

3 Nitrogen,  $N_2$ , is generally an unreactive molecule but it does react under certain conditions.

(a) Give **two** reasons to explain the lack of reactivity of nitrogen.

1 .....

2 .....

[2]

(b)  $N_2$  can react with oxygen in an internal combustion engine to form a mixture of NO and  $NO_2$ .

Fig. 3.1 shows a reaction scheme involving  $N_2$ .

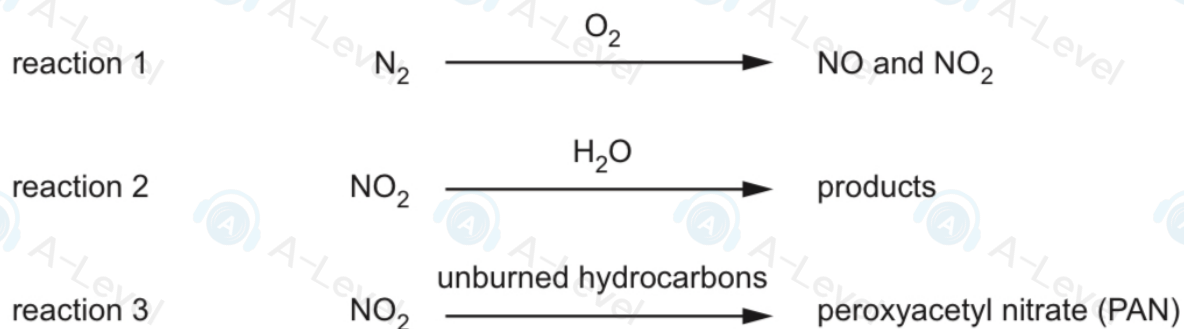


Fig. 3.1

(i) Write an equation to show the formation of a mixture of NO and  $NO_2$  in reaction 1.

..... [1]

(ii) Give the formulae of the products of reaction 2.

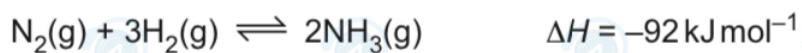
..... [1]

(iii) State **one** environmental consequence of reaction 3.

..... [1]

(c) The Haber process involves the reaction of  $\text{N}_2$  and  $\text{H}_2$  to form ammonia,  $\text{NH}_3$ .

A catalyst is used, which allows the process to be carried out at a lower temperature and pressure.



(i) Use the information in (c) to complete Table 3.1.

**Table 3.1**

compound	enthalpy change of formation, $\Delta H_f / \text{kJ mol}^{-1}$
$\text{N}_2$	
$\text{H}_2$	
$\text{NH}_3$	

[2]

(ii) Explain how the presence of a catalyst affects the reaction.

.....  
.....  
..... [1]

(iii) State and explain the effect, if any, on the **rate** of the Haber process as the pressure is lowered.

.....  
.....  
..... [2]

(d) The  $N_2F_2$  molecule has a double covalent bond between its nitrogen atoms. This consists of a  $\sigma$  and a  $\pi$  bond.

(i) Complete Fig. 3.2 to show the dot-and-cross diagram for  $N_2F_2$ .

Show outer electrons only.

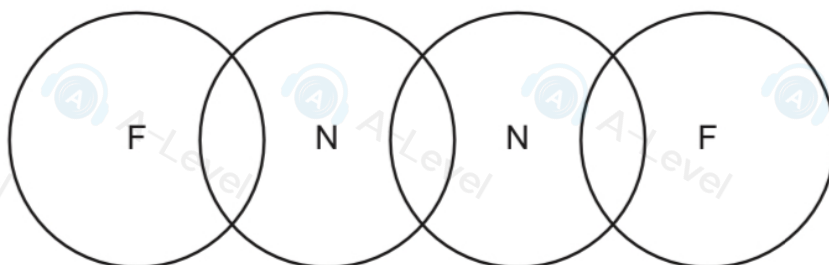


Fig. 3.2

[2]

(ii) Deduce the hybridisation of the N atoms in  $N_2F_2$ .

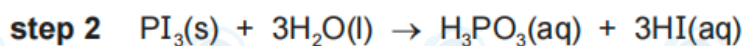
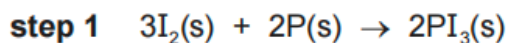
[1]

(iii) Draw a diagram of the  $\pi$  bond between the N atoms in  $N_2F_2$  and describe how it forms.

[2]

[Total: 15]

(f) In the laboratory, HI(aq) can be formed in a two-step process.



(i) Draw a 'dot-and-cross' diagram of a  $\text{PI}_3$  molecule.

[2]

(ii) Name the type of reaction in **step 2**.

[1]

(iii)  $\text{H}_3\text{PO}_3(\text{aq})$  and  $\text{HI}(\text{aq})$  are both strong Brønsted–Lowry acids.

Give the meaning of the term *strong Brønsted–Lowry acid*.

[2]

(iv) Give the formula of the conjugate base of  $\text{H}_3\text{PO}_3$ .

[1]

3 Nitrogen and phosphorus are elements in Group 15 of the Periodic Table.

(a) Nitrogen is found in inorganic compounds such as nitrogen oxides ( $\text{NO}_x$ ), nitrates and nitric acid.

(i) Identify **one** natural and **one** man-made occurrence of nitrogen oxides in the atmosphere.

natural .....

man-made .....

[2]

(ii) Write an equation to describe the role of  $\text{NO}_2$  in the direct formation of acid rain.

..... [1]

(iii) Peroxyacetyl nitrate, PAN, is a component of photochemical smog.

Describe how PAN forms from  $\text{NO}_2$ .

.....

..... [1]

(iv) Nitric acid reacts with basic oxides to form nitrates.

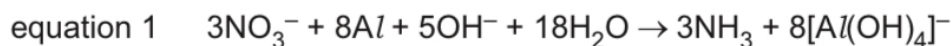
Write an equation for the reaction of nitric acid with calcium oxide.

..... [1]

(v) Describe what is seen when solid calcium nitrate is heated strongly.

..... [1]

(b) A common test for nitrates is the reaction with  $\text{NaOH}$  and  $\text{Al}$ . Equation 1 shows the reaction.



(i) Deduce the oxidation state of nitrogen in  $\text{NO}_3^-$ .

..... [1]

(ii) Identify the species that is oxidised in equation 1.

..... [1]

(iii)  $\text{NH}_3$  is a basic gas.

Describe how  $\text{NH}_3$  is able to act as a base.

.....

..... [1]

(iv) Suggest the shape of the  $[\text{Al}(\text{OH})_4]^-$  ion.

..... [1]

(c) Fig. 3.1 shows a sketch of some of the ionisation energies of phosphorus, P.

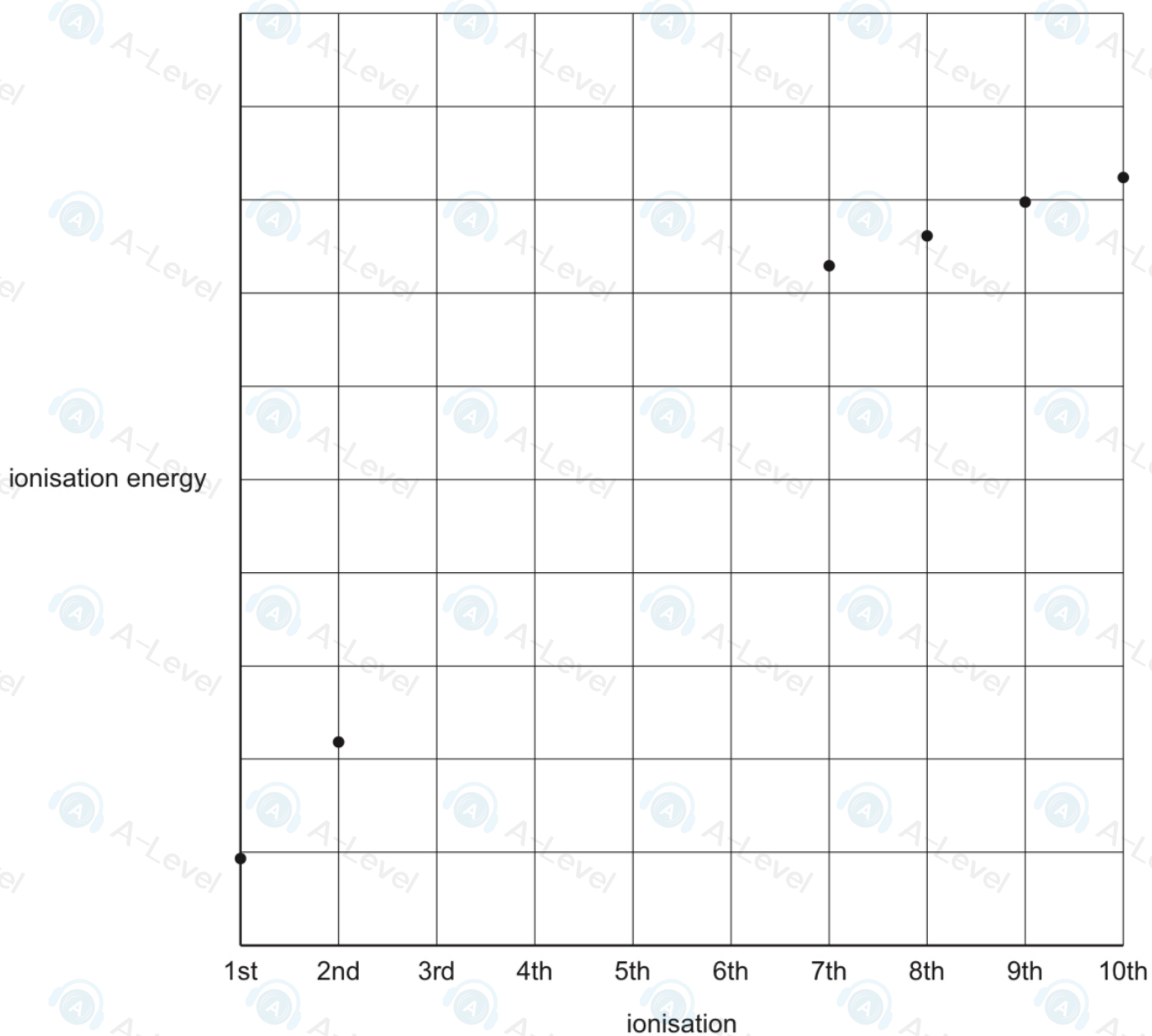


Fig. 3.1

(i) Construct an equation to represent the third ionisation energy of P.

..... [1]

(ii) Complete the graph in Fig. 3.1 to show the third to sixth ionisation energies of P.

[2]

- (d) Complete Table 3.1 to show the properties of nitrogen and phosphorus in their standard states.

**Table 3.1**

	nitrogen	phosphorus
state and appearance of standard state	colourless gas	white solid
electrical conductivity		poor
type of bonding		
type of structure	simple	

[2]

- (e) A form of solid nitrogen has a lattice structure similar to solid iodine.

Identify the type of lattice structure of solid nitrogen.

[1]

- (f) At very high temperatures, phosphorus can form  $P_2$  molecules.

$P_2$  contains a triple bond,  $P \equiv P$ .

- (i) Describe the formation of the  $P \equiv P$  bond in terms of orbital overlap.

[2]

- (ii) The bond energy of  $P \equiv P$  is  $485 \text{ kJ mol}^{-1}$ . The bond energy of  $N \equiv N$  is  $944 \text{ kJ mol}^{-1}$ . Compare the reactivity of  $P_2$  and  $N_2$ . Explain your answer.

[1]

[Total: 19]