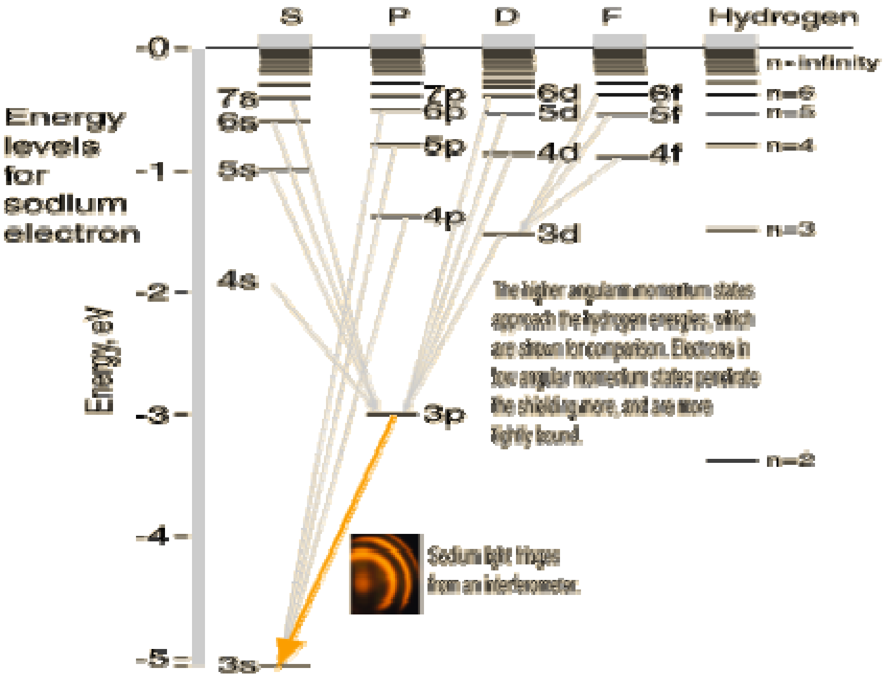
Sodium Energy Levels

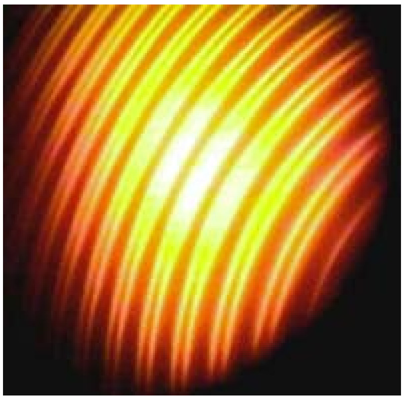


Sodium spectrum	Why do levels vary with orbital quantum number?

Electron energy level diagrams

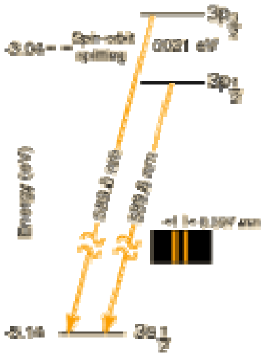
Sodium Spectrum

The sodium spectrum is dominated by the bright doublet known as the Sodium D-lines at 588.9950 and 589.5924 nanometers. From the energy level diagram it can be seen that these lines are emitted in a transition from the 3p to the 3s levels. The line at 589.0 has twice the intensity of the line at 589.6 nm. Taking the range from 400-700nm as the nominal visible range, the strongest visible line other than the D-lines is the line at 568.8205 which has an intensity about 0.7% of that of the strongest line. All other lines are a factor of two or more fainter than that one, so for most practical purposes, all the light from luminous sodium comes from the D-lines.



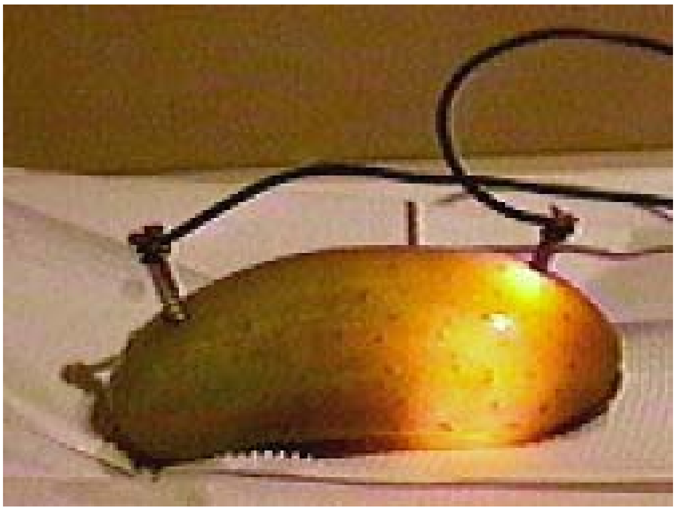
The illustration at left shows the interference pattern formed by the sodium doublet in a Fabry-Perot interferometer. At right is a sketch of the origin of the sodium doublet.

Sodium light from an electric pickle!



The Electric Pickle

A far-fetched example of a non-ohmic resistor is the electric pickle. A considerable amount of light can be obtained by connecting ordinary household 120 volt AC voltage across a pickle. After the pickling process, there are Na+ and Cl- ions present. The standard explanation is that the electric current excites the sodium ions, producing light similar to that of a sodium lamp.



Thanks to Brian Lucy for this example.

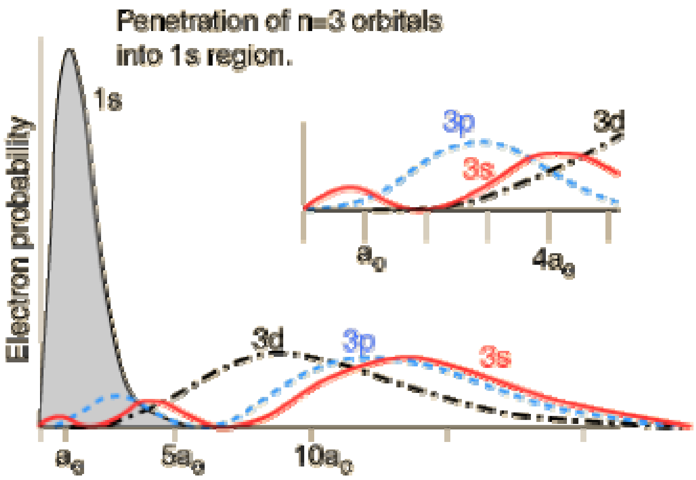
Currents in ionic solutions are often not linearly proportional to the applied voltage. When Ohm's law is used with ordinary carbon resistors, the ratio of voltage to current is constant, but the variation in light output suggests that this is not the case with the electric pickle.

Electric pickle movie

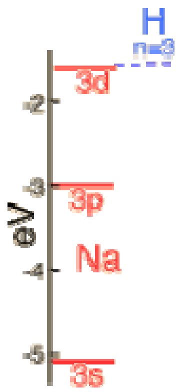
Níveis de energia do Sódio

http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/sodium.html#c2

Sodium Energy Levels:Orbital Dependence



The sodium 3s level is significantly lower than the 3p because of greater penetration past the shielding of the 1s electron.



Both levels penetrate enough to be significantly lower than the n=3 hydrogen energy which they would have if the shielding were perfect.

Why do levels vary with orbital quantum number?	Sodium doublet

HyperPhysics***** Quantum Physics *R Nave*

The Sodium Doublet

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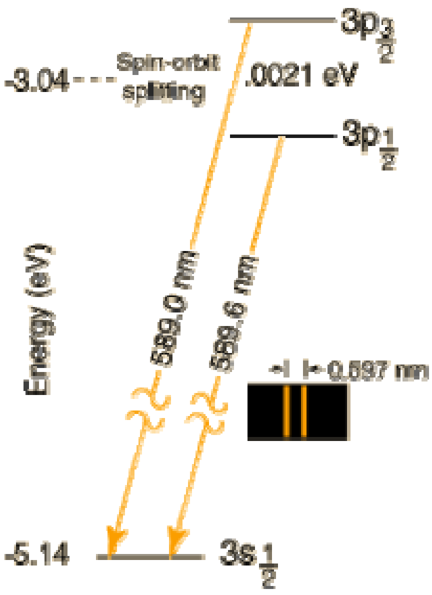
Other spectra

References
Thornton & Rex
Sec 9.2

Serway, Moses, Moyer
Sec 8.3



The well known bright doublet which is responsible for the bright yellow light from a sodium lamp may be used to demonstrate several of the influences which cause splitting of the emission lines of atomic spectra. The transition which gives rise to the doublet is from the 3p to the 3s level, levels which would be the same in the hydrogen atom. The fact that the 3s (orbital quantum number = 0) is lower than the 3p (l=1) is a good example of the dependence of atomic energy levels on angular momentum. The 3s electron penetrates the 1s shell more and is less effectively shielded than the 3p electron, so the 3s level is lower (more tightly bound). The fact that there is a doublet shows the smaller dependence of the atomic energy levels on the total angular momentum . The 3p level is split into states with total angular momentum j=3/2 and j=1/2 by the magnetic energy of the electron spin in the presence of the internal magnetic field caused by the orbital motion. This effect is called the spin-orbit effect. In the presence of an additional externally applied magnetic field, these levels are further split by the magnetic interaction, showing dependence of the energies on the z-component of the total angular momentum. This splitting gives the Zeeman effect for sodium.

The magnitude of the spin-orbit interaction has the form $\mu_z B = \mu_B S_z L_z$. In the case of the sodium doublet, the difference in energy for the $3p_{3/2}$ and $3p_{1/2}$ comes from a change of 1 unit in the spin orientation with the orbital part presumed to be the same. The change in energy is of the form

$$\Delta E = \mu_B g B = 0.0021 \text{ eV}$$

where μ_B is the Bohr magneton and g is the electron spin g-factor with value very close to 2. This gives an estimate of the internal magnetic field needed to produce the observed splitting:

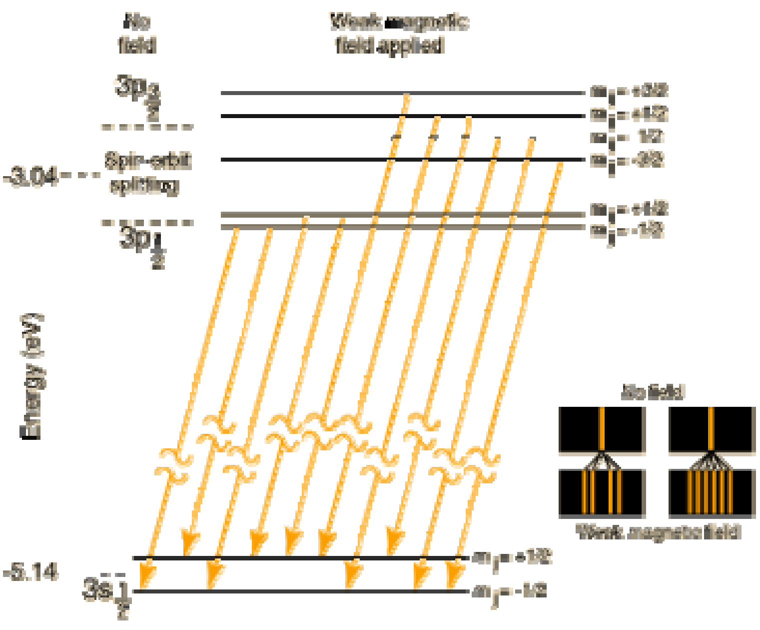
$$\mu_B g B = (5.79 \times 10^{-5} \text{ eV/T}) 2B = 0.0021 \text{ eV}$$

$$B = 18 \text{ Tesla}$$

This is a very large magnetic field by laboratory standards. Large magnets with dimensions over a meter, used for NMR and ESR experiments, have magnetic fields on the order of a Tesla.

The Sodium Zeeman Effect

The sodium spectrum is dominated by the bright doublet known as the Sodium D-lines at 588.9950 and 589.5924 nanometers. From the energy level diagram it can be seen that these lines are emitted in a transition from the 3p to the 3s levels.



The sodium doublet is further spit by the application of an external magnetic field (Zeeman effect). Using the vector model for total angular momentum, the splitting is seen to produce one level for each possible value of the z-component of the total angular momentum J.

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The size of the magnetic energy contribution depends upon a geometrical factor called the Lande' g-factor. The values for the relevant quantum numbers and the associated values for the Lande' g-factor are shown in the table below.

Term	J	L	S	g_L
$3p_{3/2}$	3/2	1	1/2	4/3
$3p_{1/2}$	1/2	1	1/2	2/3
$3s_{1/2}$	1/2	0	1/2	2

Examination of the size of the Lande g-factor g_L for the three levels will show why the splittings of the different levels are different in magnitude. The selection rules explain why the transitions shown are allowed and others not.

Some history

Sodium Zeeman Effect: Early Observations

The splitting of the sodium doublet in the presence of an external magnetic field was observed by Pieter Zeeman in 1896, and the effect was subsequently named the Zeeman effect. It is remarkable that so much detailed spectroscopy was done long before the Bohr theory, and perhaps even more remarkable that Zeeman's first study of the sodium Zeeman splitting was done the year before J. J.Thomson's discovery of the electron in 1897.

After Thomson's work, Zeeman and Lorentz did further study of the influence of magnetic fields on the spectral emissions from atoms. By analysis of the splitting of the sodium doublet, they were able to demonstrate that the charge to mass ratio of the charge responsible for the splitting was the same as Thomson's electron. This was the first direct demonstration that electrons were involved in the production of the spectral line emissions.

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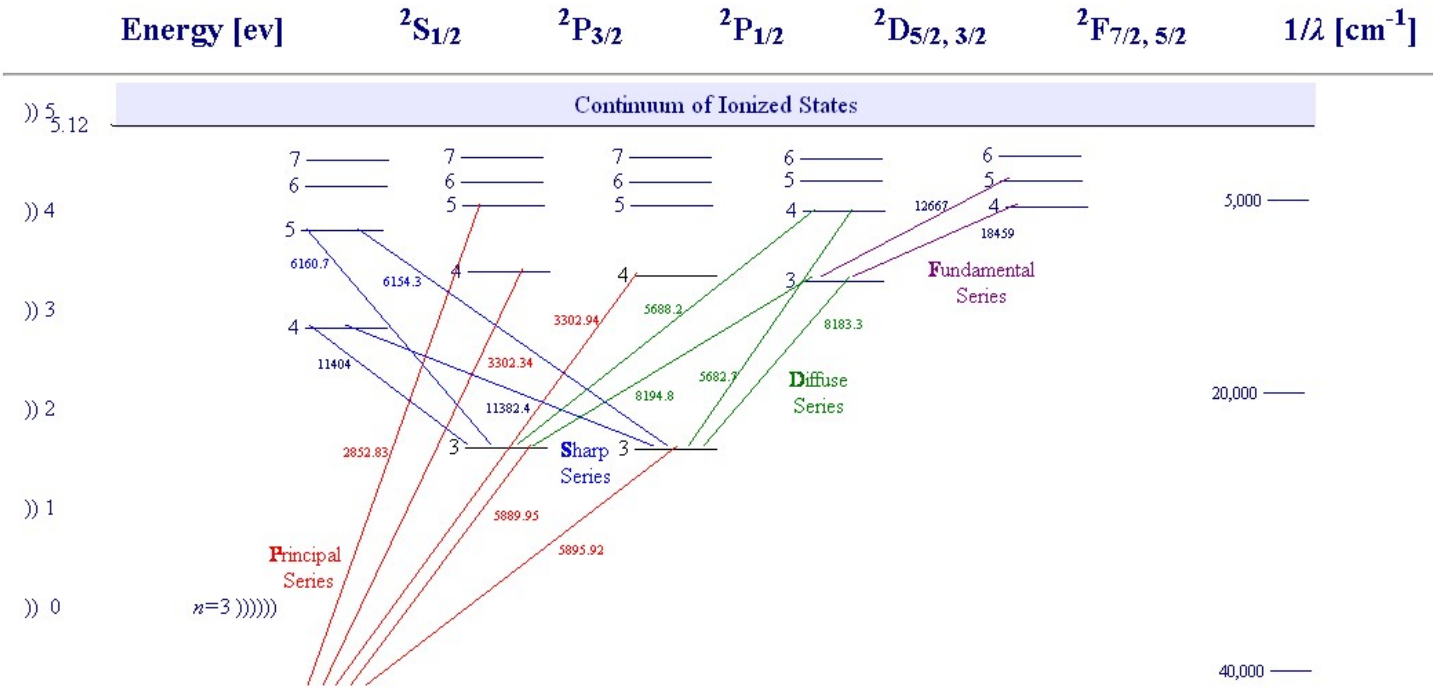
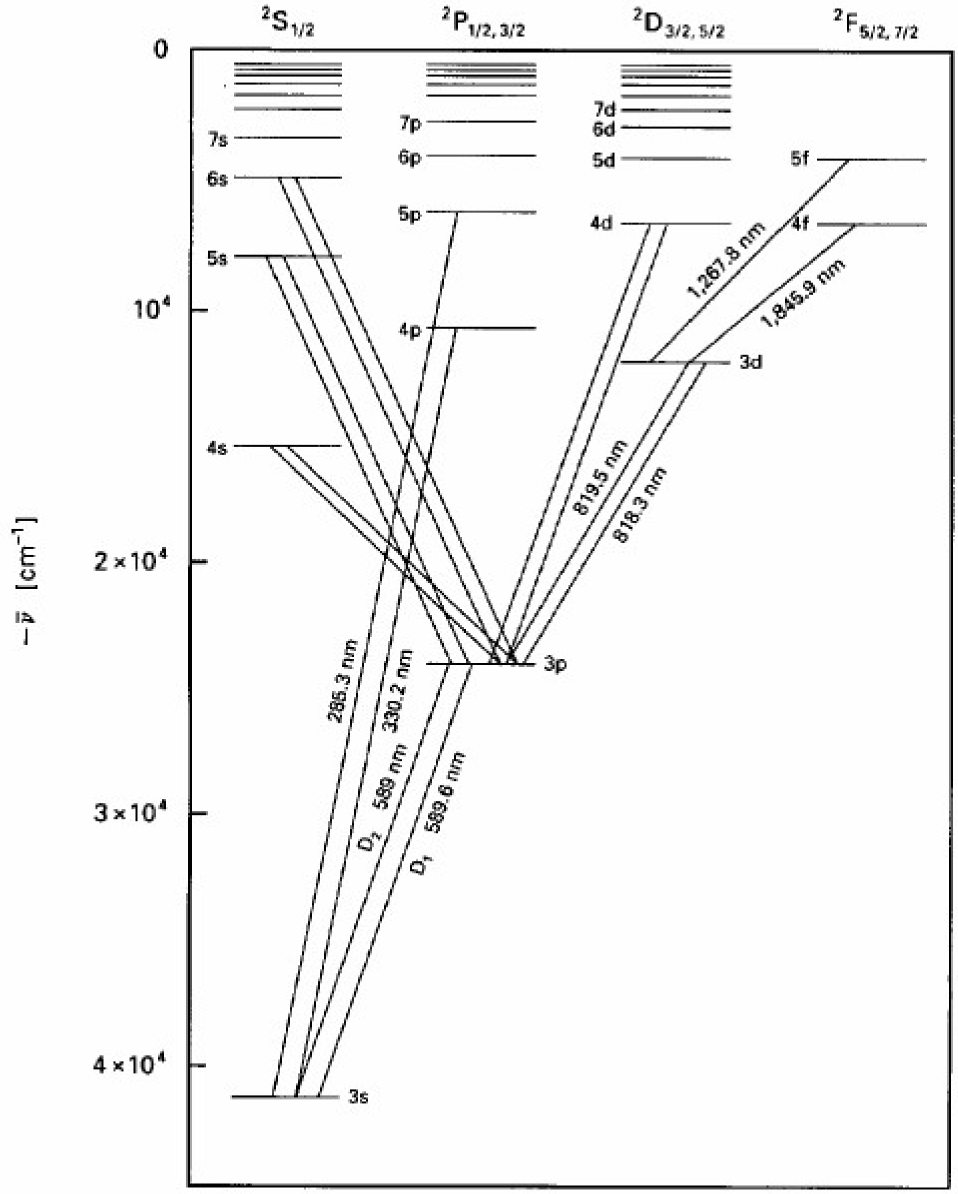
Reference
Leighton
Ch 2

Grotrian Diagram for Sodium

(Transition λs are given in D. Wave numbers are given in cm^{-1} for recombination photons.)





4p to 5p: to 3s ; ΔE=(6.63E-34 Js)(3E8 m/s)(1/285.3E-9 m – 1/330.2E-9 m) = 9.48E-20 J
4f to 5f: to 3d ; ΔE=(6.63E-34 Js)(3E8 m/s)(1/1267.8E-9 m – 1/1845.9E-9 m) = 4.91E-20 J
3d levels: to 3p ΔE=(6.63E-34 Js)(3E8 m/s)(1/818.3E-9 m – 1/819.5E-9 m) = 3.56E-22 J