Resit Structure of Matter 2022
Tuesday 12 July, 16.00-18.00

Write your name and student number on every sheet you hand in.

PROBLEM 0: Which resit?

You can either resit all of Structure of Matter (SoM), i.e. the full 10 ECTS course, or take only part 1, or take only part 2. *You have to decide*. For full SoM answer problems 1-3, and 5-7 (*so not 4 and 8*), for part 1 answer problems 1-4, for part 2 answer problems 5-8.

Which exam would you like to take? Write this down on your answer sheet!

A: full SoM, 10 ECTS, problems 1-3 and 5-7

B: part 1, problems 1-4

C: part 2, problem 5-8.

Note: regardless your answer 0, you have two hours to complete this exam unless you qualify for extra time.

Extra-time students: 10 minutes per hour => 20 min extra

Without explanation or calculation steps no points will be awarded to a sub-problem even if the answer is correct!

PROBLEM 1. Elementary Particles [10 points]

Consider a charmed baryon with quark content usc decaying into p + K^- + π^+.

Hint: quark compositions of p^+: uud and K^-: $s\bar{u}$

a) Which conservation law is violated? Explain your answer. [2 pts]
b) What is the flavor change that occurs and which particles are created or annihilated? Explain your answer. [2 pts]
c) What is the approximate time scale of the decay? Explain your answer. [2 pts]
d) Explain why mesons are much heavier than their individual quarks [2 pts]
e) K^{*-} mesons are the second lightest mesons with the same quark content as K^- mesons. What are the J value and parity of K^{*-} mesons? Explain your answer [2 pts]
f) Proof whether K^- mesons are eigenstates of the charge conjugation operator? Explain your answer. [2 pts]

PROBLEM 2. Hydrogen [10 points]

Consider a Au^{6+} ion (....$5d^5$).

a) Sketch the radial part of this 5d wave function (rR_{5d}). Indicate how you determined the shape of the wave function. [2 pts]
b) Calculate the binding energy of hydrogen-like N^{6+}(5d). [2 pts]
c) Explain why the ionization potential of Au^{6+} is much higher, higher, equal, lower or much lower than N^{6+}(5d). [2 pts]
d) Determine the ground term and level of Au^{6+}. Explain all steps in your answer. 3 [4 pts]

PROBLEM 3. Nuclei [8 points]

Use the generic sequence of nuclear shell filling: 1s, 1p, 1d, 2s, 1f, 2p, 1g, 2d, 1h....

a) Why are all even-even nuclei 0^+ nuclei? Motivate/explain your answer. [3 pts]
b) What is the nuclear spin and parity of $^{123}_{51}\mathrm{Sb}$. Explain all steps in your answer. [5 pts]

PROBLEM 4. Nuclei and Atoms [7 points]

Only answer this problem if you're taking SoM part 1.

a) Consider the isotope $_{19}\mathrm{K}$, which has a nuclear spin of I = 4. Give reasons why this is either an even-odd or odd-odd isotope. [3 pts]
b) Determine the hyperfine levels for a $_{19}\mathrm{K}$ atom in an electronic J=3/2 level. [2 pts]
c) Sketch the behavior of the states of one of the hyperfine levels as a function of a weak magnetic field B. Indicate the relevant quantum numbers. [2 pts]

PROBLEM 5. Molecular orbital diagrams [9 points]

a) Draw a molecular orbital diagram for O_2. Your diagram includes labelled & numbered atomic and molecular orbitals, bonding/anti-bonding character, and includes electrons in the appropriate orbitals. You do not need to draw pictures of the orbitals. [3 pts]

b) Calculate the bond order for O_2. [1 pt]

c) Does the bond order change when an electron is removed from O_2? If so, how? [1 pt]

d) Does the bond order change when an electron is added to O_2? If so, how? [1 pt]

e) Of the following species, which (if any) are paramagnetic: O_2, O_2^+ and O_2^-? [3 pts]

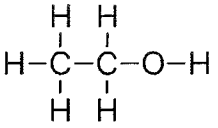
PROBLEM 6. Shapes of molecules and spectroscopy [9 points]

a) Which of the following molecules may show a pure rotational microwave spectrum and why: N_2, HBr, C_2H_6, C_2H_5Br, and $C_2H_4Br_2$? [2 pts]

b) Which of the following molecules may show infrared absorption spectra and why: N_2, HBr, NH_3, CH_2O? [2 pts]

c) What is the hybridization of the carbon atoms and the oxygen atom in ethanol molecules (see below)? Explain your answer. [2 pts]

d) How many vibrational modes does the ethanol molecule have? Explain your answer. [3 pts]



PROBLEM 7. Crystal lattices [9 points]

a) Draw the arrangements of atoms on the (100) and (110) planes of a bcc crystal with lattice spacing *a*. Indicate the lengths of the sides in your drawing. [4 pts]

b) A crystal lattice has a set of primitive vectors:

$$\vec{a}_1 = (a/2)\hat{x} + (a/2)\hat{y}$$
$$\vec{a}_2 = a\hat{y}$$
$$\vec{a}_3 = (a/\sqrt{2})\hat{z}$$

Calculate the primitive vectors of the reciprocal lattice and identify the type of crystal to which the reciprocal lattice belongs. [5 pts]

PROBLEM 8. Semiconductors [9 points]

Only answer this problem if you're taking SoM part 2.

A crystalline silicon wafer (band gap 1.12 eV) is n-doped by adding suitable atoms at a concentration of 5×10^{15} per cubic centimetre. Next, to make a pn-junction, part of the wafer is p-doped at a concentration of 5×10^{18} cm^{-3}. Assume that the pn-junction is kept in the dark and no voltage is applied. Assume that all doping atoms are ionized and that kT = 0.025 eV. The effective density of states of the conduction band, resp. valence band, of silicon is $N_C = 3.22\times10^{19}$ cm^{-3}, respectively $N_V = 1.83\times10^{19}$ cm^{-3}.

a) Draw an energy band diagram of this pn junction and indicate the direction of electron drift and electron diffusion. [3 pts]

b) Calculate the energy difference (in eV) between the Fermi level and the conduction band in the n-layer. [2 pts]

c) Calculate the energy difference (in eV) between the Fermi level and the valence band in the p-layer. [2 pts]

d) What is the density of minority carriers in the n-layer? [2 pts]