step1/2

(a) Sodium atom has electron configuration $\mathrm{Ne}\left[3s^1\right]$ in ground state. Electron in 3*s* orbital is first excited to 3*p* orbital and then to 4*s* orbital. So energy required for $3s \rightarrow 4s$ transition is obtained by addition of energy corresponding to $3s \rightarrow 3p$ transition and energy corresponding to $3p \rightarrow 4s$ transition.

Energy associated with radiation is calculated using equation

$$E = \frac{hc}{\lambda}$$

$3s \rightarrow 3p$ transition for sodium emits radiation with wavelength 589.3 nm, energy associated with it(E_1) is calculated as

$$\begin{aligned} E_1 &= \frac{6.626 \times 10^{-34} \times 3 \times 10^{10}}{589.3 \times 10^{-7}} \\ &= 3.37 \times 10^{-19}\ \mathrm{J} \end{aligned}$$

$3p \rightarrow 4s$ transition for sodium emits radiation with wavelength 1139 nm, energy associated with it(E_2) is calculated as

$$\begin{aligned} E_2 &= \frac{6.626 \times 10^{-34} \times 3 \times 10^{10}}{1{,}139 \times 10^{-7}} \\ &= 1.75 \times 10^{-19}\ \mathrm{J} \end{aligned}$$

So, energy required for transition $3s \rightarrow 4s$ is calculated as

$$\begin{aligned} E &= E_1 + E_2 \\ &= 3.37 \times 10^{-19} + 1.75 \times 10^{-19} \\ &= 5.12 \times 10^{-19}\ \mathrm{J} \end{aligned}$$

Ratio between number of excited and unexcited particles is calculated using equation

$$\frac{N_j}{N_o} = \frac{g_j}{g_o}\exp\left(\frac{-E_j}{KT}\right)$$

Where N_j and N_o are number of particles in excited state and ground state. g_j and g_o are statistical weights for $3s$ and $4s$ quantum state, K is Boltzmann constant and T is absolute temperature.

Acetylene-oxygen flame has temperature $3000\,^{o}\mathrm{C}$.Convert temperature in degree centigrade into kelvins as

$$\text{Temperature in kelvin} = T°\mathrm{C} + 273$$

Substituting $3{,}000°\mathrm{C}$ we get

$$\begin{aligned}\text{Temperature in kelvin} &= 3{,}000°\mathrm{C} + 273\\ &= 3{,}273\ \mathrm{K}\end{aligned}$$

Statistical weights for 3*s* and 4*s* quantum states are 2 and 2 respectively so,

$$\begin{aligned}\frac{g_j}{g_o} &= \frac{2}{2}\\ &= 1\end{aligned}$$

Substituting values of $E_j, \frac{g_j}{g_o}, K$ and temperature as 3273K for acetylene-oxygen flame we get

$$\begin{aligned}\frac{N_j}{N_o} &= 1\exp\left(\frac{-5.12 \times 10^{-19}\,\cancel{J}}{1.38 \times 10^{-23}\,\cancel{J}/\cancel{K} \times 3{,}273\,\cancel{K}}\right)\\ &= 1 \times 1.2 \times 10^{-5}\\ &= 1.2 \times 10^{-5}\end{aligned}$$

Therefore, ratio of number of particles in 4*s* excited state to 3*s* ground state using acetylene-oxygen flame at $3{,}000°\mathrm{C}$ for sodium atom is $\boxed{1.2 \times 10^{-5}}$

step2/2

(b)The hottest part of inductively coupled plasma source has temperature of $9000°C$ which is converted into kelvins as

$$\text{Temperature in kelvin} = T°\text{C} + 273$$

For $9,000°C$ we get

$$\begin{aligned}\text{Temperature in kelvin} &= 9,000°\text{C} + 273 \\ &= 9,273 \text{ K}\end{aligned}$$

Substituting values of $E_j, \frac{g_j}{g_o}, K$ and temperature as 3273K for acetylene-oxygen flame we get

$$\begin{aligned}\frac{N_j}{N_o} &= 1\exp\left(\frac{-5.12 \times 10^{-19} \cancel{J}}{1.38 \times 10^{-23} \cancel{J} / \cancel{K} \times 9,273 \cancel{K}}\right) \\ &= 1 \times 1.8 \times 10^{-2} \\ &= 1.8 \times 10^{-2}\end{aligned}$$

Therefore, ratio of number of particles in 4*s* excited state to 3*s* ground state using the hottest part of inductively coupled plasma source $9,000°C$ for sodium atom is $\boxed{1.8\times10^{-2}}$