

5. In a hydrogen atom, how many unique sets of four quantum numbers,  $n$ ,  $\ell$ ,  $m_\ell$  and  $m_s$  can an electron have when  $n = 3$  and  $m_\ell = 2$ ?

A. 6

B. 1

C. 2

D. 4

E. 3

ℓ s p d f  
1 2 3 4  
↑  
3  $m_\ell = 2$   
3s 3p not d

6. Which of the following statements about electrons is INCORRECT?

☒ A. Electrons can never be ejected from a metal surface by the absorption of light.

☒ B. Increasing the speed of an electron decreases its wavelength.

☒ C. An electron's position and momentum cannot be known accurately at the same time.

☐ D. An electron has a smaller mass than a neutron.

☐ E. An electron that is, on average, closer to the nucleus of a hydrogen atom is lower in energy than an electron that is, on average, further away from the nucleus.

7. Which of the following statements about a ground state yttrium (Y) atom is INCORRECT?

☒ A. There are 18 electrons with principal quantum number  $n = 3$ .

☐ B. There are 18 electrons with angular momentum quantum number  $\ell = 1$ .

☐ C. There are 4 electrons with magnetic quantum number  $m_\ell = -2$ .

☐ D. There are at least 19 electrons with spin quantum number  $m_s = -1/2$ .

☒ E. There are 10 s-electrons.

ℓ  
[Kr] 5s<sup>2</sup> 4d<sup>1</sup>  
↑  
1s<sup>2</sup> 2s<sup>2</sup> 2p<sup>6</sup> 3s<sup>2</sup> 3p<sup>6</sup> 4s<sup>2</sup> 3d<sup>10</sup>  
4p<sup>6</sup>  
39

Ga [Ar] 4s<sup>2</sup> 3d<sup>10</sup> 4p<sup>1</sup>

8. The correct condensed electron configuration of the gallium (I) ion ( $\text{Ga}^+$ ) is:

A. [Ar] 4s<sup>2</sup> 3d<sup>10</sup>    B. [Kr] 4s<sup>2</sup> 3d<sup>10</sup>    C. [Kr] 4s<sup>2</sup> 3d<sup>10</sup> 4p<sup>1</sup>    D. [Ar] 4s<sup>2</sup> 3d<sup>10</sup> 4p<sup>1</sup>    E. [Ar] 4s<sup>1</sup> 3d<sup>10</sup> 4p<sup>1</sup>

9. Which of the following statements is INCORRECT?

☒ A. When a cation (positive ion) is formed from a neutral atom, electrons are removed first from the occupied orbital having the highest principal quantum number.

☐ B. The attraction between opposite electrical charges depends on the magnitudes of the charges and the distance between them.

☒ C. A valence electron is attracted to the nucleus and repelled by the core electrons.

☐ D. Effective nuclear charge decreases from left to right across the first row of the periodic table.

☐ E. Electrons in 3d orbitals strongly shield electrons in 4d orbitals from the charge of the nucleus.

1. Which of the following pairs of ions is a pair of isoelectronic ions?

A.  $\text{Ca}^{2+}$  and  $\text{Sc}^{2+}$

B.  $\text{P}^{3-}$  and  $\text{S}^{3-}$

C.  $\text{Ga}^{3+}$  and  $\text{Cu}^{+}$

D.  $\text{Si}^{4-}$  and  $\text{Sn}^{4+}$

E.  $\text{O}^{2-}$  and  $\text{Mg}^{+}$

2. Which of the following ions has the following electron configuration.  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 4s^1$

A.  $\text{Fe}^{+2}$

B.  $\text{Mn}^{+}$

C.  $\text{Ni}^{2+}$

D.  $\text{Cr}^{3+}$

E.  $\text{Cr}^{4+}$

$[\text{Ar}] 4s^1 3d^5$   
 $4s^2 3d^5$

3. Which of the following ions has the ground state electron configuration with the MOST unpaired electrons?

A.  $\text{Sc}^{2+}$

B.  $\text{P}^{+}$

C.  $\text{I}^{+}$

D.  $\text{Co}^{3+}$

E.  $\text{Fe}^{3+}$

$\text{Co } [\text{Ar}] 4s^2 3d^6$

$\uparrow \uparrow \uparrow \uparrow \uparrow$

$\text{Fe } 4s^2 3d^5$

$[\text{Ar}] 4s^2 3d^1$   $\text{P } 3s^2 3p^2$   $\text{I } [\text{Kr}] 5s^2 4d^{10} 5p^4$

4. If  $A > B$  means that the ionization energy of A is greater than the ionization energy of B then which of the following is INCORRECT?

A.  $\text{Cl} > \text{Cl}^{-}$

B.  $\text{Na}^{+} > \text{Na}$

C.  $\text{O} > \text{N}$

D.  $\text{P} > \text{As}$

E.  $\text{Mg}^{2+} > \text{Mg}^{+}$

11. In which one of the following molecules or ions does the Lewis structure contain a double bond?

A.  $\text{H}_2\text{NNH}_2$

B.  $\text{PH}_4^{+}$

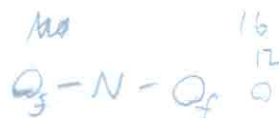
C.  $\text{C}_2\text{H}_6$

D.  $\text{OF}_2$

E.  $\text{NO}_2^{+}$

14  
4

5  
9  
4



15. Which of the following molecules has the bond or bonds that are the most polar?

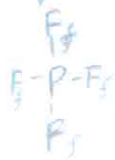
A.  $\text{PF}_4^{+}$

B.  $\text{SF}_4$

C.  $\text{N}_3^{-}$

D.  $\text{BBr}_3$

E.  $\text{SO}_2$



16. How many resonance structures of equal energy are possible for  $(\text{SFO}_3)^{-}$ ? (The central atom is S.)

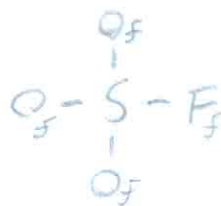
A. 1

B. 2

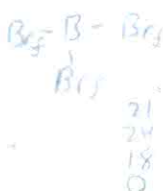
C. 3

D. 4

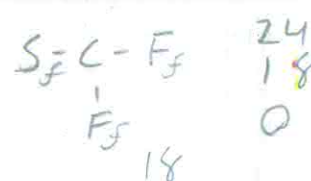
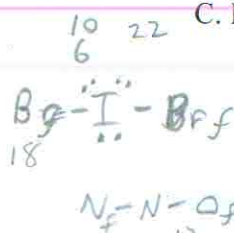
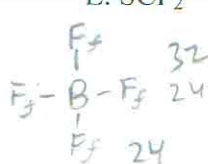
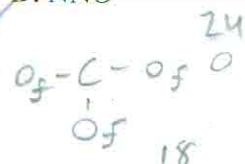
E. 5



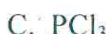
32  
8



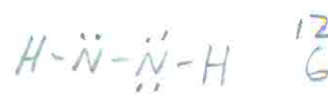
1. For which one of the following molecules or ions does the best Lewis structure (i.e. lowest and fewest formal charges) have the most non-bonding electrons?



Consider the following five substances and then answer questions 18 and 19.



18. Which substance consists of linear molecules?

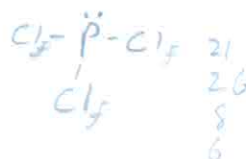
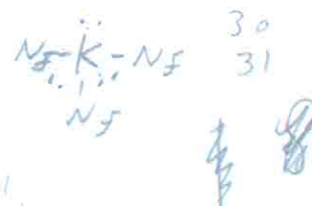
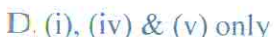
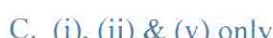


19. Which substance exhibits hydrogen bonding?

20. Consider the following set of molecules:



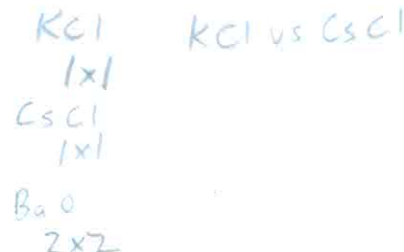
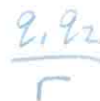
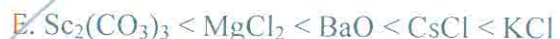
Which substance(s) consist of molecules that have all atoms in the same plane?



21. The orbital hybridization at nitrogen in  $\text{HNNH}$  is ?

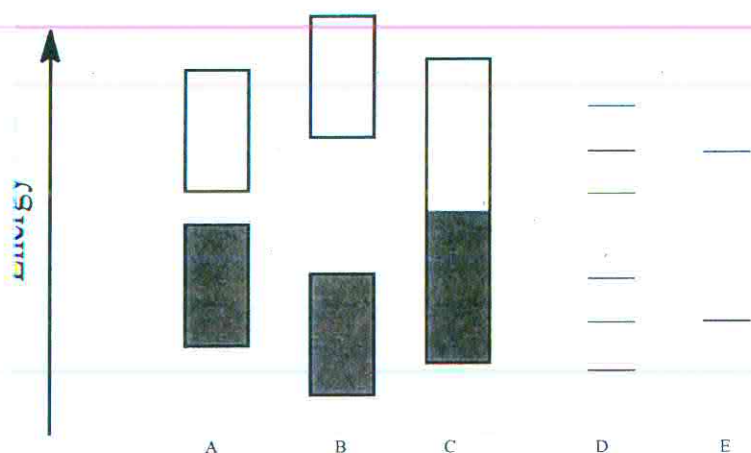


22. Which selection lists the compounds in order of increasing lattice energy (i.e. smallest to largest)?





Answer questions 23, 24 and 25 using the molecular orbital energy diagrams shown.



23. Which diagram represents the orbital energy diagram for describing the bonding in  $H_2$ ?

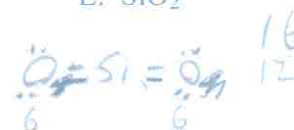
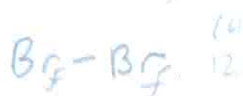
✓ 24. Which diagram represents the orbital energy diagram for describing the bonding in AsGa?

25. Which diagram represents the orbital energy diagram for describing bonding in diamond?

26. Which of the following compounds should have the highest melting point?



✓ 27. For which of the following substances are the physical properties such as melting point and boiling point due to dispersion forces alone?

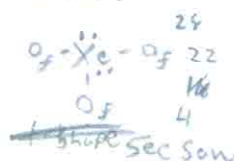
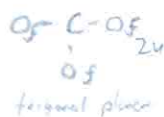
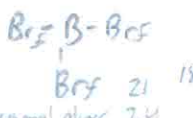
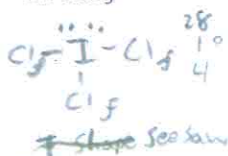
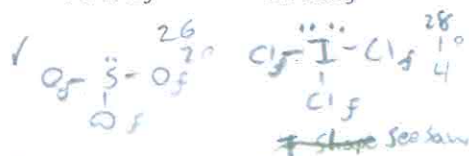


28. If each individual oblong shape is a molecule, which type of phase does this drawing best depict?

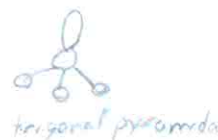


- A. Solid.
- B. Nematic liquid crystal.
- C. Smectic liquid crystal.
- D. Cholesteric liquid crystal
- E. Normal liquid

29. Which of the following molecules or ions adopts a trigonal pyramidal molecular structure?



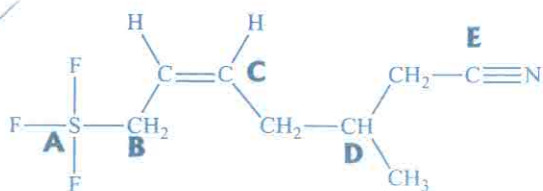
4 tetrahedral



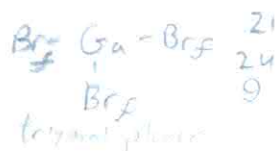
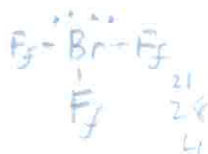
30. Which of the following represents the highest energy form of sodium & chlorine?

- A.  $\text{NaCl(s)}$
- B.  $\text{Na}^+(\text{g}) + \text{Cl}^-(\text{g})$
- C.  $\text{Na(g)} + \text{Cl(g)}$
- D.  $\text{Na(g)} + \text{Cl}^-(\text{g})$
- E.  $\text{Na}^+(\text{g}) + \text{e}^- + \text{Cl(g)}$

31. Which of the labelled centres in the molecule shown is  $sp^2$  hybridized?



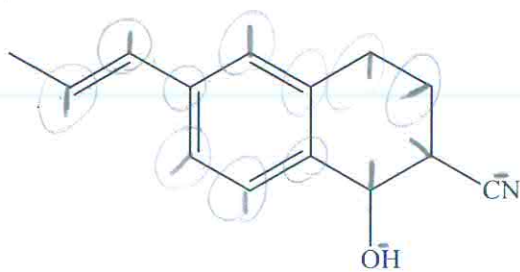
32. The structure shown at the right is a representation of which molecule?



1. Hydrogen bonding occurs in:

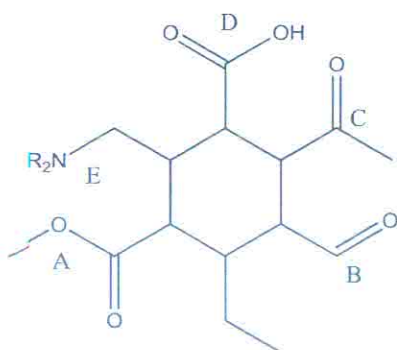
- A)  $\text{BH}_3$     B)  $\text{SiH}_4$     C)  $\text{AsH}_3$     D)  $\text{SH}_2$     E)  $\text{FH}$

1. How many  $sp^2$  hybridized atoms are present in the structure below?



- A. 6    B. 7    C. 8    D. 9    E. 10

Answer questions 35-37 referring to the compound below:

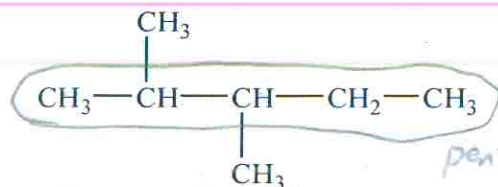


✓ 35. Which is the carboxylic acid group?

✓ 36. Which is the ester group?

✓ 37. Which is the aldehyde group?

38. The correct name for the compound below is:

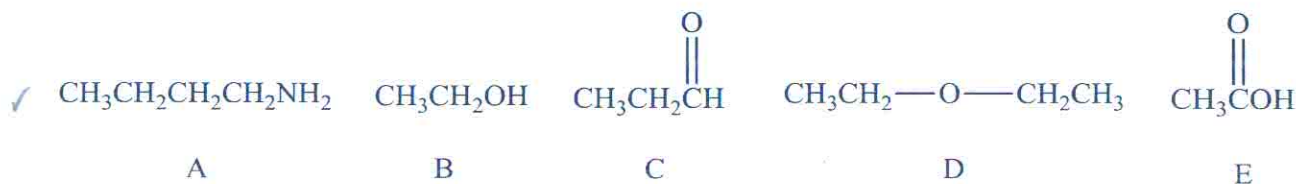


pentane

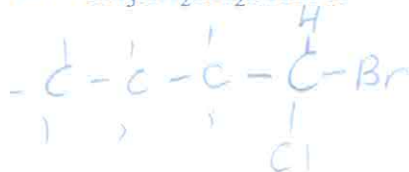
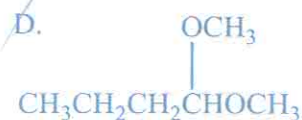
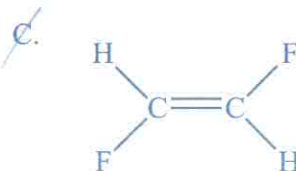
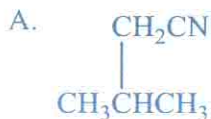
2,3 dimethylpentane

- A. 2-isopropylbutane  
 B. 3,4-dimethylpentane  
 C. ~~trans-2,3-dimethylpentane~~  
 D. 2,3-dimethylpentane  
 E. 2-ethyl-3-methylbutane

39. Which one of the following compounds forms an amide on reaction with an amine?



40. Which of the following molecules exhibit(s) the property of chirality?

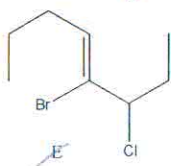
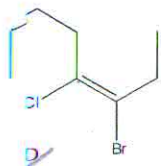
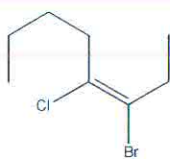
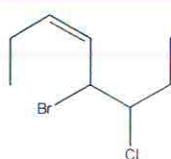
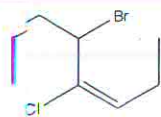


41. Which of the following drawings is *cis*-5-bromo-6-chloro-3-octene?

A

B

C



42. Consider the decomposition of hydrogen peroxide to give water and oxygen ( $O_2$ ).



Using data from the DATA sheet, calculate (estimate) the enthalpy change (heat change) for this reaction. The answer is: (in  $kJ\ mol^{-1}$ )

A. 349

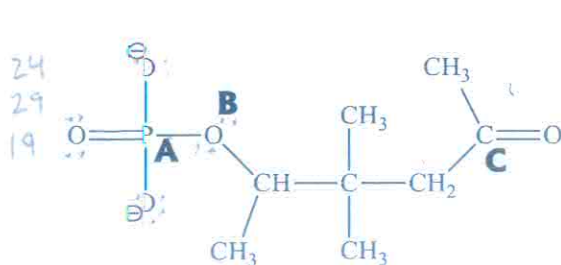
B. -349

C. 102

D. -102

E. 0.0

Consider the molecule below and answer questions 43 – 45 (Note: This is not a complete Lewis structure. Not all electrons are shown.)



43. What is the approximate O-P-O bond angle at the phosphorus atom labeled A?

A.  $90^\circ$

B.  $180^\circ$

C.  $80^\circ$

D.  $120^\circ$

E.  $109^\circ$

44. How many lone pairs are there at the oxygen atom labeled B?

A. 0

B. 1

C. 2

D. 3

E. 4

45. What is the orbital hybridization at the carbon atom labeled C?

A.  $sp$

B.  $sp^2$

C.  $sp^3$

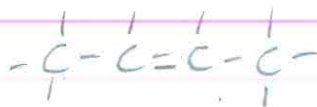
D. no hybridization

E. not enough information to determine



46. The reaction of 2-butene with water (in the presence of an acid catalyst) is best described as:

- A. condensation
- B. nitration
- C. dehydration
- D. addition
- E. halogenation



47. The products of the reaction of acetic acid ( $\text{CH}_3\text{COOH}$ ) with methanol ( $\text{CH}_3\text{OH}$ ) are :

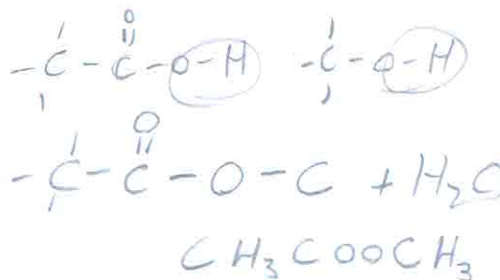
~~A.~~  $\text{CH}_4$  and  $\text{H}_2\text{O}$

B.  $\text{CH}_3\text{CH}_3$  and  $\text{H}_2\text{O}$

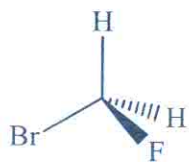
C.  $\text{CH}_3\text{C}(=\text{O})\text{OCH}_3$  and  $\text{H}_2\text{O}$

✓ D.  $\text{CH}_3\text{CH}_2\text{OH}$  and  $\text{H}_2\text{O}$

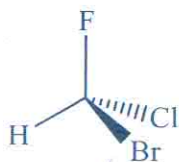
~~E.~~  $\text{CO}_2$  and  $\text{H}_2\text{O}$



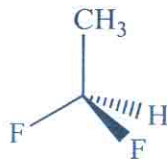
48. Which of the following molecules is/are chiral?



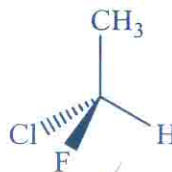
(i)



(ii)



(iii)



(iv)

- A. all are chiral
- B. none are chiral
- C. (i), (ii) and (iv)
- D. (ii) and (iv)
- E. (ii), (iii) and (iv)

49. Which of the following substances is an n-type semiconductor?

~~A.~~ GaSi

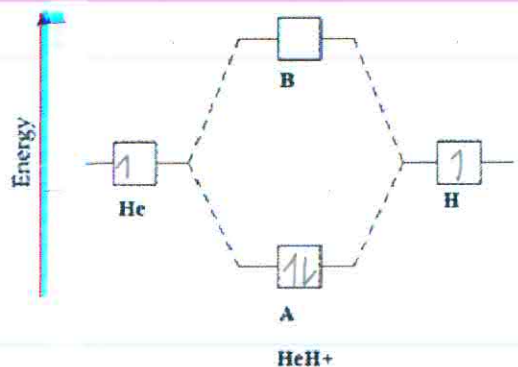
✓ B. Si doped with Ga

C. Ge doped with As

D. Ge doped with In

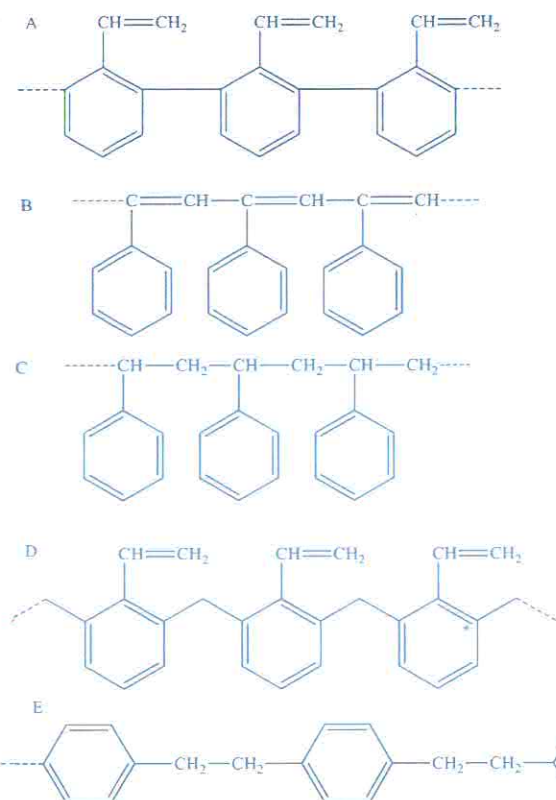
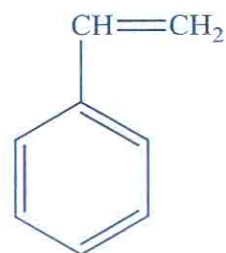
~~E.~~ SiGe

50. Use the following incomplete MO energy diagram to determine the bond order in the  $\text{HHe}^+$  ion.



- A. 0.25    B. 0.5    C. 0.75    D. 1    E. 1.5

51. The structure of the styrene molecule is shown at the right. From the selection of polymer structures given below, pick the one that correctly represents the molecular structure of polystyrene.



52. The compound  $C_3H_6ClF$  has how many structural (constitutional) isomers (*i.e.* NOT counting enantiomers)?

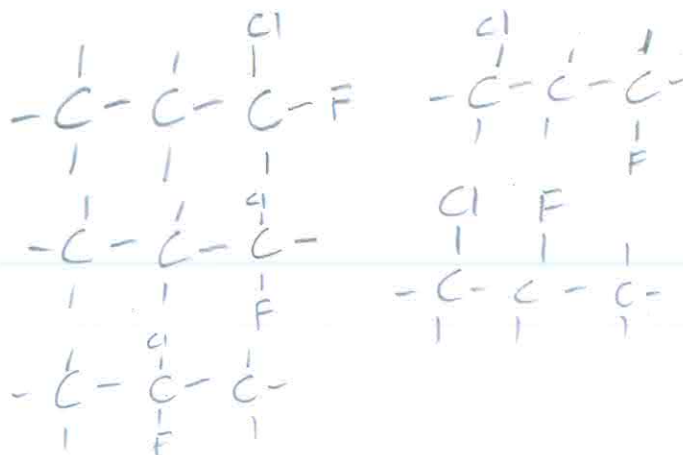
A. 3

B. 4

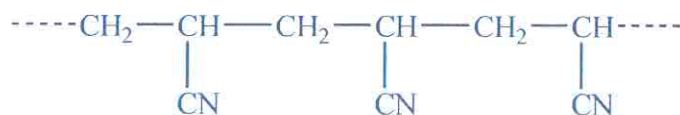
C. 5

D. 6

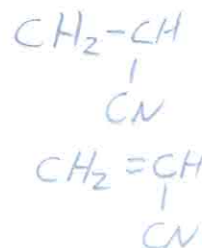
E. 7



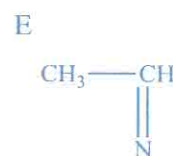
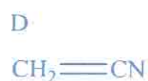
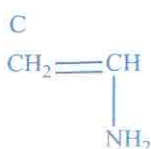
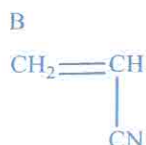
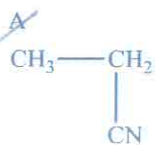
53. Polyacrylonitrile is an addition polymer used in making furniture and clothing as well as many other items. Its molecular structure is represented below.



Polyacrylonitrile



Which of the following structures is the monomer from which polyacrylonitrile is made?



54. A certain solid is moderately hard and has a high melting point. The solid conducts electricity. What class of solid is this substance?

A. polymer

B. ionic

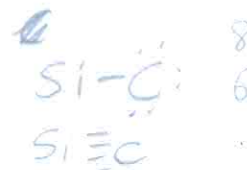
C. metallic

D. molecular

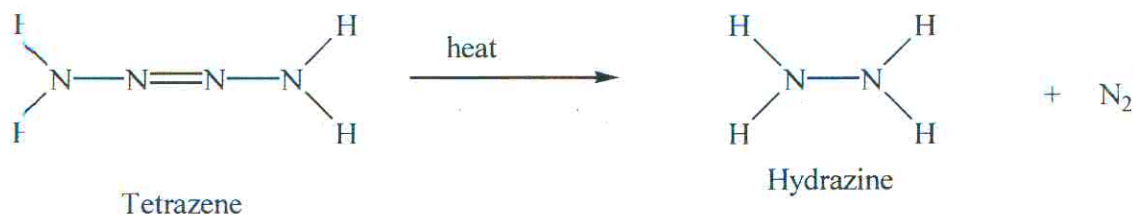
E. covalent network

55. Which identification is INCORRECT for the following substances?

- A. SiC is a covalent-network solid
- B.  $\text{Li}_2\text{CO}_3$  is an ionic liquid
- ~~C.~~ Table sugar (sucrose) is a molecular solid
- ~~D.~~ Diamond is a covalent-network solid
- ~~E.~~ Sodium is a metallic solid



5. Tetrazene decomposes above 0°C to form hydrazine and nitrogen gas. Use the average bond energies from the data sheet and those given here to calculate the enthalpy change for this reaction in kJ mol<sup>-1</sup>. (The bond energy for N=N is 409 kJ/mol and for N-H is 388 kJ/mol.)



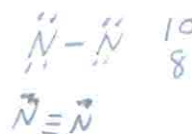
- A. +373      B. -163      C. 163      D. -572      E. -373

✓ Break

$$\begin{array}{rcl}
 2 \text{ N-N} & 326 & \\
 1 \text{ N=N} & 409 & \\
 & 735 &
 \end{array}$$

Form

$$\begin{array}{rcl}
 1 \text{ N-N} & & \\
 1 \text{ N}\equiv\text{N} & & \\
 & 1105 &
 \end{array}$$



5. The compounds Br<sub>2</sub> and ICl have the **same number of electrons**, yet Br<sub>2</sub> melts at -7.2°C and boils at 59.5°C while ICl melts at 27.2 °C and boils at 97.4 °C. Explain briefly this difference. That is, explain why ICl both melts and boils at temperatures above the corresponding ones for Br<sub>2</sub>.

- ✓
- A. Br<sub>2</sub> has both dispersion forces and dipole-dipole forces, whereas ICl has only dispersion forces.  
 B. Br<sub>2</sub> molecules are linear whereas ICl molecules get wound around each other.  
 C. ICl has both dispersion forces and dipole-dipole forces, whereas Br<sub>2</sub> has only dispersion forces.  
 D. ICl has hydrogen bonding and dispersion forces, whereas Br<sub>2</sub> has only dispersion forces.  
 E. It would be a cosmic coincidence if they had the same melting and boiling points.



58. Consider the following reaction.

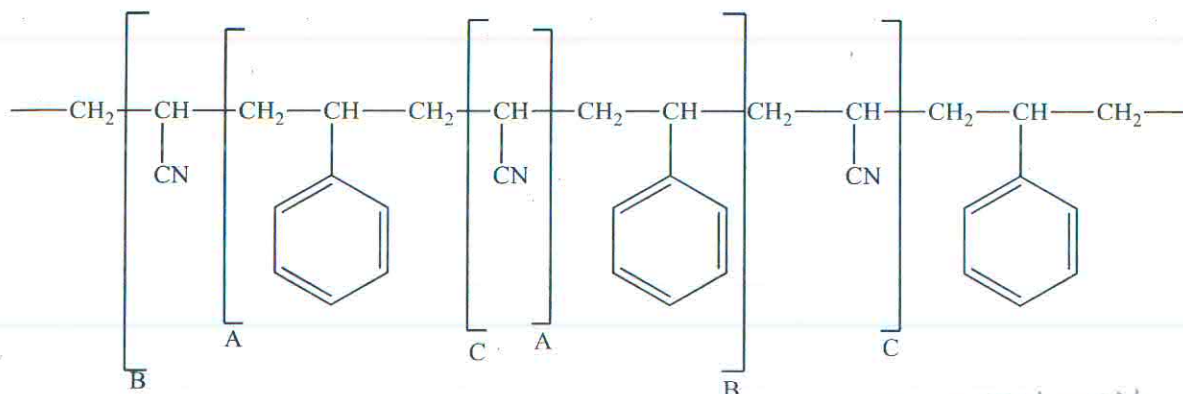


The missing reactant represented by the question mark (?) is...

- A. H<sub>2</sub>O      B. H<sub>2</sub>      C. HF      D. HOOH      E. CH<sub>4</sub>



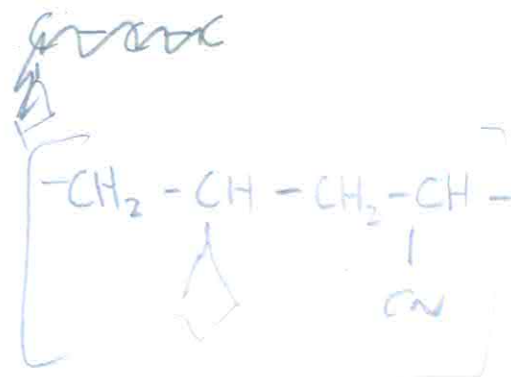
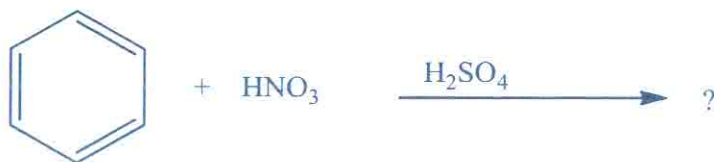
59. Which set of square brackets correctly defines the repeating unit of the copolymer whose structure is shown? (It is made from styrene (question 51) and acrylonitrile (question 53).)



- A. Set of brackets A does.  
 B. Set of brackets B does.  
 C. Set of brackets C does.  
 D. None of these sets of brackets correctly define the repeating unit.  
 E. All of these sets of brackets correctly define the repeating unit.



60. Consider the following substitution reaction with benzene.

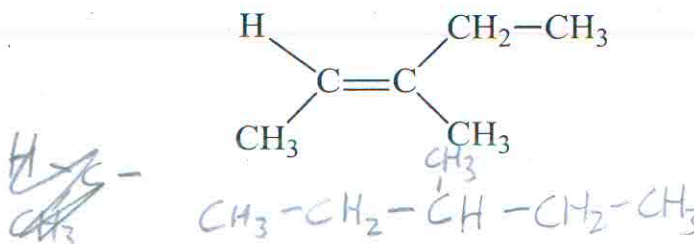


The correct organic product of this reaction is...?

- A.  $\text{NO}_2$   
 B.  $\text{NO}_2$   
 C.  $\text{NO}_2$   
 D.  $\text{SO}_3\text{H}$   
 E.  $\text{SO}_3\text{H}$

61. Addition of  $H_2$  to *cis*-3-methyl-2-pentene (structure shown) (with the help of a catalyst such as Ni) produces ...

- A 4-methylpentane
- E 3-methylpentane
- C 3-ethylbutane
- F 2-ethylbutane
- E 2-methylpentane



62. Consider doping the semiconducting material silicon (Si). Addition of a very small amount of which element would make the silicon a better electrical conductor?

- A) Gallium (Ga)
- B) Phosphorus (P)
- C) Arsenic (As)
- D) Indium (In)
- E) Any of the above

For questions 63 to 67, enter the correct letter (A, B, C, D, or E) in the numbered spaces below, then shade the bubble corresponding to that letter for the same-numbered question on the bubble sheet.

A student was given five solid samples that were labeled V, W, X, Y, and Z. The student was told that the samples could be copper (substance A), quartz (substance B), potassium chloride (substance C), polyethylene (substance D), paraffin wax/candle wax (substance E). The student performed a number of tests on the samples and obtained the following results:

- (a) Sample W is a good electrical conductor. The other samples did not conduct electricity.
- (b) When the solids are hit with a hammer sample V flattens and is broken apart, W flattens just a little, sample Y shatters into many pieces, sample Z is crushed to a powder, and sample X is essentially unaffected.
- (c) When treated with water, sample Z dissolves and the other samples are unaffected.
- (d) When held over the warm element of an electric stove, samples V and X soften and then melt. On cooling they take new shapes. The other samples are essentially unaffected.

Identify the five samples.

- 63. V is E (Now shade in your response on the bubble sheet.)
- 64. W is A (Now shade in your response on the bubble sheet.)
- 65. X is D (Now shade in your response on the bubble sheet.)
- 66. Y is B (Now shade in your response on the bubble sheet.)
- 67. Z is C (Now shade in your response on the bubble sheet.)

W copper A

V E or D

X E or D

END OF EXAM