

**Part 1. Multiple Choice (14 marks total)**

For each numbered statement below, circle the letter that corresponds to the best answer. There is only one correct answer per question. Each question is worth 2 marks.

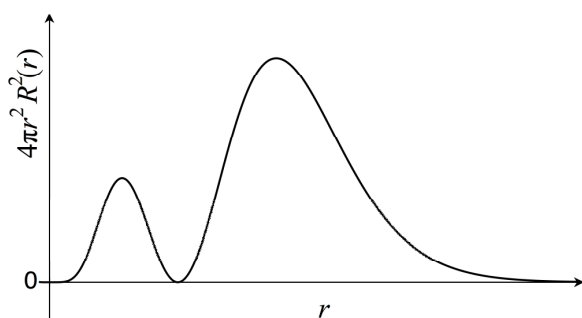
1. Which of the following statements is FALSE?

- (a) The product of wavelength and momentum of an electron is a constant.
- (b) It is impossible to simultaneously measure precisely both position and momentum of a microscopic particle.
- (c) Neutrons have no charge.
- (d) Electrons may behave both as particles and as waves, but protons can only behave as particles.
- (e) Electromagnetic radiation of all wavelengths travels at the same velocity in vacuum.

**Answer:**

**D**

2. The radial probability distribution for a particular orbital of the hydrogen atom with  $n = 3$  is shown. Which of the following orbitals is represented by this distribution?



- (a)  $3s$
- (b)  $3p_x$
- (c)  $3d_{xy}$
- (d)  $3d_{x^2-y^2}$
- (e)  $3d_{yz}$

**Answer:**

**B**

3. Arrange the following species in order of increasing melting point:



- (a)  $\text{Al}_2\text{O}_3 < \text{Xe} < \text{CH}_3\text{Cl} < \text{Br} < \text{C}_{60} < \text{S}_8$
- (b)  $\text{Xe} < \text{CH}_3\text{Cl} < \text{S}_8 < \text{C}_{60} < \text{Al}_2\text{O}_3$
- (c)  $\text{CH}_3\text{Cl} < \text{Xe} < \text{S}_8 < \text{Al}_2\text{O}_3 < \text{C}_{60}$
- (d)  $\text{Xe} < \text{CH}_3\text{Cl} < \text{C}_{60} < \text{S}_8 < \text{Al}_2\text{O}_3$
- (e)  $\text{CH}_3\text{Cl} < \text{Xe} < \text{Al}_2\text{O}_3 < \text{S}_8 < \text{C}_{60}$

**Answer:**

**B**

4. Which of the following is a Lewis acid?

- (a)  $\text{H}_2\text{O}$
- (b)  $\text{BH}_3$
- (c)  $\text{H}^-$
- (d)  $\text{NH}_3$
- (e)  $[\text{NH}_4]^+$

**Answer:**

**B**

5. Hydrogen atoms are generated in an excited state where the electron occupies the  $2p$  orbital. The excited sample of atoms then emits radiation that is directed to an unknown metal. The radiation ejects electrons with kinetic energy  $8.77 \times 10^{-19}$  J. Given the data in the table below, identify the unknown metal.

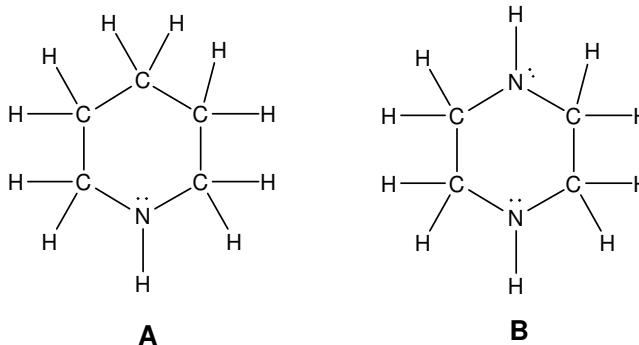
Metal	Ag	Cr	Ca	Mg	Au
Binding energy (J)	$7.58 \times 10^{-19}$	$7.21 \times 10^{-19}$	$4.60 \times 10^{-19}$	$5.86 \times 10^{-19}$	$8.17 \times 10^{-19}$

- (a) Ag  
 (b) Cr  
 (c) Ca  
 (d) Mg  
 (e) Au

**Answer:**

**A**

6. The Lewis structures of two organic compounds (**A** and **B**) are shown below. Molecule **A** has a boiling point of  $106^\circ\text{C}$ , and molecule **B** has a boiling point of  $146^\circ\text{C}$ .



The major reason **B** has a higher boiling point than **A** is:

- (a) Molecule **B** is nonpolar while molecule **A** is polar.  
 (b) Molecule **B** has a larger molecular weight than molecule **A**.  
 (c) Molecule **B** has more hydrogen bonding than molecule **A**.  
 (d) Molecule **B** has less hydrogen bonding than molecule **A**.  
 (e) Molecule **B** is polar while molecule **A** is nonpolar.
7. What is the wavelength of radiation with  $200.0$  kJ/mol of energy?

**Answer:**

**C**

- (a) 167 nm  
 (b) 598 nm  
 (c)  $5.98 \times 10^5$  nm  
 (d)  $1.67 \times 10^5$  nm  
 (e)  $9.93 \times 10^{-22}$  nm

**Answer:**

**B**

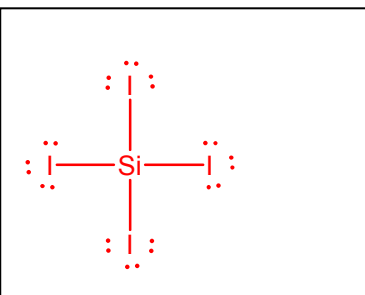
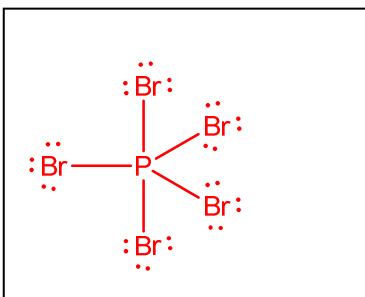
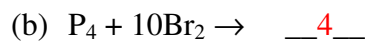
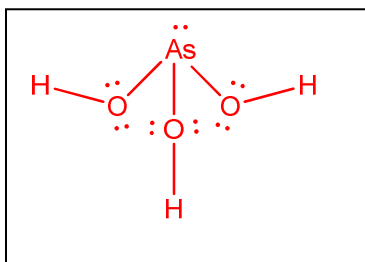
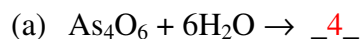
## Part 2. Short Answer Questions

5 marks

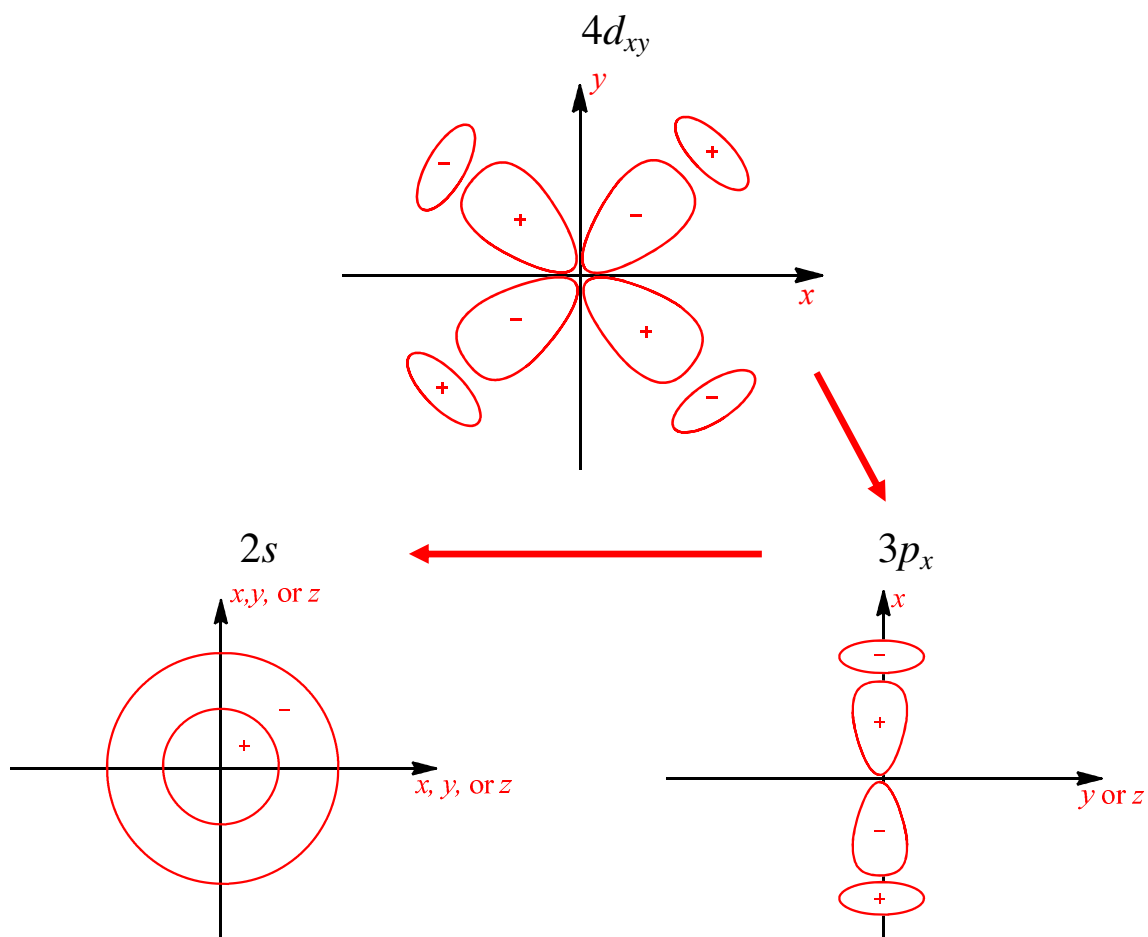
1. Fill in the blanks, using only elements from the third period of the periodic table and their compounds.
- (a) S reacts with oxygen to give two gases SO<sub>2</sub> and SO<sub>3</sub>.  
The molecules of one gas are polar, the molecules of the other gas are nonpolar.
- (b) Si reacts with oxygen to give a network covalent solid SiO<sub>2</sub>.
- (c) Ar does not form any compounds that can be isolated at room temperature.
- (d) Al forms an amphoteric oxide with the empirical formula X<sub>2</sub>O<sub>3</sub>.

8 marks

2. Balance the following equations by adding the appropriate stoichiometric coefficients, and draw a Lewis structure for the product formed in each case (assume sufficient heat is present to give a reaction in each case). Write any non-zero formal charges on the appropriate atoms, show all lone pairs of electrons as pairs of dots and all bond pairs as lines.



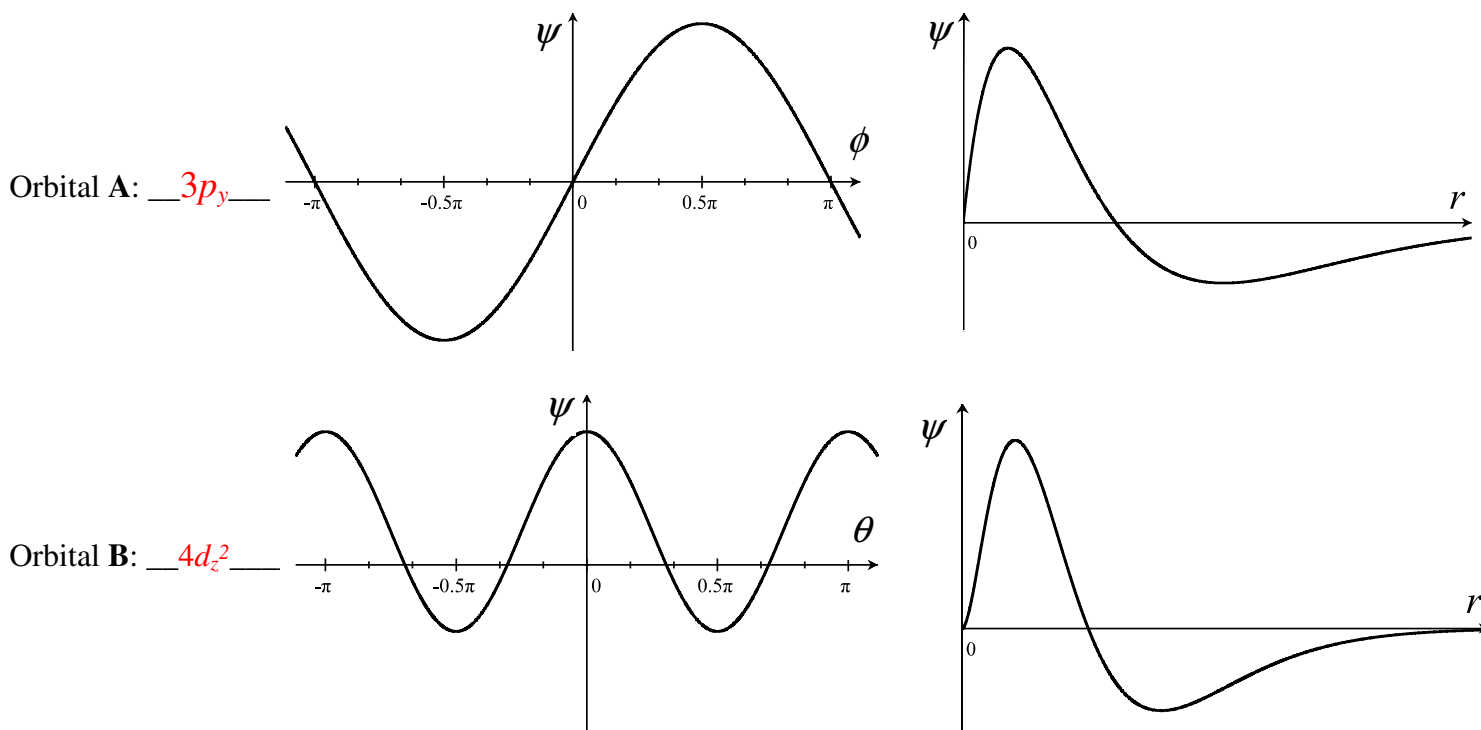
- 8 marks** 3. (a) Draw cross-sections for the following orbitals of the hydrogen atom. Show phases as (+) and (-) and label the axes.



- (b) The electron in the hydrogen atom can transition between orbitals while emitting or absorbing radiation. By drawing **single-headed** arrows ( $\rightarrow$ ), connect the boxes in part (a) to show the transitions that emit radiation.

5 marks

4. The sketches below show the radial and angular parts of the wavefunction of two orbitals. Label each sketch with the appropriate orbital label (e.g.  $1s$ ,  $2s$ ,  $2p_x$ , etc.). Angles  $\theta$  and  $\phi$  are the spherical polar coordinates.



4 marks

5. The longest wavelength of light that causes ionization of the electron from the  $4p$  orbital of an excited one-electron species is  $58.4 \text{ nm}$ . Identify the one-electron species in the box below, and use the additional space to show your work.

$$E_{\text{light}} = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ Js})(3 \times 10^8 \text{ ms}^{-1})}{58.4 \times 10^{-9} \text{ m}} = 3.40 \times 10^{-18} \text{ J}$$

The electron transition is from  $n = 4 \rightarrow n = \infty$ :

$$\Delta E_{4 \rightarrow \infty} = -2.18 \times 10^{-18} Z^2 \left( \frac{1}{\infty^2} - \frac{1}{4^2} \right)$$

$$\Delta E_{4 \rightarrow \infty} = 2.18 \times 10^{-18} Z^2 \left( \frac{1}{4^2} \right)$$

$$E_{\text{light}} = \Delta E_{4 \rightarrow \infty}$$

$$3.40 \times 10^{-18} \text{ J} = 2.18 \times 10^{-18} \frac{Z^2}{4^2}$$

Solving for  $Z$ :

$$Z = 5;$$

Therefore, the one – electron species is  $B^{4+}$

Species:

 $B^{4+}$

**8 marks**

6. Electrons in molecules with alternating single and double bonds can move freely within the molecule. Consider  $\beta$ -carotene, the compound which gives carrots their characteristic colour.  $\beta$ -carotene can be represented by a one-dimensional box of size 1.85 nm with 11 quantum states occupied by electrons. The lowest energy absorption of light by  $\beta$ -carotene involves the transition of an electron from the  $n = 11$  state to the  $n = 12$  state.

(a) How many nodes does the wavefunction of the  $n = 11$  state have?

**Answer:**

**10**

(b) Use the particle in a one-dimensional box model for the electrons in  $\beta$ -carotene to calculate the kinetic energy (in Joules) of an electron in the  $n = 11$  state.

$$E_k = \frac{n^2 h^2}{8mL^2} = \frac{(11)^2 (6.626 \times 10^{-34} \text{ Js})^2}{8(9.11 \times 10^{-31} \text{ kg})(1.85 \times 10^{-9} \text{ m})^2} = 2.13 \times 10^{-18} \text{ J}$$

**Answer:**

**$2.13 \times 10^{-18} \text{ J}$**

- (c) Use the particle in a one-dimensional box model to calculate the wavelength of light in nm that can excite an electron from the  $n = 11$  state to the  $n = 12$  state in  $\beta$ -carotene.

$$\Delta E = \frac{(n_2^2 - n_1^2)h^2}{8mL^2}$$

$$\Delta E = \frac{(12^2 - 11^2)(6.626 \times 10^{-34} \text{ Js})^2}{8(9.11 \times 10^{-31} \text{ kg})(1.85 \times 10^{-9} \text{ m})^2}$$

$$\Delta E = 4.05 \times 10^{-19} \text{ J}$$

$$E_{\text{light}} = \Delta E = 4.05 \times 10^{-19} \text{ J}$$

$$E_{\text{light}} = \frac{hc}{\lambda}$$

$$4.05 \times 10^{-19} \text{ J} = \frac{hc}{\lambda}$$

Solving for  $\lambda$  :

$$\lambda = 4.91 \times 10^{-7} \text{ m} = 491 \text{ nm}$$

**Answer:**

**491nm**

- (d) Given that the visible region of the electromagnetic spectrum spans the range 390-760 nm, explain why the presence of  $\beta$ -carotene gives carrots an orange/red colour.

White color is a mix of electromagnetic waves with all different colors.  $\beta$ -carotene absorbs 491nm light, which is in the blue region of the electromagnetic spectrum. If the blue color is removed from the white, the result is a mix of electromagnetic waves that appear red/orange (the complementary color).

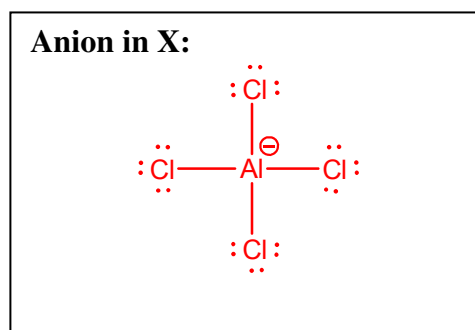
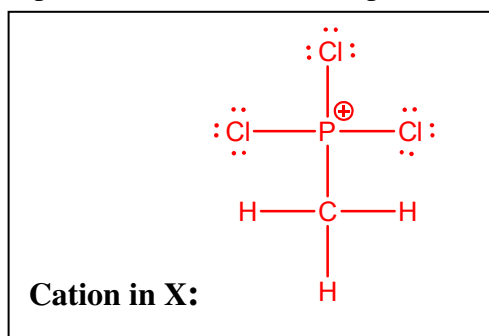
**8 marks**

7. The reaction of  $\text{PCl}_3$  (1 mol),  $\text{CH}_3\text{Cl}$  (1 mol) and  $\text{AlCl}_3$  (1 mol) results in the formation of one product, an ionic solid **X**. Both the cation and anion in **X** have a tetrahedral molecular shape at the central atoms. The anion contains only Al and Cl. Reaction of **X** (1 mol) with  $\text{H}_2\text{O}$  (1 mol) results in the formation of a compound **Y**, as well as  $\text{HCl}$  (1 mol) and  $\text{HAlCl}_4$  (1 mol).

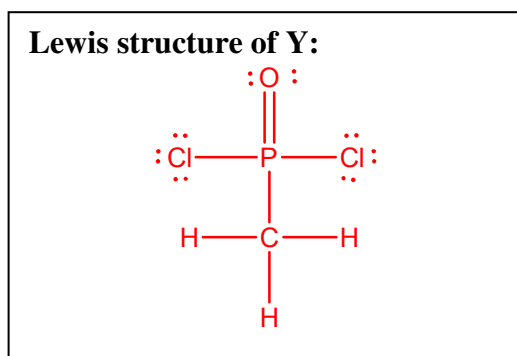
- (a) Write chemical formulae for **X** and **Y**.



- (b) Draw Lewis structures of both the cation and anion in **X**. Write any non-zero formal charges on the appropriate atoms, show all lone pairs of electrons as pairs of dots and all bond pairs as lines.



- (c) Draw a Lewis structure for **Y**.



Show your work here

**End of Examination**