

1) Each step is elementary.

$$\begin{aligned} r_{1f} &= k_{1f} [\text{CO}_2] [\text{S}] \\ r_{1b} &= k_{1b} [\text{CO}_2 \cdot \text{S}] \end{aligned}$$

r_{1f} = forward
 r_{1b} = backward
 $n = [1, 5]$

$$\begin{aligned} r_1 &= r_{1f} - r_{1b} \\ &= k_{1f} [\text{CO}_2] [\text{S}] - k_{1b} [\text{CO}_2 \cdot \text{S}] \\ &= k_{1f} \left[[\text{CO}_2] [\text{S}] - \frac{[\text{CO}_2 \cdot \text{S}]}{K_1} \right] \quad \text{fast} \end{aligned}$$

$$r_2 = k_{2f} \left[[\text{H}_2] [\text{S}] - \frac{1}{K_2} [\text{H}_2 \cdot \text{S}] \right] \quad \text{fast}$$

$$r_3 = k_{3f} \left[[\text{CO}_2 \cdot \text{S}] [\text{H}_2 \cdot \text{S}] - \frac{1}{K_3} [\text{CO} \cdot \text{S}] [\text{H}_2\text{O} \cdot \text{S}] \right] \quad \text{Slow}$$

$$r_4 = k_{4f} \left[[\text{CO} \cdot \text{S}] - \frac{1}{K_4} [\text{CO}] [\text{S}] \right] \quad \text{fast}$$

$$r_5 = k_{5f} \left[[\text{H}_2\text{O} \cdot \text{S}] - \frac{1}{K_5} [\text{H}_2\text{O}] [\text{S}] \right] \quad \text{fast.}$$

$\therefore 1, 2, 4, 5$ are in equilibrium.

$$\therefore [\text{CO}_2] [\text{S}] = \frac{[\text{CO}_2 \cdot \text{S}]}{K_1}$$

$$\therefore K_1 [\text{CO}_2 \cdot \text{S}] = [\text{CO}_2] [\text{S}] \cdot K_1 \quad (1)$$

$$\therefore [\text{H}_2 \cdot \text{S}] = [\text{H}_2] [\text{S}] \cdot K_2 \quad (2)$$

$$[\text{CO} \cdot \text{S}] = [\text{CO}] [\text{S}] / K_4 \quad (4)$$

$$[\text{H}_2\text{O} \cdot \text{S}] = [\text{H}_2\text{O}] [\text{S}] / K_5 \quad (5)$$

For slow reaction:
Substituting 1, 2, 4, 5:

$$r_3 = k_3 f \left([CO_2][S] K_1 \cdot [H_2][S] - K_2 - \frac{1}{K_3} \cdot \frac{[CO][S]}{K_4} \cdot \frac{[H_2O][S]}{K_5} \right)$$

$$= k_3 f [S] \cancel{[CO_2] K_1 K_2} \quad \underline{K_n = K_n} \quad (n \in \{1, 5\})$$

$$\therefore r_3 = k_3 f [S] \left[[CO_2][H_2] K_1 K_2 - \frac{1}{K_3 K_4 K_5} \cdot [CO][H_2O] \right] \quad \text{--- (6)}$$

Now:

$$[S_0] = [S] + [H_2 \cdot S] + [CO_2 \cdot S] + [CO \cdot S] + [H_2O \cdot S]$$

$$[S_0] = [S] + [H_2][S] K_2 + [CO_2][S] K_1 + \frac{[CO][S]}{K_4} + \frac{[H_2O][S]}{K_5}$$

$$\therefore [S_0] = [S] \left[1 + [H_2] K_2 + K_1 [CO_2] + \frac{[CO]}{K_4} + \frac{[H_2O]}{K_5} \right]$$

$$\therefore r_3 = k_3 f \cdot \left[1 + [H_2] K_2 + K_1 [CO_2] + \frac{[CO]}{K_4} + \frac{[H_2O]}{K_5} \right]^{-1} \cdot [S_0] \cdot \left[[CO_2][H_2] K_1 K_2 - \frac{1}{K_3 K_4 K_5} [CO][H_2O] \right]$$