

Introduction to Atomic Physics

Lab Report

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1 Theory

1.1 Atomic structure and electron energies

Atoms are build up by a positive core and negatively charged electrons circulating around it. The wave functions of the electrons are distinguished by their quantum numbers, which in the Bohr model for hydrogen are given by the principal number n , the orbital angular momentum l and its z-component m_l , the spin s and its z-component m_s .

In fine structure theory relativistic effects are taken into account. That is a relativistic correction to the kinetic energy, a coupling between spin angular momentum and orbital angular momentum, and the Darwin term. As the hamiltonian of the spin-orbit coupling does not commute with the operators L_z and S_z , m_l and m_s are no longer good quantum numbers. Instead we use the total angular momentum j and its z-component m_j .

Depending on the quantum numbers, the electrons have different energies. According to the Bohr model for hydrogen, the energies only depend on the principal quantum number n : The energy increases for larger n . The fine structure removes some of this degeneracy: According to this, the energy also depends on the the total angular momentum j . Again the energy increases with the total angular momentum.

If the spin of the nucleus is taken into account, the energy becomes dependent on this as well, giving rise to the hyperfine structure. Quantum electro dynamics also gives rise to a shift in energy depended of the quantum number l . These effects are not relevant in this exercise.

1.2 Many electron atoms and transitions

Other atoms than hydrogen has many electrons circulating around the nucleus which interact with each other. The inner electrons (with low n and l values) are 'screening' the positive nucleus from the outer electrons, which are thereby looser bound to the atom. The higher n and l the electrons have, the farther away the electron is from the nucleus and the larger will this screening effect be. The energy of the electrons will thus increase for higher l . The a Grotrian digram for sodium can be seen in figure 2.

It is possible for an electron to make a transition between two quantum states through emission of a photon. As the photon has a spin of 1, there must be a difference in orbital angular momentum of 1 between the two states: $\Delta l = \pm 1$. The emitted photons have

a well defined wavelengths proportional to the energy difference of the quantum states, this gives rise to spectral lines characteristic of the different elements.

As indicated in figure 2 this energy difference between the states is dominated by the difference in quantum numbers n and l , due to Bohr's atom model and the screening effects. Fine structure will, though, cause a slight energy difference depending the the quantum number j . This will be seen as splitting of the spectral lines.

2 Setup and Procedure

In the experiment we study the spectral lines of sodium. Different wavelengths of sodium light are separated in a crystal in a spectrometer, and the spectral lines can hereby be observed and the wavelengths measured.

In part a of the exercise we use a low pressure Na-lamp to calibrate the spectrometer. We measured the wavelength of the characteristic yellow double line 10 times going from low to high frequencies and 10 times going from high to low frequencies, and set the spectrometer so the mean value corresponded to the tabular values. Afterward we studied the full spectrum, noting the wavelength, colour, sharpness and intensity of the all the lines we could identify, and the number of splittings.

In part b of the exercise we studied the spectrum from a high pressure Na lamp, noting the same parameters as in part a.

3 Results and Discussion

3.1 Part a

We measured the center of the yellow doublet, which should be at $\lambda = 5893 \text{ \AA}$, to be

	Mean (\AA)	σ (\AA)
From low frequency	5890	2.29
From high frequency	5885	2.07

We measured the following wavelengths and identified them

$\langle \lambda \rangle$ (\AA)	σ (\AA)	λ_{tabular} (\AA)	Tabular line splitting	Description	Transition
6164	5	6157	Sharp red doublet	doublet	3p-5s
5898	4	5892	Sharp yellow doublet	doublet	3s-3p
5692	3	5685	Sharp green doublet	triplet	3p-4d
5155	3	5151	Sharp cyan doublet	doublet	3p-6s
4990	3	4980	Sharp blue doublet	doublet	3p-5d
4757	3	4749	Diffuse violet singlet	doublet	3p-7s
4674	3	4666	Diffuse violet doublet	doublet	3p-6d
4556	4	4543	Diffuse violet singlet	doublet	3p-8s
4502	3	4496	Diffuse violet singlet	doublet	3p-7d

The reason we identify the green line at $\lambda = 5685 \text{ \AA}$ as a doublet is that two of the lines lie so close that they are almost impossible to distinguish. The reason we identify the violet lines as singlets is that they are so faint that it is impossible to distinguish.

We do not see the expected connection between the spectroscopic designation (s,p,d,...) and the sharpness of the spectral lines. This is most likely because it was very hard to see, and we mostly designated sharp and diffuse based on the intensity.

We made a plot of the tabular values of the wavelength and our measured wavelength and got the calibration curve shown in figure 1.

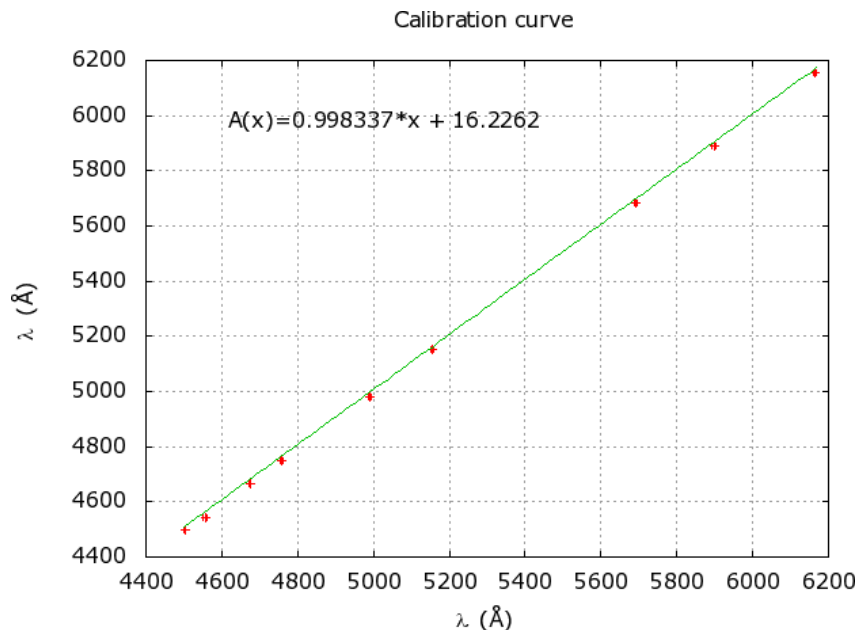


Figure 1: Calibration curve for our experiment.

A Grotrian diagram of the transitions can be seen as figure 2.

3.2 Part b

When we measured the spectral lines from the high pressure lamp, we found several of the same lines as using the low pressure lamp, but also five lines that did not belong in the sodium spectrum. Using available literature, and in particular the supplied Bright Line Spectra figure, we determined that the lines that were not sodium were most likely argon. We reached this conclusion because argon has lines corresponding to all five lines we could not identify as being from sodium, we got numerical values for these lines from the CRC Handbook of Chemistry and Physics 84th edition, however there was no data for the line splitting.

Using the calibration curve (figure 1), we got the following calibrated wavelengths, which we compare to the tabular values of sodium and argon.

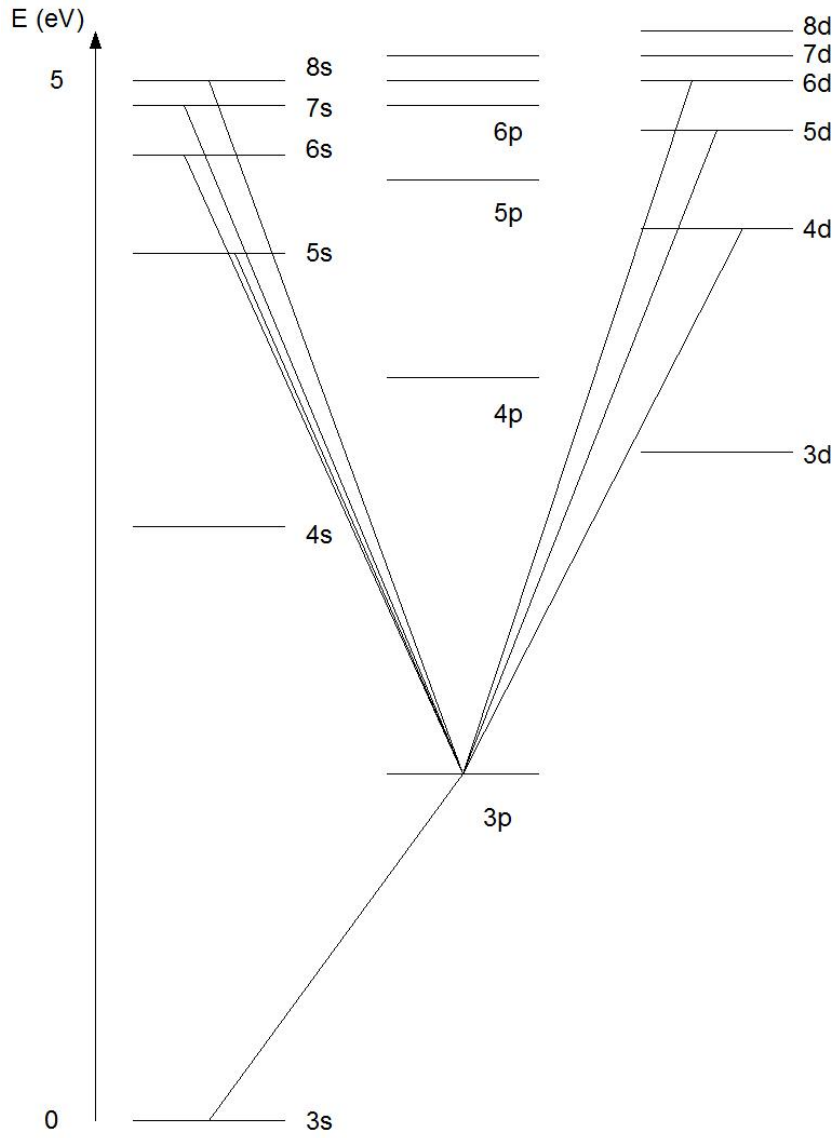


Figure 2: Grotrian diagram of the visible spectrum of sodium.

$\lambda_{calibrated}$ (Å)	λ_{Na} (Å)	λ_A (Å)	Description	Tabular line splitting
6745		6753	Sharp red singlet	doublet doublet
6193	6157		Sharp red doublet	
5926	5892		Black singlet	
5713		5713	Diffuse yellow singlet	doublet doublet
5485		5470	Sharp green/cyan doublet	
5361		5346	Sharp black doublet	
5164	5151		Green singlet	doublet doublet
4995	4980		Diffuse green singlet	
4370		4364	Diffuse violet singlet	

It is interesting to note that the yellow line we for the low pressure lamp had around $\lambda = 5893 \text{ Å}$ and the cyan line around $\lambda = 5151 \text{ Å}$ have turned black. This is because the high pressure send out light in the full visible spectrum, and the black lines come from

absorbption by the sodium atoms, whereas the coloured lines came from emission.

4 Conclusion

Using a spectrometer we studied the spectral lines of light emitted from low and high pressure Na lamps. We found a clear correspondence between the the wavelengths of the observed lines and the tabular values. In the high pressure Na lamp we found five lines originating from a Argon. We could not find a clear connection between the sharpness of the lines and the quantum number l , and it was not always possible to identify the correct number of splittings of the spectral lines, caused by fine structure theory.