The nature of the 760 nm Fraunhofer line in the solar spectrum

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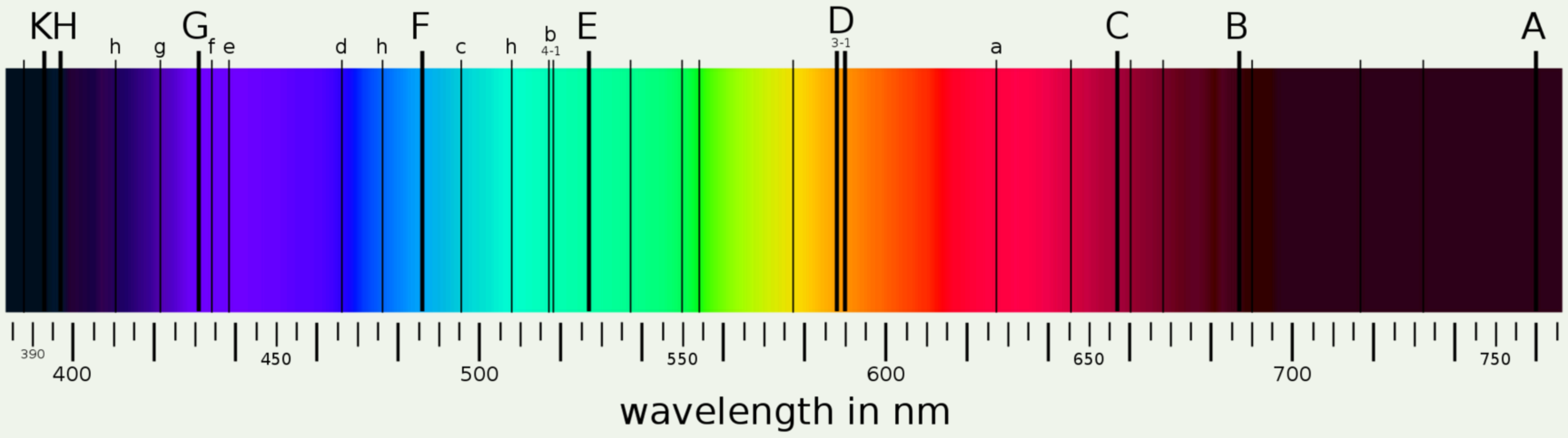
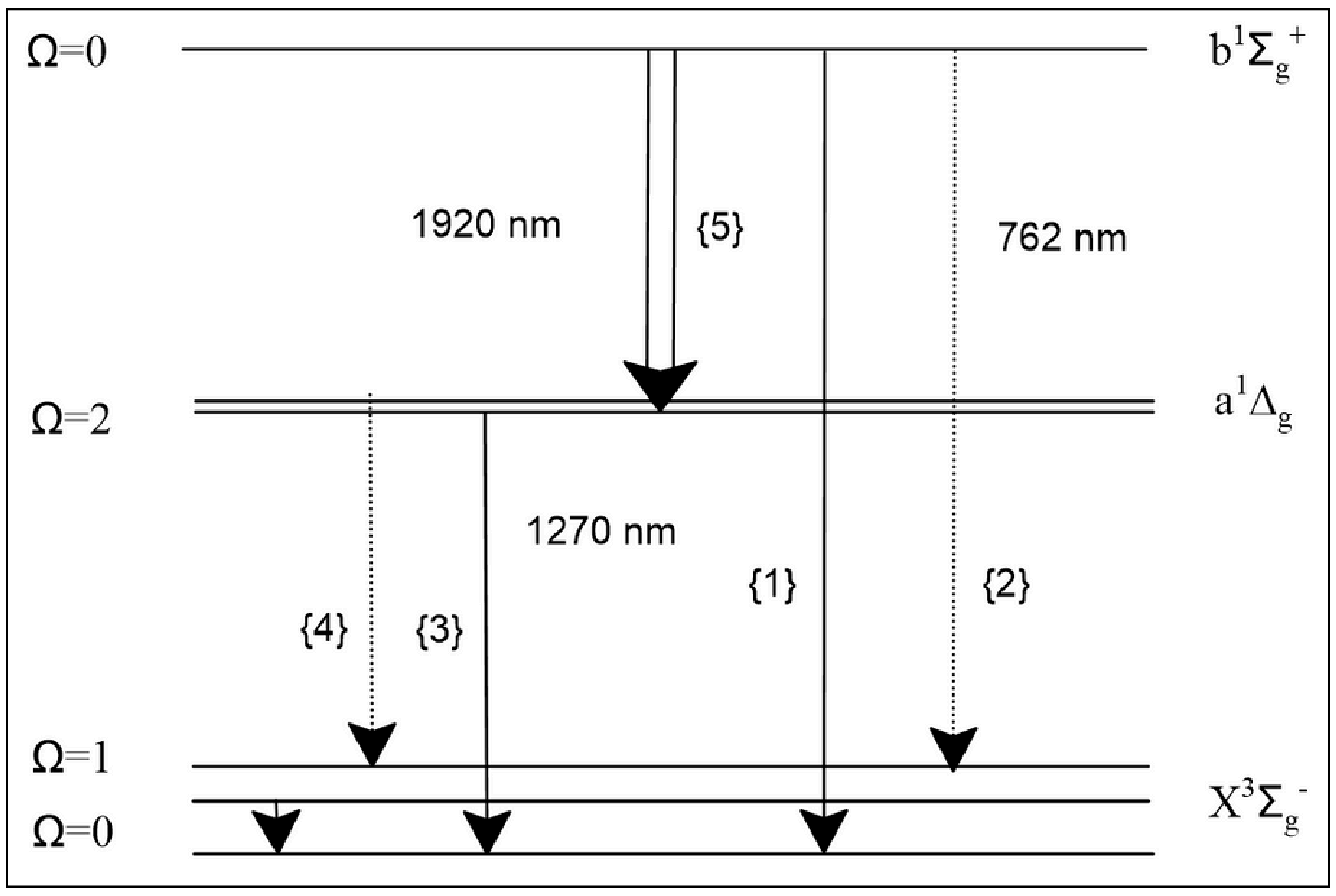
Introduction

The Fraunhofer lines are absorption lines observed in the solar spectrum that result from the absorption of light by the solar or terrestrial atmosphere. The line located at 762 nm is at the dark red edge of the visible spectrum and is the result of light absorption by atmospheric oxygen. The study of the nature of the Fraunhofer line formation in the 760 nm region will help to understand the interaction of atmospheric oxygen with solar radiation at the quantum level, which is important for the development of atmospheric spectroscopy and is used to study dynamic and chemical processes in the middle and upper layers of the Earth's atmosphere.



Results



The magnetic dipole transition moment between perturbed $b^1\Sigma_g^+$ i $X^3\Sigma_{g,1}^-$ states:

$$\boxed{\mu_{b-X,1} = \langle \phi_b | \mu | \phi_{X,1} \rangle}$$

M or μ – the magnetic dipole moment operator:

$$\boxed{M = \mu_B (L + g_e S)}$$

where μ_B is the Bohr magneton, $g_e = 2.0023$ is the electronic g-factor, the orbital (L) and spin (S) contributions.

The spin-orbit coupling between the singlet and triplet $b^1\Sigma_g^+$ and $X^3\Sigma_{g,0}^-$ states is given by:

$$\left\langle X^3\Sigma_{g,0}^- \middle\| \hat{H}_{SO} \middle\| b^1\Sigma_g^+ \right\rangle = \left\langle {}^3\Phi_0 \middle\| H_{SO}^Z \middle\| {}^1\Phi_3 \right\rangle = \left\langle \pi_x \middle\| \hat{B}_z \middle\| \pi_y \right\rangle = -i\xi_O = -153i(cm^{-1})$$

At the first-order level of perturbation theory, the wave functions of triplet (quantum number $M_S = 0$) and singlet states are mixed due to SOC :

$$\psi_b = \left| b^1\Sigma_g^+ \right\rangle + c \left| X^3\Sigma_{g,0}^- \right\rangle$$

$$\psi_{X,0} = \left| X^3\Sigma_{g,0}^- \right\rangle - c^* \left| b^1\Sigma_g^+ \right\rangle$$

where the mixing coefficient:

$$c = \frac{\left\langle X^3\Sigma_{g,0}^- \middle\| H_{SO} \middle\| b^1\Sigma_g^+ \right\rangle}{E\left(b^1\Sigma_g^+\right) - E\left(X^3\Sigma_{g,0}^-\right)} = \frac{176}{13195} = 0,0134i$$

The main contribution to the intensity of the transition b-X is made by the spin component:

$$\mu_{b-X,1}^s = C_{b,X}^* \mu_B \left\langle \psi\left(X^3\Sigma_{g,0}^-\right) \middle| g_e S_{\mp} \middle| \psi\left(X^3\Sigma_{g,1}^-\right) \right\rangle = C_{b,X}^* g_e \mu_B = -0.0268i\mu_B$$

which agree with observed intensity of the line

Conclusions

1. Oxygen, due to its unique quantum nature, causes unique optical transitions and is an interesting and important object for studying its absorption of light in the Earth's atmosphere.
2. The Fraunhofer line in the visible region of the spectrum at 760 nm arises from the $^1\Sigma_g^+ - {}^3\Sigma_g^-$ transition, which is prohibited by the selection rules for the electro-dipole transition, but due to spin-orbit interaction can occur due to the magnetic dipole moment of the transition and is a magnetic-dipole allowed transition.
3. The transition $^1\Sigma_g^+ - {}^3\Sigma_g^-$ in the visible region (red band 762 nm) takes the intensity from the microwave transition between the spin magnetic sublevels $^3\Sigma_{g,0}^- - {}^3\Sigma_{g,1}^-$ (magnetic-dipole EPR transition induced by the spin operator).

References

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