University of Zululand/University of the Western Cape
MANUS/MATSCI

SECTION B Final Assessment
Metals and Semiconductors
4PHY504/PHY725
25th November 2021
NB: (Open 10H30 and closes 12H00)

Examiner: **Dr B. Kibirige (University of Zululand)**

Duration: **1 hour 30 mins**

INSTRUCTIONS TO THE CANDIDATES

The test form will be opened at 10H30 and will be closed at 12H00. Please make sure that the following is adhered to:

- Attempt **ALL** the questions.
- **Only one submission** will be allowed by the system.

Section B is accessed by clicking here.
Make sure that you follow the submission process. You must summit before 12H00.

Good luck

Characteristics of Selected Elements

Element	*Symbol*	*Atomic Number*	*Atomic Weight (amu)*	*Density of Solid, 20°C (g/cm³)*	*Crystal Structure, 20°C*	*Atomic Radius (nm)*	*Ionic Radius (nm)*	*Most Common Valence*	*Melting Point (°C)*
Aluminum	Al	13	26.98	2.71	FCC	0.143	0.053	3+	660.4
Argon	Ar	18	39.95	—	—	—	—	Inert	−189.2
Barium	Ba	56	137.33	3.5	BCC	0.217	0.136	2+	725
Beryllium	Be	4	9.012	1.85	HCP	0.114	0.035	2+	1278
Boron	B	5	10.81	2.34	Rhomb.	—	0.023	3+	2300
Bromine	Br	35	79.90	—	—	—	0.196	1−	−7.2
Cadmium	Cd	48	112.41	8.65	HCP	0.149	0.095	2+	321
Calcium	Ca	20	40.08	1.55	FCC	0.197	0.100	2+	839
Carbon	C	6	12.011	2.25	Hex.	0.071	~0.016	4+	(sublimes at 336
Cesium	Cs	55	132.91	1.87	BCC	0.265	0.170	1+	28.4
Chlorine	Cl	17	35.45	—	—	—	0.181	1−	−101
Caromium	Cr	24	52.00	7.19	BCC	0.125	0.063	3+	1875
Cobalt	Co	27	58.93	8.9	HCP	0.125	0.072	2+	1495
Copper	Cu	29	63.55	8.94	FCC	0.128	0.096	1+	1084
Fluorine	F	9	19.00	—	—	—	0.133	1−	−220
Gallium	Ga	31	69.72	5.90	Ortho.	0.122	0.062	3+	29.8
Germanium	Ge	32	72.59	5.32	Dia. cubic	0.122	0.053	4+	937
Gold	Au	79	196.97	19.32	FCC	0.144	0.137	1+	1064
Helium	He	2	4.003	—	—	—	—	Inert	−272 (at 26 atm
Hydrogen	H	1	1.008	—	—	—	0.154	1+	−259
Iodine	I	53	126.91	4.93	Ortho.	0.136	0.220	1−	114
Iron	Fe	26	55.85	7.87	BCC	0.124	0.077	2+	1538
Lead	Pb	82	207.2	11.35	FCC	0.175	0.120	2+	327
Lithium	Li	3	6.94	0.534	BCC	0.152	0.068	1+	181
Magnesium	Mg	12	24.31	1.74	HCP	0.160	0.072	2+	649
Manganese	Mn	25	54.94	7.44	Cubic	0.112	0.067	2+	1244
Mercury	Hg	80	200.59	—	—	—	0.110	2+	−38.8
Molybdenum	Mo	42	95.94	10.22	BCC	0.136	0.070	4+	2617
Neon	Ne	10	20.18	—	—	—	—	Inert	−248.7
Nickel	Ni	28	58.69	8.90	FCC	0.125	0.069	2+	1453
Niobium	Nb	41	92.91	8.57	BCC	0.143	0.069	5+	2468
Nitrogen	N	7	14.007	—	—	—	0.01–0.02	5+	−209.9
Oxygen	O	8	16.00	—	—	—	0.140	2−	−218.4
Phosphorus	P	15	30.97	1.82	Ortho.	0.109	0.035	5+	44.1
Platinum	Pt	78	195.08	21.45	FCC	0.139	0.080	2+	1772
Potassium	K	19	39.10	0.862	BCC	0.231	0.138	1+	63
Silicon	Si	14	28.09	2.33	Dia. cubic	0.118	0.040	4+	1410
Silver	Ag	47	107.87	10.49	FCC	0.144	0.126	1+	962
Sodium	Na	11	22.99	0.971	BCC	0.186	0.102	1+	98
Sulfur	S	16	32.06	2.07	Ortho.	0.106	0.184	2−	113
Tin	Sn	50	118.69	7.3	Tetra.	0.151	0.071	4+	232
Titanium	Ti	22	47.88	4.51	HCP	0.145	0.068	4+	1668
Tungsten	W	74	183.85	19.3	BCC	0.137	0.070	4+	3410
Vanadium	V	23	50.94	6.1	BCC	0.132	0.059	5+	1890
Zinc	Zn	30	65.39	7.13	HCP	0.133	0.074	2+	420
Zirconium	Zr	40	91.22	6.51	HCP	0.159	0.079	4+	1852

Properties of semiconductors at 300 K

Name	**Symbol**	**Germanium**	**Silicon**	**Gallium Arsenide**
Bandgap energy at 300 K	E_g (eV)	0.66	1.12	1.424
Density	(g/cm^3)	5.33	2.33	5.32
Effective density of states in the conduction band at 300K	N_c (cm^{-3})	1.02 x 10^{19}	2.82 x 10^{19}	4.35 x 10^{17}
Effective density of states in the valence band at 300 K	N_v (cm^{-3})	5.65 x 10^{18}	1.83 x 10^{19}	7.57 x 10^{18}

Intrinsic concentration at 300 K	n_i (cm^{-3})	2.8 x 10^{13}	1.0 x 10^{10}	2.0 x 10^{6}
Effective mass for density of states calculations				
Electrons	m_e^* / m_0	0.55	1.08	0.067
Holes	m_h^* / m_0	0.37	0.81	0.45
Electron affinity	χ (V)	4.0	4.05	4.07
Lattice constant	a (pm)	564.613	543.095	565.33
Mobility at 300 K (undoped)				
Electrons	μ_n (cm^2/V-s)	3900	1400[†]	8800
Holes	μ_p (cm^2/V-s)	1900	450[†]	400
Relative dielectric constant	$\varepsilon_s / \varepsilon_0$	16	11.9	13.1

Formulae sheet:

$$n = N_C \exp(-(\frac{E_C - E_F}{k_B T})), \quad p = N_V \exp(-(\frac{E_F - E_V}{k_B T})), \quad n_i = \sqrt{N_C N_V} \exp(-\frac{E_g}{2k_B T})$$

$$N_{C(T)} = N_{C(300)}(\frac{300}{T})^{\frac{3}{2}}, \quad N_{V(T)} = N_{V(300)}(\frac{300}{T})^{\frac{3}{2}}, \quad E_F \approx \frac{Eg}{2} + \frac{kT}{2}\ln(\frac{p}{n})$$

$$, \quad \frac{D_{n,p}}{\mu_{n,p}} = \frac{k_B T}{e}, \quad E = \frac{\hbar^2 k^2}{2m}, \quad \mu = \frac{e\tau}{m}, \quad \sigma = e(n\mu_e + p\mu_p), \quad J = \sigma E, \quad \Delta n = \Delta p = \tau G,$$

$$G = \alpha \frac{P_D}{E_{ph}}$$

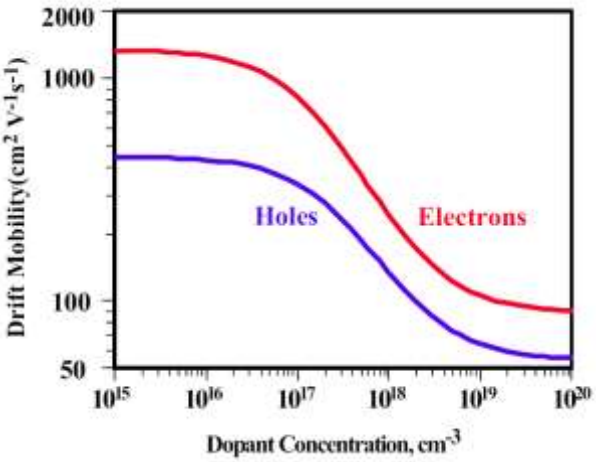

Figure 2. The variation of the drift mobility with dopant concentration in **Si** for electrons and holes **at 300 K.**

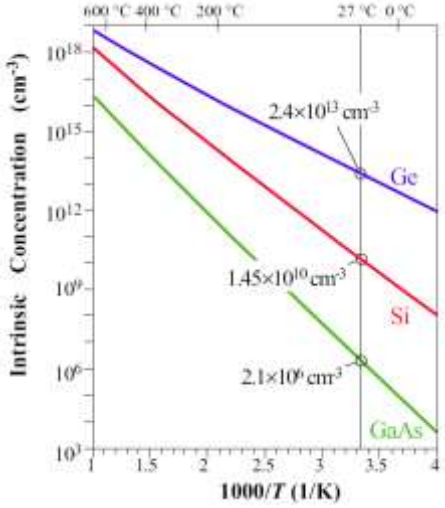

Figure 2. Temperature dependence of the intrinsic concentration for various semiconductors.

Physical Constants (SI and cgs units)

Mass of electron (free electron mass; rest mass)	$m_0 = 9.11 \times 10^{-31}$ (kg) $= 9.11 \times 10^{-28}$ (g)
Charge of electron	$e = 1.602 \times 10^{-19}$ (C) (SI-unit) $= 4.803 \times 10^{-10}$ (statcoul) $\equiv$ ($cm^{3/2} \cdot g^{1/2}/s$) (el. static cgs units) $= 1.602 \times 10^{-20}$ (abcoul) $\equiv$ ($g^{1/2} \cdot cm^{1/2}$) (el. magnetic cgs units)
Velocity of light in vacuum	$c = 2.998 \times 10^{8}$ (m/s) $= 2.998 \times 10^{10}$ (cm/s)
Planck constant	$h = 6.626 \times 10^{-34}$ (J · s) $= 6.626 \times 10^{-27}$ (g · cm^2/s) $= 4.136 \times 10^{-15}$ (eV · s) $\hbar = 1.054 \times 10^{-34}$ (J · s) $= 1.054 \times 10^{-27}$ (g · cm^2/s) $= 6.582 \times 10^{-16}$ (eV · s)
Avogadro constant	$N_0 = 6.022 \times 10^{23}$ (atoms/mol)
Boltzmann constant	$k_B = 1.381 \times 10^{-23}$ (J/K) $= 1.381 \times 10^{-16}$ (erg/K) $= 8.616 \times 10^{-5}$ (eV/K)
Bohr magneton	$\mu_B = 9.274 \times 10^{-24}$ (J/T) $\equiv$ (A · m^2) $= 9.274 \times 10^{-21} \left(\frac{\text{erg}}{\text{G}}\right) \equiv$ ($g^{1/2}$ $cm^{5/2}$/s)
Gas constant	$R = 8.314$ (J/mol · K) $= 1.986$ (cal/mol · K)
Permittivity of emtpy space (vacuum)	$\varepsilon_0 = 1/\mu_0 c^2 = 8.854 \times 10^{-12}$ (F/m) $\equiv$ (A · s/V · m)
Permeability of empty space (vacuum)	$\mu_0 = 4\pi \times 10^{-7} = 1.257 \times 10^{-6}$ (H/m) $\equiv$ (V · s/A · m) $\equiv$ (kg · m/$A^2 \cdot s^2$)

Electronic Properties of Some Metals

Material	Effective mass $\left(\frac{m^*}{m_0}\right)_{el}$	Effective mass $\left(\frac{m^*}{m_0}\right)_{opt}$	Fermi energy, E_F [eV]	Number of free electrons, N_{eff} $\left[\frac{\text{electrons}}{\text{m}^3}\right]$	Work function (photoelectric), ϕ [eV]	Resistivity, ρ [$\mu\Omega$ cm] at 20°C
Ag		0.95	5.5	6.1×10^{28}	4.3	1.59
Al	0.97	1.08	11.8	16.7×10^{28}	4.1	2.65
Au		1.04	5.5	5.65×10^{28}	4.8	2.35
Be	1.6		12.0		3.9	4.0
Ca	1.4		3.0		2.7	3.91
Cs			1.6		1.9	20.0
Cu	1.0	1.42	7.0	6.3×10^{28}	4.5	1.67
Fe	1.2				4.7	9.71
K	1.1		1.9		2.2	6.15
Li	1.2		4.7		2.3	8.55
Na	1.0		3.2		2.3	4.20
Ni	2.8				5.0	6.84
Zn	0.85		11.0	3×10^{28}	4.3	5.91