THE COLLEGE OF THE BAHAMAS

FINAL EXAMINATION

SEMESTER 04-2009

FACULTY OF PURE AND APPLIED SCIENCES

SCHOOL OF CHEMISTRY, ENVIRONMENTAL & LIFE SCIENCES

X NASSAU
FREEPORT
EXUMA
ELEUTHERA

DATE AND TIME OF EXAMINATION: Monday 7th December 2009, 2 pm, Room MHEC-1B
DURATION: 3 HOURS

COURSE NUMBER: CHEM 235

COURSE TITLE: Inorganic Chemistry

STUDENT NAME:

STUDENT NUMBER:

LECTURER'S NAME

INSTRUCTIONS TO CANDIDATES: This paper has 13 pages and 2 sections. Please follow the instructions given with each section.

PERIODIC TABLE OF THE ELEMENTS

Periods	I	II	III	IV	V	VI	VII	0
1	1 **H** hydrogen 1.0							2 **He** helium 4.0
2	3 **Li** lithium 6.9	4 **Be** beryllium 9.0	5 **B** boron 10.8	6 **C** carbon 12.0	7 **N** nitrogen 14.0	8 **O** oxygen 16.0	9 **F** fluorine 19.0	10 **Ne** neon 20.2
3	11 **Na** sodium 23.0	12 **Mg** magnesium 24.3	13 **Al** aluminium 27.0	14 **Si** silicon 28.1	15 **P** phosphorus 31.0	16 **S** sulfur 32.1	17 **Cl** chlorine 35.5	18 **Ar** argon 39.9
4	19 **K** potassium 39.1	20 **Ca** calcium 40.1	21 **Sc** scandium 45.0	22 **Ti** titanium 47.9	23 **V** vanadium 50.9	24 **Cr** chromium 52.0	25 **Mn** manganese 54.9	26 **Fe** iron 55.8	27 **Co** cobalt 58.9	28 **Ni** nickel 58.7	29 **Cu** copper 63.5	30 **Zn** zinc 65.4	31 **Ga** gallium 69.7	32 **Ge** germanium 72.6	33 **As** arsenic 74.9	34 **Se** selenium 79.0	35 **Br** bromine 79.9	36 **Kr** krypton 83.8
5	37 **Rb** rubidium 85.5	38 **Sr** strontium 87.6	39 **Y** yttrium 88.9	40 **Zr** zirconium 91.2	41 **Nb** niobium 92.9	42 **Mo** molybdenum 95.9	43 **Tc** technetium 98.9	44 **Ru** ruthenium 101.1	45 **Rh** rhodium 102.9	46 **Pd** paladium 106.4	47 **Ag** silver 107.9	48 **Cd** cadmium 112.4	49 **In** indium 114.8	50 **Sn** tin 118.7	51 **Sb** antimony 121.8	52 **Te** tellurium 127.6	53 **I** iodine 126.9	54 **Xe** xenon 131.3
6	55 **Cs** cesium 132.9	56 **Ba** barium 137.3	57 **La** lanthanum 138.9	72 **Hf** hafnium 178.5	73 **Ta** tantalum 180.9	74 **W** tungsten 183.85	75 **Re** rhenium 186.2	76 **Os** osmium 190.2	77 **Ir** iridium 192.2	78 **Pt** platinum 195.1	79 **Au** gold 197.0	80 **Hg** mercury 200.6	81 **Tl** thallium 204.4	82 **Pb** lead 207.2	83 **Bi** bismuth 209.0	84 **Po** polonium	85 **At** astatine	86 **Rn** radon
7	87 **Fr** francium	88 **Ra** radium	89 **Ac** actinium															

Key: 19 ← proton number; K ← symbol of element; potassium ← name of element; 39.1 ← relative atomic mass

Lanthanides:

58 **Ce** cerium 140.1	59 **Pr** praseodymium 140.9	60 **Nd** neodymium 144.2	61 **Pm** promethium	62 **Sm** samarium 150.4	63 **Eu** europium 152.0	64 **Gd** gadolinium 157.3	65 **Tb** terbium 158.9	66 **Dy** dysprosium 162.5	67 **Ho** holmium 164.9	68 **Er** erbium 167.3	69 **Tm** thulium 168.9	70 **Yb** ytterbium 173.0	71 **Lu** lutetium 175.0

Actinides:

90 **Th** thorium 232.0	91 **Pa** protoactinium 231.0	92 **U** uranium 238.0	93 **Np** neptunium 237.0	94 **Pu** plutonium	95 **Am** americium	06 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium	103 **Lr** lawrencium

Note: relative atomic masses are omitted for highly unstable elements.

FBB NASC 4/11/09 C235

SECTION I: Multiple Choice Questions

Mark the letter corresponding to the best or most appropriate alternative on the multiple choice answer sheet provided. Circle the appropriate answer letter using soft pencil. There is one mark for each question in this section, making a total of 40 marks.

QUESTIONS 1 to 5

The elements may be classified as:

A metals
B extended structures with covalent bonds
C diatomic molecules
D monatomic molecules
E elements with appreciable characteristics of both metals and non-metals

Into which classification would you place the elements which have the characteristics described below? Each classification may be used once, more than once, or not at all.

1) An outer electronic configuration of s^2p^6.
2) The lowest electronegativity.
3) The highest melting point for lighter (Z<20) main-group elements.
4) Group VII elements.
5) An element whose oxide dissolves in both alkalis and acids.

QUESTIONS 6 to 11

These questions concern the following types of substance.

A hydride of an alkali metal or alkaline earth metal
B chloride of a non-metallic element
C halogen
D d-block element
E compound of a d-block element

Select from A to E the heading under which you could best classify the substance described in each question below. Each classification may be used once, more than once, or not at all.

6) A solid at room temperature which reacts with water to give a colourless, flammable gas and a solution of high pH.
7) An orange solid which forms an orange solution in water. Addition of dilute sulphuric acid to this solution followed by aqueous potassium iodide liberates iodine.
8) A colourless liquid which is insoluble in water.
9) A substance which is a good conductor of electricity. The substance is insoluble in water and reacts with dilute hydrochloric acid to liberate a colourless gas.
10) A liquid at room temperature which reacts vigorously with water to form a solution of low pH. This solution liberates a colourless, flammable gas when granulated zinc is added to it.
11) A volatile coloured solid at room temperature which dissolves in sodium thiosulfate solution to give a colourless solution and readily in potassium iodide solution to give a red solution.

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QUESTIONS 12 to 17

These questions concern the elements of group 4 of the periodic table.

A Carbon
B Silicon
C Germanium
D Tin
E Lead

In each of the following cases select the appropriate element. Each element may be used once, more than once, or not at all.

12) has the highest first ionization energy.
13) has an outer electron shell configuration of $4s^24p^2$
14) forms an oxide which on warming with concentrated hydrochloric acid gives chlorine gas.
15) forms an oxide which is a major component of glass.
16) forms an extremely extensive series of hydrides.
17) in a mixture with hydrochloric acid is used as a reducing agent, especially in organic chemistry.

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18) An element X forms an acidic oxide. Which element is most likely to be X?

A Sodium
B Caesium
C Iron
D Calcium
E Sulphur

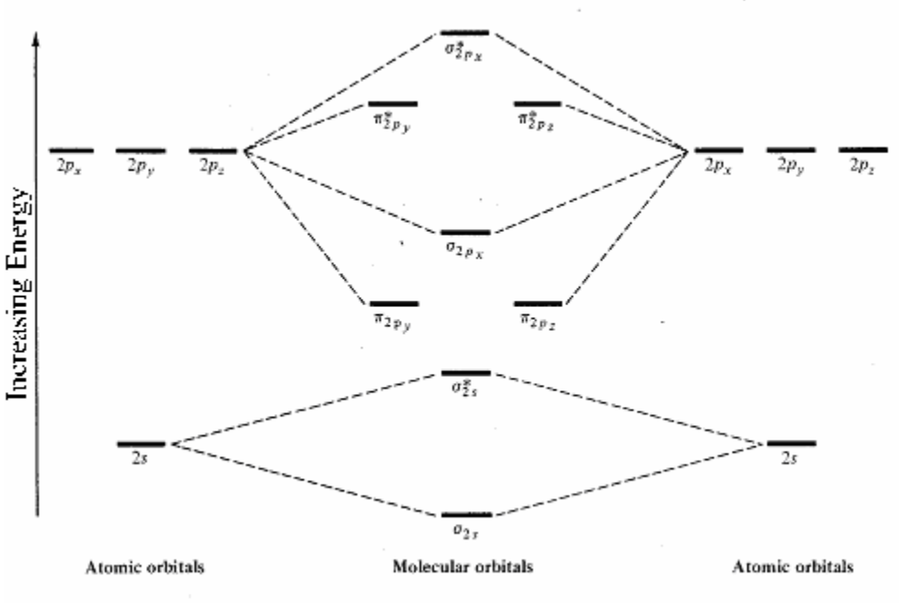
Questions 19-23 concern the following classification of the elements.

A noble gas
B s-block
C p-block except noble gas
D d-block
E f-block

Classify each of the following elements. Each classification may be used once, more than once, or not at all.

19) the element with the electronic configuration 2.8.1
20) the element with the electronic configuration $1s^22s^22p^63s^23p^63d^14s^2$.
21) the element with the configuration $[Ar]3d^{10}4s^24p^3$
22) the element whose **ANION** has the electronic configuration $1s^22s^22p^63s^23p^6$
23) the element with atomic number 97.

QUESTIONS 24 TO 27 refer to the following energy level diagram and the nitrogen oxide molecule, NO.



24) The NO^- ion should be:
- A paramagnetic
- B diamagnetic
- C non-magnetic
- D ferromagnetic
- E magnetic above a certain temperature.

25) The bond in the NO^+ ion should be
- A longer and stronger than that in NO.
- B longer and weaker than that in NO.
- C shorter and stronger than that in NO.
- D shorter and weaker than that in NO.
- E the same length and strength as that in NO.

26) The bond order in the NO molecule is
- A 0.5
- B 1
- C 1.5
- D 2
- E 2.5

27) The ionization energy of the NO^+ ion should be
- A lower than that of the nitrogen atom but higher than that of the oxygen atom.
- B higher than that of the nitrogen atom but lower than that of the oxygen atom.
- C higher than that of the NO molecule.
- D lower than that of the NO molecule.
- E lower than that of either the nitrogen atom or the oxygen atom.

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28) Which chloride is most extensively hydrolysed when an aqueous solution is evaporated?
- A magnesium chloride
- B calcium chloride
- C strontium chloride
- D barium chloride
- E sodium chloride

29) Which one of the following statements regarding the characteristics of elements within any one group of the periodic table is correct?
- A The elements are either all metals or all non-metals.
- B The melting and boiling points always increase with increasing atomic number.
- C The first ionization energy of the elements usually decreases with increasing atomic number.
- D The hardness of the solid elements always increases going down the group.
- E The acidity of the oxides always increases going down a group.

30) A metal reacts on heating with both dry chlorine and also dry hydrogen chloride to give a different product in each case. Which of the following metals behaves in this way?
- A Iron
- B Magnesium
- C Zinc
- D aluminium
- E calcium

31) In which one of the following respects is hydrogen ***different*** in its properties from a halogen?
- A It reacts with alkali metals to form ionic compounds.
- B It reacts with non-metals to form covalent compounds.
- C It forms an extensive series of compounds with carbon.
- D It consists of diatomic molecules.
- E It burns in air.

32) Which one of the following suggested properties of the element astatine is most consistent with its position at the bottom group VII?

A The element can be prepared from its compounds by the action of a reducing agent.
B The element is more electronegative than chlorine.
C The hydride is very stable to heat.
D The element explodes on contact with hydrogen.
E The element forms an At^- ion.

33) Which one of the following substances normally consists of discrete small molecules when in the solid state?

A Carbon
B Magnesium oxide
C Aluminium
D Carbon dioxide
E Silicon dioxide

34) Which one of the following substances is the main product of the Solvay (ammonia-soda) process?

A carbon dioxide
B calcium carbonate
C potassium carbonate
D ammonium chloride
E calcium oxide

35) Which one of the following electronic configurations does **NOT** represent an atom of an alkali metal in the ground state?

A $1s^2 2s^1$
B $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
C $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$
D $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^1$
E $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2\ 5p^6 6s^1$

36) The electronic configuration of the element radium can be represented as [noble gas]$7s^2$. Which one of the following statements is *least* likely to be correct?

A Radium has an oxidation number of +2 in all its compounds.
B Radium decomposes water at room temperature, liberating hydrogen.
C Radium carbonate decomposes on heating strongly.
D Radium hydroxide is amphoteric.
E Radium sulphate is sparingly soluble in water.

37) Fluorine reacts with water at room temperature to liberate mainly oxygen according to the equation

$$2F_2(g) + 2H_2O(l) \rightarrow 4HF(g) + O_2(g)$$

In which one of the following ways is the water acting in this reaction?

A an acid
B a base
C an oxidizing agent
D a reducing agent
E a solvent

38) Which one of the following is ***NOT*** a characteristic property of a d-block element or its compounds?

A catalytic activity.
B formation of coloured ions.
C formation of volatile oxides.
D paramagnetism.
E formation of complex ions.

39) When an excess of aqueous ammonia is added to a solution of a zinc salt, a white precipitate forms. This precipitate dissolves in excess ammonia to give a colourless solution. Which one of the following formulae best represents the complex ion formed in this reaction?

A $[Zn(NH_3)_4]^{2+}$
B $[Zn(OH)_4]^{2-}$
C $[ZnO_2]^{2-}$
D $[Zn(H_2O)_4]^{2+}$
E $[Zn(OH)_4(H_2O)_2]^{2-}$

40) Only one third of the total chlorine in a compound with the empirical formula $CrCl_3.6H_2O$ can be precipitated by silver nitrate solution at room temperature. Which one of the following best indicates the structure of the compound?

A $[CrCl(H_2O)_5]^{2+}(Cl^-)_2.H_2O$
B $[CrCl_2(H_2O)_4]^{+}Cl^-.2H_2O$
C $[CrCl_3(H_2O)_3].3H_2O$
D $[Cr(H_2O)_6]^{3+}(Cl^-)_3$
E $Cr^{3+}(Cl^-)_3.6H_2O$

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SECTION II: Short answer questions

Answer ANY FOUR of the following seven questions in the spaces provided on your question paper. Illustrate your answers with chemical equations wherever appropriate. Each question is worth 15 marks. There is a total of 60 marks for this section.
NB. If you answer more than four questions only your first four answers will be marked.

1) This question concerns the hydrides of a range of elements.
   a) In each of the following cases give the *name* of a hydride and write an *equation* to illustrate your answer.
      i) A hydride which hydrolyses violently in cold water to give a strongly basic solution. (2)

Name:

Equation:

      ii) A hydride which is ***spontaneously*** flammable in air. (2)

Name:

Equation:

      iii) A hydride which, on electrolysis in the molten state, gives hydrogen at the anode. (2)

Name:

Equation at anode:

      iv) A hydride which, in water, is a monoprotic acid. (2)

Name:

Equation:

      v) A hydride which dissolves readily in water to give a weakly alkaline solution. (2)

Name:

Equation:

      vi) A hydride which can act as a ligand with d-block metal ions. (2)

Name:

Equation:

   b) Give the names of two elements, besides carbon, which each form more than three different hydrides. (2)

   c) The enthalpy of combustion of methane is highly exothermic. To what do you attribute the stability of methane in air? (1)

2) This question concerns the d-block elements.

a) State, in terms of electronic structure, what is meant by the term d-block element. (2)

b) Give the electronic configurations of $_{29}Cu^{+}$, $_{26}Fe^{2+}$, and $_{25}Mn^{2+}$. You may use the abbreviation [Ar] if you wish. (Z for argon = 18) (3)

Cu^{+}:

Fe^{2+}:

Mn^{2+}:

c) How do you account for the fact that

i) Fe^{2+} ions are readily oxidized to Fe^{3+} ions, but Mn^{2+} ions are not readily oxidized to Mn^{3+} ions? (3)

ii) in solution Cu^{+} ions are colourless but Fe^{2+} and Mn^{2+} ions are coloured? (3)

d) Choose a hexa-coordinated complex ion of a d-block element and:

i) write its formula, (1)

ii) give its name, (1)

iii) draw and name its shape, (2)

3) This question concerns the halides of various elements.

a) The standard bond dissociation enthalpy of the hydrogen halides decreases in the order:

HF > HCl > HBr > HI ... (i)

The thermal stability also falls off in the same way:

HF > HCl > HBr > HI ... (ii)

The acid strength increases in the order:

HF < HCl < HBr < HI ... (iii)

Explain how statements (ii) and (iii) follow from statement (i) (4)

b) i) Draw a diagram showing the shape of a molecule of BCl_3. (1)

ii) What term is used to describe this shape? (1)

iii) What type of hybridisation of atomic orbitals is used to explain this shape? (1)

c) Iodine is often dissolved in aqueous potassium iodide rather than in pure water. Why is this? What is responsible for the characteristic red colour of these solutions? (2)

d) Anhydrous aluminium chloride reacts vigorously and exothermically with water as follows:

$$AlCl_3(s) + 6H_2O(l) \rightarrow [Al(H_2O)_6]^{3+}(aq) + 3Cl^-(aq)$$

Explain, in terms of polarising power, why sodium chloride does not behave in this way. (3)

e) Amongst the halides of silver there is a distinct trend of decreasing solubility in water:

AgF>AgCl>AgBr>AgI

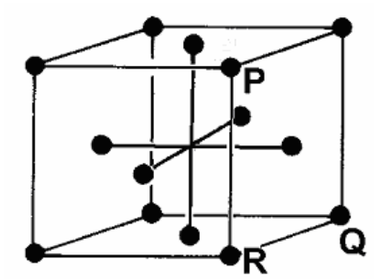
i) Give an explanation of this trend in terms of polarisability. (3)

4) The following question concerns metallic lattices.

a) There are the three types of metallic lattice, apart from the face-centred cubic close-packed lattice shown below. Sketch *two* of these lattices below and give their names. (4)

b) What is meant by the term *unit cell*? (2)

c) Aluminium is a metal which shows a face-centred cubic close-packed lattice. Such a lattice is illustrated in the diagram below (not to scale).



On the diagram clearly circle 3 atoms which are in contact and lie in a straight line. (1)

d) Write down a relationship between the radius of an aluminium atom (***r***) and the face-diagonal (PQ) of the unit cell (1)

e) Use your result from part (d) above to derive the relationship $V = 16\sqrt{2}\, r^3$ between the volume of the unit cell (V) and the radius of an aluminium atom, ***r***. (3)

f) Describe and explain how many atoms are present in the unit cell of aluminium. (2)

g) Show that the percentage occupancy of the unit cell of aluminium is 74.0%. (2)

5) This question concerns the metallic elements of group I of the periodic table.

a) What common feature of electronic structure do the metallic elements of group I share? (1)

b) In what way is the standard electrode potential for lithium ($E^{\ominus}$ for $Li^+(aq) \rightarrow Li(s) + e^-$) anomalous in the context of group I and its trends? Give a brief explanation of this anomalous behaviour. (4)

c) The chemistry of lithium and its compounds is in many ways different from that of the other elements of group I. For example, lithium nitrate behaves differently from sodium nitrate on heating. Write two chemical equations to illustrate this difference. (2)

d) Given the following information:

Standard enthalpy of sublimation of lithium metal $(\Delta H^{\ominus}_{sub}(Li)) = 161\,kJ\,mol^{-1}$

Standard enthalpy of first ionization of lithium (first ionisation energy)

$\Delta H^{\ominus}_{I}(Li) = 520\,kJ\,mol^{-1}$

Standard enthalpy of atomisation of chlorine (per mole of chlorine atoms)

$\Delta H^{\ominus}_{at}(Cl_2) = 121\,kJ\,mol^{-1}$

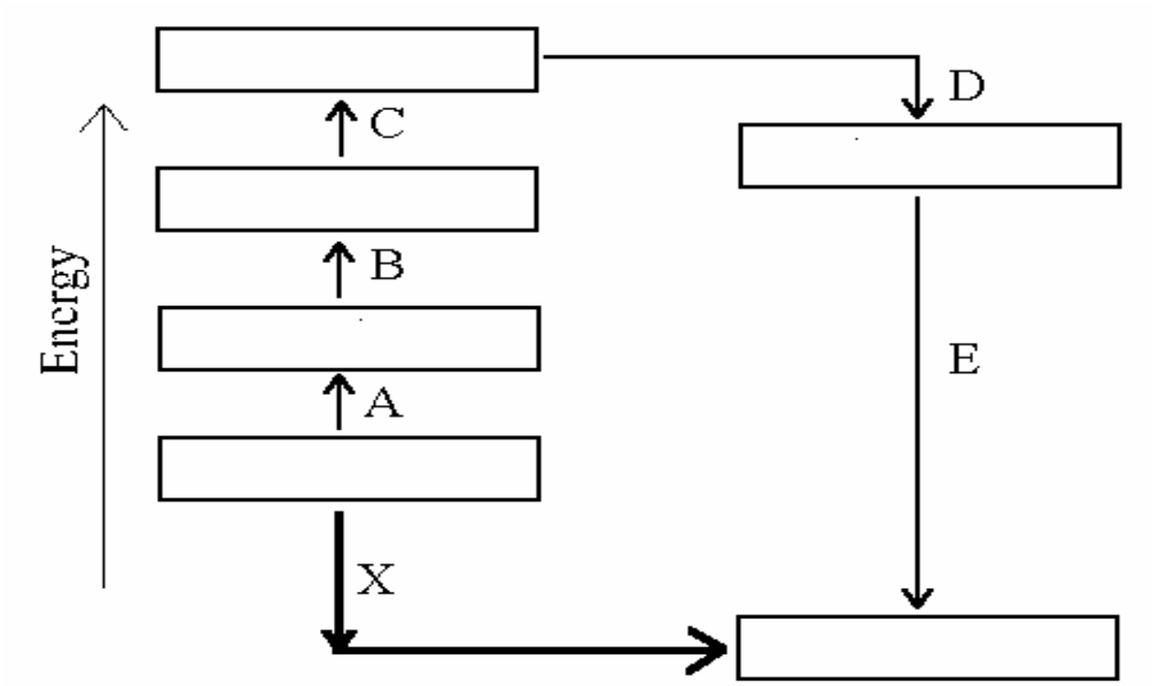
Standard first electron attachment enthalpy of chlorine (first electron affinity)

$\Delta H^{\ominus}_{EA}(Cl) = -364\,kJ\,mol^{-1}$

Standard enthalpy of formation of lithium chloride $\Delta H^{\ominus}_{f}(LiCl) = -409\,kJ\,mol^{-1}$

Standard lattice enthalpy of LiCl $\Delta H^{\ominus}_{LAT}(LiCl) = 849\,kJ\,mol^{-1}$

i) Carefully fill in the boxes in the Born-Haber cycle shown below, e.g. "NaCl(s)" (3)



ii) Write an expression in terms of the energy changes A through E and X for the standard lattice enthalpy of LiCl and calculate it. (2)

iii) Mention one factor which favours high lattice energy. (1)

iv) The standard lattice enthalpy of $Li^{2+}(Cl^-)_2$ has been estimated to be $3000\,kJ\,mol^{-1}$, which might suggest greater stability than Li^+Cl^-. Given that the standard enthalpy of second ionization of lithium = $7300\,kJ\,mol^{-1}$ suggest why $Li^{2+}(Cl^-)_2$ is not formed. (2)

6) This question is concerned with atomic and molecular orbital theory.

a) What is meant by the term *orbital*? (1)

b) Sketch the bonding and antibonding molecular orbitals formed in each of the following cases. Give a designation (e.g. π_p^*) for each molecular orbital and indicate the relative phases of the lobes.

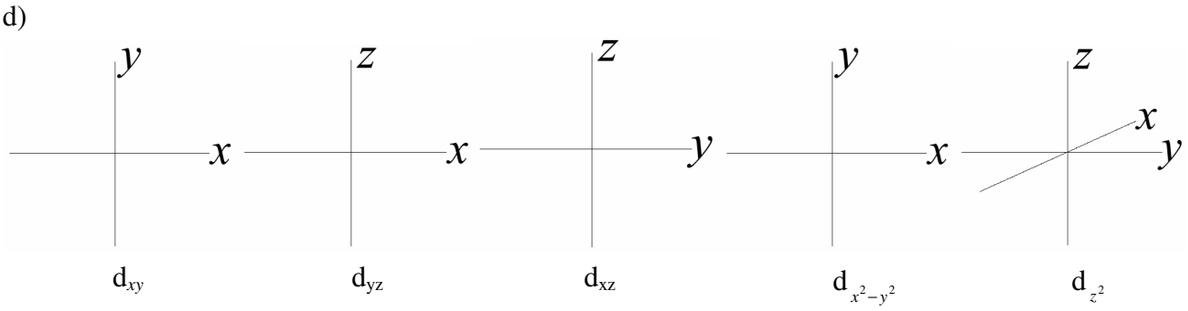
i) The overlap of two *s*-orbitals (3)

ii) The overlap of two *p*-orbitals, end-on (3)

iii) The overlap of two *p*-orbitals, side-on (3)

c) i) Sketch the five *d*-orbitals in a sub-shell using the axes below. (2½)

d)



d_{xy} d_{yz} d_{xz} $d_{x^2-y^2}$ d_{z^2}

Indicate the relative phases of the lobes on your diagram. (½)

ii) Briefly describe how the relative energies of these orbitals is affected by an octahedral field of ligands. (2)

7) Explain each of the following statements, giving *chemical equations* and *diagrams* wherever relevant.

a) There are two ions with the formula $[CrCl_2(NH_3)_4]^+$. (3)

b) Addition of alkali to potassium dichromate solution produces a colour change from orange to yellow. (3)

c) Addition of hydrogen sulfide solution to a solution of a lead(II) salt gives a black precipitate which turns white on addition of dilute hydrogen peroxide solution. (3)

d) When an excess of potassium iodide solution is added to a solution of a copper(II) salt, a white precipitate and a brown solution are formed. (3)

e) When dilute sulfuric acid is added to copper(I) oxide, a blue solution and a pinkish brown solid are formed. (3)