Advanced Atomic and Molecular Physics

Final Exam

Dear Students, please aim for short and economic answers. In many cases, a single sentence will be sufficient to answer the extra questions. When discussing experimental setups, please also provide labelled sketches.

All the best,

Andreas Hauser

1) Interferometry

- (4p) How is the free spectral range of an interferometer defined? Derive an expression for $\Delta\lambda_{FSR}$ and transform to $\Delta\nu_{FSR}$.
- (3p) Draw the transmission intensities as a function of the frequency for a Fabry-Perot interferometer with a large and with a small value for the finesse F.
- (1p) Which effect, occurring only for the directly reflected beam, guarantees that the transmitted and the reflected interference patterns are opposite at all times?
- (1p) How is the resolution related to the finesse?
- (1p) Which property must your source of light have if you want to project the interference pattern of plane-parallel plate without additional lenses (draw a sketch)?

2) Photo Electron Spectroscopy

a) (3p) Describe the basic principle of photo electron spectroscopy (PES) and distinguish between the techniques UPS, XPS and ESCA.
b) (3p) How does ZEKE (Zero Kinetic Energy) -PES work? What is its advantage compared to normal PES?
c) (2p) In a ZEKE setup we assume radial symmetry and a detection zone with a radius of r = 2 mm. How large is the maximum kinetic energy of the electrons which will still be detected in a measurement delayed by $\tau = 1$ ms?
d) (2p) Draw the following figure: Assume an arbitrary diatomic molecule consisting of atoms A and B and draw its potential energy surface in its electronic ground state with asymptotic energy A+B. Now add another potential energy surface for an ionized state of the same system with asymptote $A+B^+$. For a given ionization energy E_{ion}, draw the expected kinetic electron energies. Which principle, typically applied to vibronic transitions between bound states, can tell you something about the actual distribution of electron kinetic energies in this case?

3) From Hund-Mulliken-Bloch to Hartree-Fock

a) (3p) What is our ansatz for the total electron wavefunction of H_2 (not for the Hamiltonian) in the Hund-Mulliken-Bloch approach? How do we build molecular orbitals? Write down the wave function for the electronic ground state, a "singlet" state.
b) (2p) The concept of Slater-Determinants extends this approach towards N-electron systems. How?
c) (3p) The Hartree-Fock method is based on the same ansatz for the wave function. Characterize this fundamental method of electronic structure theory in a few keywords. What kind of method is it? What is minimized, and how is this achieved?
d) (2p) Which dependence enforces the HF method to be iterative? Do the Lagrange multipliers we introduced have a physical meaning? Does HF retrieve the exact electronic energy?

PLEASE TURN OVER

4) Atomic beam magnetic resonance

a) (3p) Describe the principle and the setup of the atomic beam magnetic resonance experiment of Rabi. Provide a labelled sketch of the apparatus.

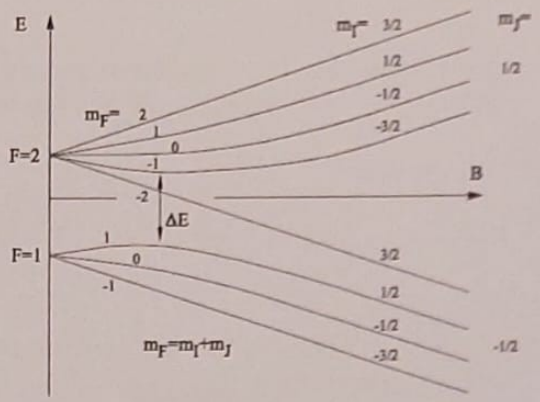
b) (1p) Why is it necessary to apply an inhomogeneous magnetic field in the first and the third section?

c) (1p) Why is a homogeneous magnetic field applied in the middle section?

d) (1p) Look at the figure to the right. What are the quantum numbers I, J and F denoting?

e) (1p) How do we call the regime in which F is still a good quantum number?

f) (1p) Which of the upper m_F levels is particularly well suited for this experiment and why?



g) (2p) How large should the field gradient of a 20 cm long magnetic field be to achieve a deflection of sodium atoms (m = 23 u) in their $^2S_{1/2}$ state by 3° in a Rabi-type apparatus if the atoms fly with v = 600 m/s through the field? ($\mu_B = 9.27 \cdot 10^{-24}$ J/T)

5) Laser absorption and Doppler cooling

a) (2p) What is the reason for Doppler-broadening of spectral lines? What is the typical shape of such a profile and how is it different from natural broadening?

b) (1p) What is the reason for the natural linewidth of a molecular transition?

c) (2p) Describe the principle of Doppler-cooling in detail. What is the Doppler temperature?

d) (2p) Often, Doppler-cooling is combined with magnetic trapping forces. Describe a typical experimental setup (sketch) and explain the principle.

e) (3p) A laser beam ($\lambda = 500$ nm) with 100 mW power runs through an absorption cell with absorption coefficient $\alpha = 10^{-6}$ cm^{-1}. How many fluorescence photons are emitted per cm path length if every absorbed laser photon yields a fluorescence photon? How large is the output current of a photo detector if it catches the fluorescence emitted into a solid angle of 0.2 sterad, its cathode has a conversion efficiency of 40%, and the current amplification of the detector is 10^6 ?

Universal Constants

Speed of light	$c = 2.998 \times 10^8\ m/s$
Planck's constant	$h = 6.626 \times 10^{-34}\ Js$
Electron charge	$e = 1.602 \times 10^{-19} C$
Electron mass	$e = 9.109 \times 10^{-31} kg$
Atomic mass unit	$u = 1.660 \times 10^{-27} kg$