Consider now the combustion of an arbitrary fuel ($C_\alpha H_\beta O_\gamma N_\delta$) with air. If the products of combustion are limited to CO_2, CO, H_2O, H_2, O_2 and N_2, then the generalised combustion equation with air can be written as

$$C_\alpha H_\beta O_\gamma N_\delta + \lambda(\alpha + \beta/4 - \gamma/2)\left\{O_2 + \frac{79.05}{20.95}N_2\right\} \rightarrow$$

$$n_1 CO_2 + n_2 CO + n_3 H_2O + n_4 H_2 + n_5 O_2 + n_6 N_2 \quad (3.8)$$

where the excess air ratio (λ) is unity for stoichiometric reactions, and greater than unity for weak mixtures.

Four *atomic* balances can be written:

$$C\ balance: \quad \alpha = n_1 + n_2 \quad (3.9)$$

$$H\ balance: \quad \beta = 2n_3 + 2n_4 \quad (3.10)$$

$$O\ balance: \quad \gamma + \lambda(\alpha + \beta/4 - \gamma/2)2 = 2n_1 + n_2 + n_3 + 2n_5 \quad (3.11)$$

$$N\ balance: \quad \delta + \lambda(\alpha + \beta/4 - \gamma/2)2 \times \frac{79.05}{20.95} = 2n_6 \quad (3.12)$$

With six unknowns and only four simultaneous equations, then two further equations are needed. A convenient simplification is to assume no oxygen in the products of rich combustion, and no hydrogen or carbon monoxide in the products of weak combustion. In other words:

rich mixtures ($\lambda < 1$): $\quad n_5 = 0 \quad$ (3.13)

weak mixtures ($\lambda > 1$): $\quad n_2 = n_4 = 0 \quad$ (3.14)

stoichiometric mixtures ($\lambda = 1$): $\quad n_2 = n_4 = n_5 = 0 \quad$ (3.15)

For rich mixtures a further equation is still required, and this is provided by the water gas equilibrium:

$$CO_2 + H_2 \rightleftharpoons CO + H_2O \quad (3.16)$$

for which the equilibrium constant is K_p:

$$K_p = \frac{n_2 n_3}{n_1 n_4} \quad (3.17)$$

Simultaneous solution of equations (3.9) to (3.15) and (3.17) yields the results that are summarised in table 3.2.

For the rich products of combustion in table 3.2 the compositions have been written with variable n_2 included; this can now be eliminated by use of the

Table 3.2 *Simplified products of combustion*

Species	i	Weak ($\lambda > 1$)	Rich ($\lambda < 1$)
CO_2	1	α	$\alpha - n_2$
CO	2	0	n_2
H_2O	3	$\beta/2$	$\gamma + \lambda(\alpha + \beta/4 - \gamma/2)\,2 - 2\alpha + n_2$
H_2	4	0	$\beta/2 - \gamma - \lambda(\alpha + \beta/4 - \gamma/2)2 + 2\alpha - n_2$
O_2	5	$(\lambda - 1)(\alpha + \beta/4 - \gamma/2)$	0
N_2	6	$\lambda(\alpha + \beta/4 - \gamma/2)\ 79.05/20.95 + \delta/2$	$\lambda(\alpha + \beta/4 - \gamma/2)\ 79.05/20.95 + \delta/2$

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$$\textit{rich mixtures } (\lambda < 1): \quad n_5 = 0 \tag{3.13}$$
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