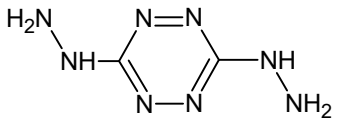
1. This question is about environmentally friendly fireworks

Recent research on fireworks has sought to reduce the quantity of heavy metal salts used for colouration, and perchlorate or chlorate(VII), an oxidiser that is also toxic. By employing a fuel that generates less smoke, less metal salt is required for the same visual effect.

Replacing the carbon and hydrogen in fuels by nitrogen can cut the smoke evolved, but many compounds containing mostly nitrogen are dangerously unstable. However, one compound finding favour as a fuel is *dihydrazinotetrazine* (shown below) which, despite its high nitrogen content, is remarkably stable.



dihydrazinotetrazine

(a) **i)** By considering the bonding in the ring suggest why this compound is so stable.

ii) It is possible to record nitrogen NMR spectra, due to the presence of the NMR-active ^{15}N isotope. Predict the number of signals you would expect to see in the ^{15}N NMR spectrum in dihydrazinotetrazine by working out how many different nitrogen environments are present in the molecule.

iii) When dihydrazinotetrazine is burnt in excess oxygen the products are nitrogen gas and two other substances. Write a balanced equation for this combustion in excess oxygen.

Octanitrocubane is another potential fuel. Its structure has a cage of carbon atoms at the corners of a cube with each carbon atom bonded to a nitro group ($–NO_2$). Due to bond strain, the molecule is difficult to make and less stable than dihydrazinotetrazine.

(b) **i)** How many degrees smaller is the C–C–C bond angle in octanitrocubane compared with that in a straight-chained alkane?

ii) Give a balanced chemical equation to show that no additional oxygen – and therefore no (toxic) oxidiser – is required when octanitrocubane is used as a fuel.

(c) Another nitrogenated fuel is the polymer nitrocellulose whose repeat unit is shown below. Give the empirical formula of nitrocellulose, and hence write an equation for the combustion of this formula unit in excess oxygen.