μm (B) 0.5 μm (C) 0.8 μm (D) 1.2 μm (E) 2.0 μm