Orbitals & electron spin

Question Paper 2

Level	Pre U
Subject	Chemistry
Exam Board	Cambridge International Examinations
Topic	Orbitals & electron spin-Atomic structure
Booklet	Question Paper 2

Time Allowed: **70 minutes**

Score: **/58**

Percentage: **/100**

Grade Boundaries:

1. **(a)** **(i)** What is meant by the term *bond energy*?

....

....

.... [3]

(ii) Use the bond energy data in the table to find the enthalpy change of reaction for the reaction between ethane and chlorine shown below.

$$C_2H_6(g) + 2Cl_2(g) \rightarrow C_2H_4Cl_2(g) + 2HCl(g)$$

bond	average bond energy / kJ mol^{-1}
C–C	347
C–H	413
Cl–Cl	243
C–Cl	346
H–Cl	432

[3]

(b) At low temperatures and pressures the alkali metals can exist as gaseous diatomic molecules. Recent research has investigated the mixing of gaseous diatomic molecules of different alkali metals (reported in *Science* 2010).

Spectroscopic techniques can be used to measure the bond energies of diatomic molecules. When measured in this way the values of bond energies are given in wavenumbers, which has the unit cm^{-1}.

Some values are shown in the table.

diatomic molecule	bond energy / cm^{-1}
K_2	4405
Rb_2	3966
KRb	4180

(i) Calculate the enthalpy change, in cm^{-1}, for the reaction between K_2 and Rb_2.

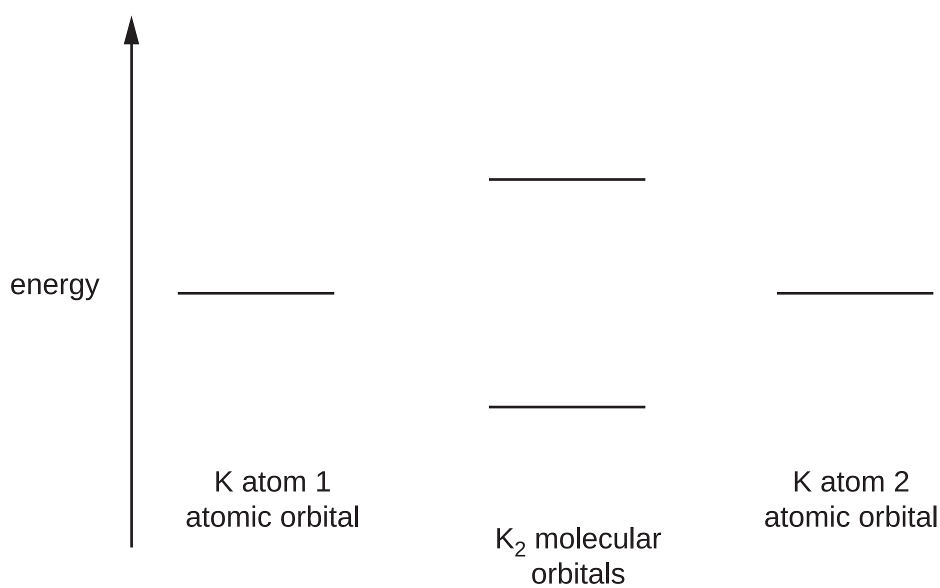
$$K_2(g) + Rb_2(g) \rightarrow 2KRb(g)$$

.... cm^{-1} [1]

(ii) Complete the electron configuration of a potassium atom.

$1s^2$ .... [1]

(iii) If only the outer shell electrons are considered, the molecular orbital diagram for an alkali metal diatomic molecule is much like that for hydrogen, H_2. Label all the orbitals in the molecular orbital diagram for K_2 and include the electrons.



[3]

(iv) Explain why potassium has a greater first ionisation energy than rubidium.

....

....

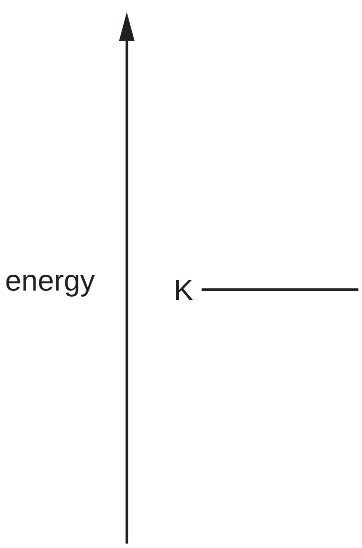
....

....

....

.... [3]

(v) Complete the molecular orbital diagram for KRb, showing relevant atomic and molecular orbitals. Only include outer shell orbitals. Label all the orbitals in your diagram.



[2]

(vi) Wavenumbers, $\bar{v}$, are converted into energy, E, using the equation

$$E = hc\,\bar{v}$$

where h is Planck's constant and c is the speed of light.

Using your answer to **(b)(i)**, work out the enthalpy change in $kJ\,mol^{-1}$ for the reaction between K_2 and Rb_2.

.... $kJ\,mol^{-1}$ [2]

[Total: 18]

2. **(a)** Fluorine forms simple molecular compounds with nearly all the non-metals.

For Use

(i) What is the name of the theory or model used to determine the shape of molecules?

.... [1]

(ii) Name the shape and give the bond angle in boron trifluoride.

name of shape ....

bond angle .... [2]

(b) Many non-metals form hypervalent compounds with fluorine.

(i) Explain what is meant by the term *hypervalent*.

....

.... [1]

(ii) IF_7 is a hypervalent compound.

Name the shape and give the bond angles in the molecule.

name of shape ....

bond angles .... and .... [3]

(iii) Unlike IF_7, BrF_7 is not known to exist. Suggest why IF_7 exists but BrF_7 does not.

....

.... [1]

(c) The trioxide of xenon, XeO_3, is simple molecular and hypervalent. It has three Xe=O double bonds and a lone pair on the xenon atom.

(i) Deduce and name the shape of an XeO_3 molecule.

.... [1]

(ii) In 2011 xenon dioxide, XeO_2, was synthesised for the first time (reported in the *Journal of the American Chemical Society*). Xenon dioxide exists as a polymer in which the oxygen atoms are bonded to xenon in a square planar arrangement.

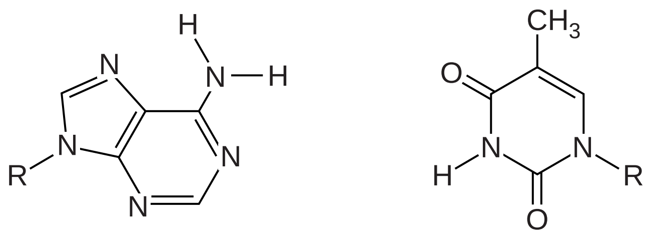
Work out the number of

- bonding electron pairs around each Xe atom, ...
- lone pairs around each Xe atom. .... [2]

(d) Hydrogen-bonding is the interaction that holds the two strands of DNA together through its purine and pyrimidine bases.

(i) The structures of adenine and thymine are shown below (R indicates the DNA backbone).

Show both the hydrogen bonds linking these bases.

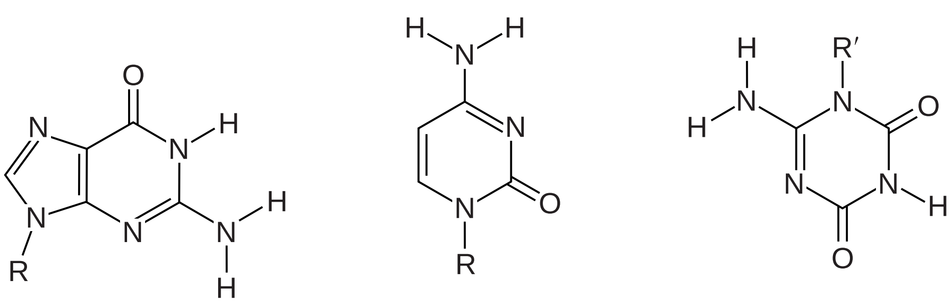


adenine　　　　thymine

[2]

(ii) A Janus wedge is a molecule that can insert itself between a purine and a pyrimidine base in DNA using hydrogen-bonding interactions to each base. (It is named after the Roman god Janus who had two faces.)

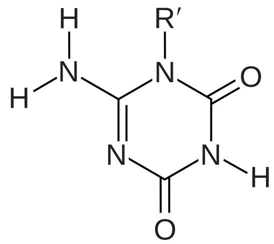
The structures of guanine, cytosine and a Janus wedge are shown. (R′ indicates the remainder of the Janus wedge structure.)



guanine　　　　cytosine　　　　Janus wedge

The guanine forms **three** hydrogen bonds with the Janus wedge, while the cytosine forms **two**.

Re-draw the guanine and cytosine on the next page, showing all the hydrogen bonds between the three molecules. The Janus wedge is drawn for you.



Janus
wedge

[3]

[Total: 16]

3.

....

....

....[3]

(ii) Use the bond energy data in Table 2.1 to find the enthalpy change of reaction for the reaction between ethane and chlorine shown below.

$$C_2H_6(g) + 2Cl_2(g) \longrightarrow C_2H_4Cl_2(g) + 2HCl(g)$$

Table 2.1

bond	average bond energy / kJ mol^{-1}
C−C	347
C−H	413
Cl−Cl	243
C−Cl	346
H−Cl	432

[3]

(b) At low temperatures and pressures the alkali metals can exist as gaseous diatomic molecules. Recent research has investigated the mixing of gaseous diatomic molecules of different alkali metals (reported in *Science* 2010).

Spectroscopic techniques can be used to measure the bond energies of diatomic molecules. When measured in this way the values of bond energies are given in wavenumbers, which has the unit cm^{-1}.

Some values are shown in Table 2.2.

Table 2.2

diatomic molecule	bond energy / cm^{-1}
K_2	4405
Rb_2	3966
KRb	4180

(i) Calculate the enthalpy change, in cm^{-1}, for the reaction between K_2 and Rb_2.

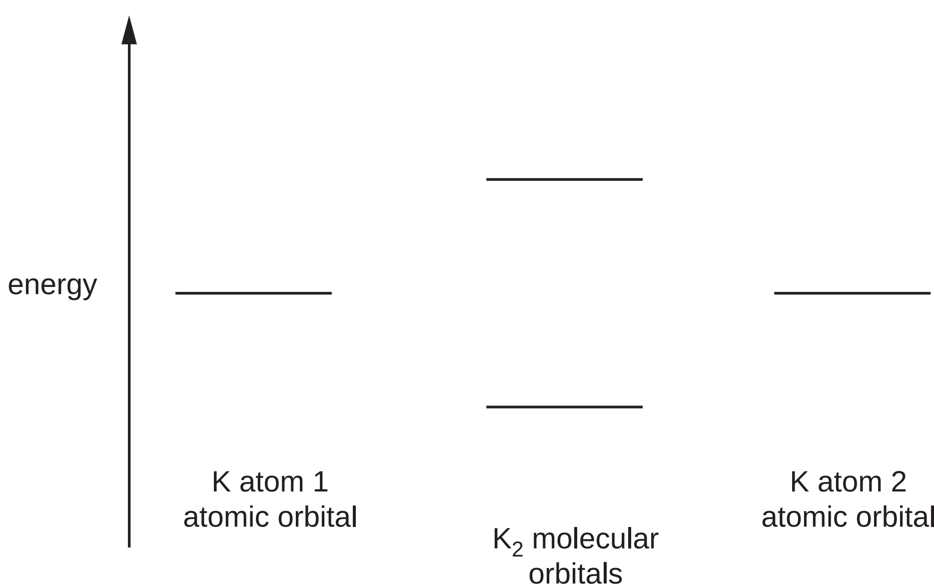
$$K_2(g) + Rb_2(g) \longrightarrow 2KRb(g)$$

.... cm^{-1} [1]

(ii) Complete the electron configuration of a potassium atom.

$1s^2$ .... [1]

(iii) If only the outer shell electrons are considered, the molecular orbital diagram for an alkali metal diatomic molecule is much like that for hydrogen, H_2. Label all the orbitals in the molecular orbital diagram for K_2 and include the electrons.



[3]

(iv) Explain why potassium has a greater first ionisation energy than rubidium.

....

....

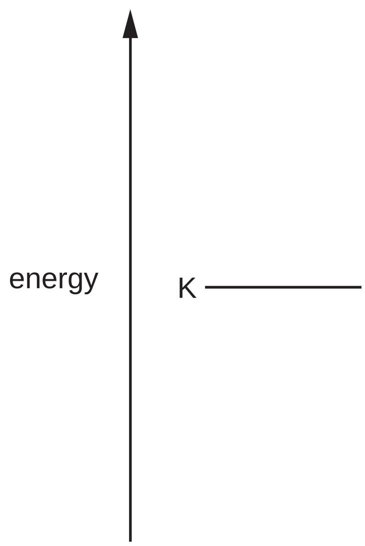
....

....

....

.... [3]

(v) Complete the molecular orbital diagram for KRb, showing relevant atomic and molecular orbitals. Only include outer shell orbitals. Label all the orbitals in your diagram.



[2]

(vi) Wavenumbers, $\bar{v}$, are converted into energy, E, using the equation

$$E = hc\bar{v}$$

where h is Planck's constant and c is the speed of light.

Using your answer to **(b)(i)**, work out the enthalpy change in $kJ\,mol^{-1}$ for the reaction between K_2 and Rb_2.

.... $kJ\,mol^{-1}$ [2]

[Total: 18]

4. The scientific community was shocked at the recent claim of the discovery of an isotope of a new element with a mass number of 292 (published in *arXiv*, 2008): this is over 50 mass units higher than uranium, the heaviest known naturally-occurring element. There is a possibility that there is an 'island of stability' beyond the known Periodic Table at some very high atomic numbers.

(a) The authors of this claim suggested that the atomic number of the element is 122. How many neutrons are there in this isotope?

.... [1]

(b) If this element really exists then it will require a new block of the periodic table, corresponding to the occupancy of another type of subshell, beyond the *s*, *p*, *d* and *f*. This would be a *g* subshell, which is predicted to be found in the 5th shell of an atom, i.e. the 5g subshell.

Based upon the sequence of subshells in the Periodic Table, *s*, *p*, *d*, *f*, predict how many orbitals there are in a *g* subshell.

.... [1]

(c) Predict how many elements there would be in the first row of the *g*-block.

.... [1]

Below is a scheme of the 17 lowest energy subshells, which can be used to show the order in which the subshells are filled by electrons (the Aufbau principle).

1s 2s 7s

2p

3d

4f

(d) List the order of filling subshells from 4p to 5d.

.... [1]

(e) The subshells in the scheme above are those that are occupied by the elements up to uranium. Add to the above diagram the next four subshells that would be expected to be filled. [1]

(f) Following the Aufbau principle, how many electrons in the 5g subshell would element 122 be expected to have?

.... [1]

[Total: 6]