Växjö universitet

TENTAMEN

Institution: MSI, Fysik

Examinator: Pieter Kuiper

Datum: 27 oktober 2009

Tid:

Plats:

Kurskod: FY2022

Kurs/provmoment: Fasta Tillståndets Fysik I

Hjälpmedel: linjal, räknedosa, två sidor egna anteckningar, ”Si-kristall”

Namn: ....

Adress: ....

....

Personnummer: ☐☐☐☐☐☐ – ☐☐☐☐

Skriv helst lösningarna på tentan. Skriv ditt namn på eventuella tillägsblad.

Den här tentan har 0 problem.

Lycka till!

	1	2	3	4	5	Summa	Betyg
Inlämnad							
Poäng							

Uppvisat legitimation:	Ja ☐	Nej ☐
Uppvisat kårlegitimation:	Ja ☐	Nej ☐
Tid för inlämning:	Tentavaktens signatur:	

LÖSNINGAR

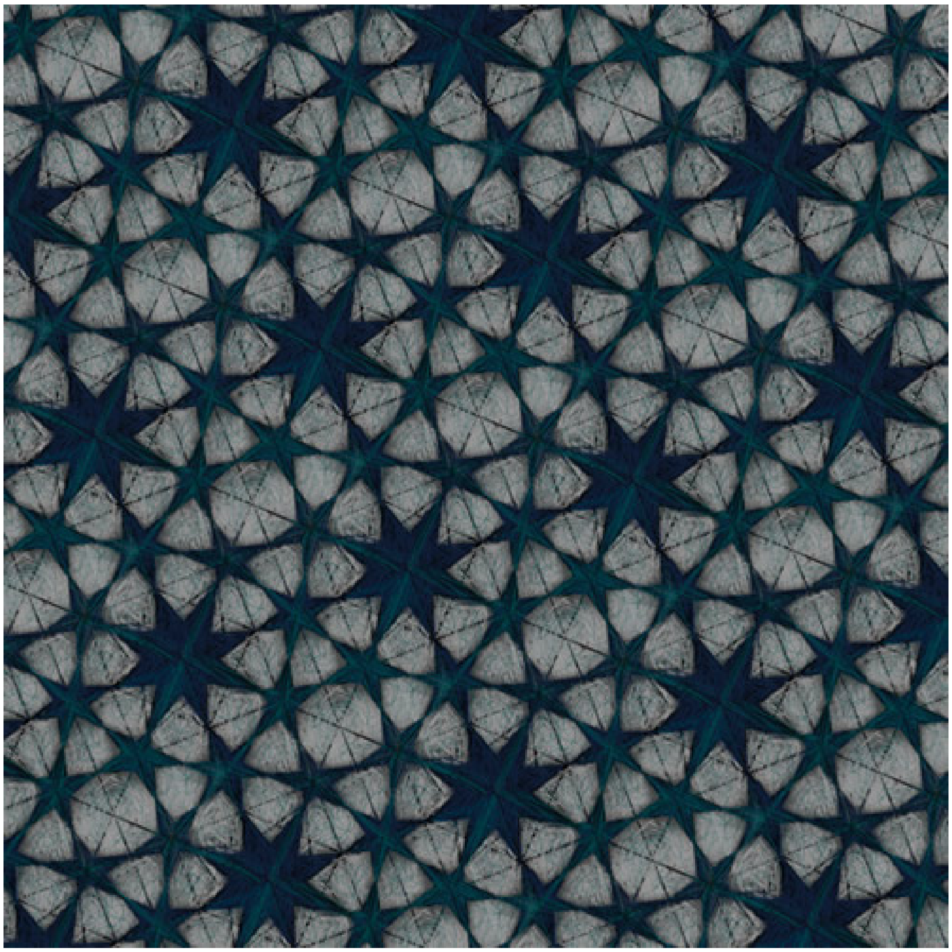
Tabell 1: Några utvalda naturkonstanter:

Namn	Symbol	Värde	Enhet
Ljushastighet	c	$2{,}998.10^{8}$	m/s
Elementarladdning	e	$1{,}602.10^{-19}$	C
Plancks konstant	h	$6{,}626.10^{-34}$	Js
	$\hbar$	$1{,}055.10^{-34}$	Js
Finstrukturkonstanten	α	1/137,04	
Boltzmanns konstant	k_B	$1{,}381.10^{-23}$	J/K
Absoluta nollpunkten		-273,15	°C
Avogadros tal	N_A	$6{,}022.10^{23}$	mol^{-1}
Gaskonstanten	$R = k_B N_A$	8,314	J/(mol K)
Coulombkonstant	$1/(4\pi\epsilon_0)$	$8{,}99.10^{9}$	$\mathrm{Nm}^2/\mathrm{C}^2$
Elektriska fältkonstanten	ϵ_0	$1/(\mu_0 c^2)$	As/Vm
Magnetiska fältkonstanten	μ_0	$4\pi \times 10^{-7}$	$\mathrm{Vs/Am} = \mathrm{N/A}^2$
Elektronens massa	m_e	$9{,}109.10^{-31}$	kg
Protonens massa	m_p	$1{,}673.10^{-27}$	kg
Atomära massenheten	amu	$1{,}661.10^{-27}$	kg
Bohr magneton $eh/2m_e$	μ_B	$9{,}274.10^{-24}$	J/K
Bohr radie	a_0	$5{,}292.10^{-11}$	m
Rydberg	R_∞	13,606	eV
Lorentztal	L	$2{,}45.10^{-8}$	$\mathrm{W\Omega/K}^2$
Madelungkonstant (NaCl)	α	1,747565	
tyngdkraftens acceleration	g	9,81	$\mathrm{m/s}^2$

Tabell 2: Några viktiga data för halvledare:

•	Kisel	Germanium	Galliumarsenid	Indiumantimonid
•	Si	Ge	GaAs	InSb
E_g (eV) vid 300 K	1,1	0,72	1,4	
E_g (eV) vid 0 K	1,21	0,785	1,52	
densitet ($\mathrm{g/cm}^3$)	2,33	5,32		
Atommassa	28,09	72,59		
gitterkonstant a (Å)	5,431	5,657		
n_i (m^{-3}) vid 300 K	$1{,}5.10^{16}$	$2{,}5.10^{19}$	$1{,}1.10^{13}$	
ϵ_r	12	16	11	
m_n^*/m_e	0,43	0,60	0,065	
m_p^*/m_e	0,54	0,28	0,5	
μ_n (m^2/Vs)	0,13	0,38	0,85	
μ_p (m^2/Vs)	0,05	0,18	0,04	

Problem 1. Figuren nedan är ett mönster ritat av John Dilworth. The figure below is a lattice drawn by John Dilworth.



a) Rita en translationsvektor **T** i figuren som lämnar mönstret oförändrat. Draw in the figure a translation vector **T** which transforms the lattice into itself. (1p)

Lösning: There is an infinity of correct solutions. 1

b) Rita två basvektorer **a** och **b** samt en enhetscell. Draw two base vectors **a** and **b** as well as a unit cell. (1p)

Lösning: A square unit cell is suitable. 1

c) Markera alla gitterpunkter i figuren som genereras av **a** och **b**. Mark all lattice points in the figure that are generated by **a** and **b**. (1p)

Lösning: Be consistent: $\mathbf{R} = n\mathbf{a} + m\mathbf{b}$. In this figure, a primitive lattice should contain about 10 to 15 points (depending a bit on the choice of origin); I should have asked for a complete set of lattice points instead. 1

Problem 2. It is well known that mercury is a liquid metal with a density of 13.6 gram per millilitre. Its atomic weight is 200.6 amu and there are two valence electrons per atom. The resistivity at room temperature is $9.58 \cdot 10^{-7}$ Ωm.

a What is the Fermi energi in eV? (1p)

Lösning: 1

One millilitre contains 13.6/200.6 mole of atoms or about 0.136 times Avogadro's number of electrons. So the electron concentration is $8.17 \cdot 10^{28}$ m^{-3} or 0.0817 Å^{-3}. This gives a Fermi energy of $1.10 \cdot 10^{-18}$ J = 6.88 eV.

b) What is the Drude relaxation time? (1p)

Lösning: 1

$\tau = \frac{m_e}{\varrho n e^2} = 4.5 \cdot 10^{-16}$ s.

c) How long is the mean free path for electrons? (1p)

Lösning: 1

$\lambda = v_F \tau = \sqrt{\frac{2E_F}{m_e}} \times \tau = 1.55 \cdot 10^6 \times 4.5 \cdot 10^{-16} = 7.0 \cdot 10^{-10}$ m.

d) How does this compare to distances between mercury atoms? (1p)

Lösning: 1

The distance between mercury atoms depends on their coordination number in the liquid. If there are six nearest neighbours as in a simple cubic lattice, the distance is simply $1/\sqrt[3]{0.0408} = 2.3$ Å (most interatomic distances in condensed matter are about 2 Å). The electron mean free path in mercury is extremely short, much shorter than in crystalline simple metals, because scattering is very strong when there is no regular lattice.

e Do the ions contribute to the electric conductivity? Explain. (1p)

Lösning: 1

Naively, the electric field would exert a force on the ions that is twice as large on the electrons, and their acceleration would be much smaller because of their higher mass. Also, the mean free path of the ions would be expected to be much shorter. But the ionic charges are shielded, and the atoms are even dragged along the the other way, pushed by the electron wind.

Problem 3. *a*) Rita i samma spänning-töjning-graf två kurvor: den ene för ett sprött material med elasticitetsmodul $Y = 200$ GPa och den andra för ett töjbart material med $Y = 300$ GPa. Draw in the same stress-strain graph two curves: one for a brittle material with a modulus of elasticity $Y = 200$ GPa and the other one for a ductile material with $Y = 300$ GPa. (2p)

Lösning: 2

The graph for a ductile material shows a straight line starting at the origin (elastic region) which curves over (in the direction of decreasing stress/strain ratio) in the plastic-deformation region and then ends abruptly at the yield point. For a brittle material, the graph is a straight line which ends abruptly at the fracture point. The linear region extends to $\varepsilon \approx 10^{-3}$.

b) Vad är orsaken till att det elastiska området är begränsat i dessa två typer av material? What is in these two different materials the reason for the limited elastic range? (1p)

Lösning: 1

For a ductile material, the yield point is determined by the behaviour of dislocations. For a brittle material, the fracture point is determined by surface imperfections, leading to cracking.

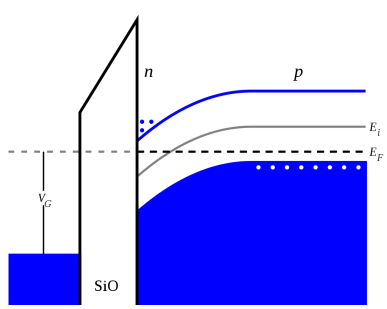
Problem 4. Consider a MOSFET with a *p*-doped substrate when a conducting channel is formed. Make a sketch of the band bending (1p), of the electric field (1p), and of the charge distribution (1p). Explain your reasoning.

Betrakta en MOSFET med ett *p*-dopat substrat där en ledande har formats. Gör en skiss av bandböjningen (1p), av det elektriska fältet (1p) och av det elektriska fältet (1p). Förklara hur du tänker.

Lösning: 3

For the band bending see the figure in Turton chapter 6.9. The *n*-channel is the inversion layer, the region where the Fermi level is closer to the conduction band than to the valence band. The field is the derivative of the potential, strongest at a constant level inside the oxide layer (like between the plates of a capacitor); in the depletion layer, it is a linear function of distance to the oxide.

As for the charge distribution: the bulk semiconductor is neutral, in the depletion layer there is a constant negative charge due to the negatively charged acceptor ions, in the *n*-channel there is additionally a negative charge from electrons in the conduction band; the surface charge on the metal is positive and equal in magnitude to the charge in the semiconductor. The charge distribution is the derivative of the potential.



Problem 5. *a*) Give an explanation of why fermions obey the Pauli exclusion principle. (1p)

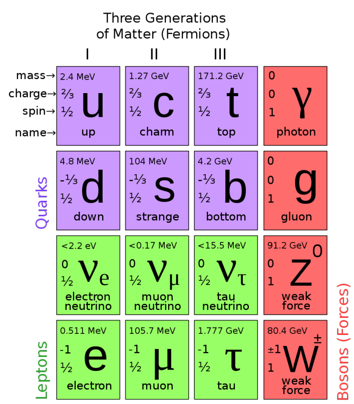
Lösning: 1

The short answer is that the wave function of identical (indistinguishable) particles must be symmetric or antisymmetric under exchange (because two exchanges are equal to doing nothing). An exchange is like a rotation over one half of the circle: and fermions are antisymmetric because they have half-integer spin. For two fermions in the same state, their wave function would equal to its negative, so it must be zero. This is Pauli's exclusion principle.

b) Mention all the fermions in the Standard Model of elementary particle physics. (1p)

Lösning: 1

There are three generations of matter, each with two quarks and two leptons. The first generation consists of the up and the down quark, the electron, and the electron neutrino. The next generations contain the charm, strange, top, and bottom quarks as well as the muon and the tauon and their neutrinos. For each of these 12 fermions there is an antiparticle, so 24 in total.



c) Mention at least three other fermions. (1p)

Lösning: Proton, neutron, the deuterium atom, ^{3}He. 1