2. This question is about the redox chemistry of vehicle pollution

The unwanted pollutants from the exhausts of vehicles include unburnt hydrocarbons (HCs), carbon monoxide and oxides of nitrogen, mainly NO and NO_2.

The first two pollutants arise if there is insufficient oxygen present to oxidise them fully. The oxides of nitrogen are formed in larger quantities if too much oxygen is present.

(a) Write an equation for the complete combustion of petrol, assuming that the only hydrocarbon present is octane, C_8H_{18}.

Any unburnt hydrocarbons and carbon monoxide may be removed by being oxidised, either by oxygen or water. Platinum and / or palladium metal is used to catalyse these oxidation reactions.

(b) Write an equation for the oxidation of CO by **i)** oxygen and **ii)** water.

The nitrogen oxides must be removed by being reduced to nitrogen gas. Any carbon monoxide present can accomplish this, as can any hydrogen gas present. These reduction reactions are catalysed by rhodium metal.

(c) Write an equation for the reduction of NO by **i)** carbon monoxide and **ii)** hydrogen.

To help maintain a stable oxygen : fuel ratio, so-called 'oxygen-storage materials' are used. One commonly used is ceria which exists as an equilibrium mixture of cerium(III) and cerium(IV) oxides.

(d) Write an equation for this equilibrium. (The symbol for cerium is Ce.)

The combustion of diesel is less efficient than that of petrol. Despite an excess of oxygen, unburnt hydrocarbons, CO and even solid carbon are produced. Whilst the first two pollutants may be removed as before in the catalytic converter, the carbon formed would simply block it up were it not removed. At the operating temperatures within the catalyst, very little of the carbon reacts with oxygen; it is, however, oxidised by nitrogen dioxide, NO_2, forming CO_2 and NO.

(e) Write an equation for the reaction between carbon and NO_2.

In order to remove the oxides of nitrogen emitted from the catalyst, further reducing agent is added. One such reducing agent is ammonia, prepared by the decomposition of an aqueous solution of urea, H_2NCONH_2. The urea solution is known commercially as 'AdBlue'.

(f) Draw the structure for urea indicating the approximate angles for the N–C–O and the H–N–H bonds.

(g) Write an equation for the production of ammonia from urea and water.

(h) Write an equation for the reaction between ammonia and **i)** NO and **ii)** NO_2.

(i) On your answers for parts **b**, **c**, **d**, **e** and **h** underline with a <u>single line</u> the atom(s) which undergo oxidation and underline with a <u>double line</u> those atom(s) which undergo reduction.