University of KwaZulu-Natal
School of Electrical, Electronic and Computer Engineering

Examinations: November 2025

Nuclear and Semiconductor Physics (ENEL2NP H2)

Duration: 2 hours **Total Marks: 120**

Examiners: Internal: Prof A.L.L. Jarvis
Mr S. Nxumalo
External: Mr M. Brown

General Instructions:

1. Full marks are equal to 120 marks
2. Follow the instructions carefully
3. Answer ALL questions for Sections A and B
4. Please keep answers neat and concise. Take note of the mark assignment.
5. The use of any calculator is permitted
6. Note that some equations and formulae are given
7. **Sections A must be answered in booklet and MCQ answer sheet put inside the booklet**

Data Sheet

$$p_0 = \frac{N_a - N_d}{2} + \sqrt{\left(\frac{N_a - N_d}{2}\right)^2 + n_i^2}\ ;\ n_i^2 = n_0.p_0\ ;\ V_{bi} = \frac{kT}{e}\ln\left(\frac{N_a N_d}{n_i^2}\right); W = \left[\frac{2\varepsilon_s V_{bi}}{e}\left[\frac{N_a + N_d}{N_a N_d}\right]\right]^{1/2};$$

$$E_{\max} = -\frac{eN_z x}{\varepsilon_s};\ V_{BE} = V_t \ln\left(\frac{n_p(0)}{n_{p0}}\right);\ n_0 = N_c \exp\left[\frac{-(E_c - E_F)}{kT}\right]$$

Silicon, gallium arsenide, and germanium properties (T = 300 K)			
Property	**Si**	**GaAs**	**Ge**
Atoms (cm^{-3})	5.0×10^{22}	4.42×10^{22}	4.42×10^{22}
Atomic weight	28.09	144.63	72.60
Crystal structure	Diamond	Zincblende	Diamond
Density (g/cm^{-3})	2.33	5.32	5.33
Lattice constant (Å)	5.43	5.65	5.65
Melting Temperature (°C)	1415	1238	937
Dielectric constant	11.7	13.1	16.0
Bandgap energy (eV)	1.12	1.42	0.66
Electron affinity, χ, (volts)	4.01	4.07	4.13
Effective density of states in conduction band, N_c, (cm^{-3})	2.8×10^{19}	4.7×10^{17}	1.04×10^{19}
Effective density of states in valence band, N_v, (cm^{-3})	1.04×10^{19}	7.0×10^{18}	6.0×10^{18}
Intrinsic carrier concentration (cm^{-3})	1.5×10^{10}	1.8×10^{6}	2.4×10^{13}
Mobility (cm^2/V-s)			

Electron, μ_n Hole, μ_p	1350 480	8500 400	3900 1900
Effective mass (density of states) Electrons (m_n^*/m_0) Holes (m_p^*/m_0)	 1.08 0.56	 0.067 0.48	 0.55 0.37

Physical Constants	
Avogadro's number	N_A = 6.02 x 10^{23} atoms per gram molecular weight
Boltzmann's constant	k = 1.38 x 10^{-23} J/K = 8.62 x 10^{-5} eV/K
Electronic charge	1.60 x 10^{-19} C
Free electron rest mass	m_0 = 9.11 x 10^{-31} kg
Permeability of free space	$\mu_0 = 4\pi$ x 10^{-7} H/m
Permittivity of free space	ε_0 = 8.85 x 10^{-14} F/cm = 8.85 x 10^{-12} F/m
Planck's constant	h = 6.625 x 10^{-34} J-s = 4.135 x 10^{-15} eV.s $\hbar = h/2\pi$=1.054 x 10^{-34} J-s
Proton rest mass	M = 1.67 x 10^{-27} kg
Speed of light in vacuum	c = 2.998 x 10^{10} cm/s
Thermal voltage (T = 300 K)	V_t = kT/e = 0.0259 volt kT = 0.0259 eV

Section A (60 marks)

Question 1 - **Semiconductors**

(a) How does one 'create' a p-type semiconductor, name the process?

(5)

(b) Draw a well labelled band diagram of a p-type semiconductor, clearly showing all the important energy levels.

(5)

(c) Determine the thermal equilibrium electron and hole concentration for an n-type silicon semiconductor (N_d = 10^{16} cm^{-3}) at T = 300 K.

(5)

[15]

Question 2 - **Diodes**

(a) In a pn-diode, explain how the space charge region forms.

(5)

(b) Draw the voltage versus current relationship for a diode.

(5)

(c) Draw the energy band diagram of a diode in reverse bias condition.

(5)

[15]

Question 3 – **Bipolar Junction Transistors**

(a) Draw the energy band diagram of a NPN bipolar transistor biased in the forward active mode.

(6)

(b) Describe the electron flow in an NPN bipolar transistor biased in the forward active mode.

(6)

(c) Why is the base made very thin in a BJT?

(3)

[15]

Question 4 – **MOSFETS and SCR**

(a) What TWO physical changes do you think are made to a MOSFET to make it a power device?

(3)

(b) **MOSFET:** Draw the drain current, I_D versus drain source voltage, V_{DC} for three different gate source voltages, V_{GS}, which are greater than the threshold voltage, V_T.

(6)

(c) Draw the two-transistor equivalent circuit of an SCR device, and explain how the device is switch 'on' and how it switches 'off'.

(6)

[15]

SECTION B: NUCLEAR PHYSICS (20 Questions)

Answer ALL questions in pencil

Q1. Which of the following statements about the nuclear force is incorrect?

A) The nuclear force is independent of charge

B) The nuclear force is very short-ranged

C) The nuclear force acts on both protons and neutrons

D) The nuclear force is attractive

E) The nuclear force is weaker than the electrostatic force

Q2. Which of the following is true for the Bohr model of atoms?

A) Only applicable to single-electron atoms/ions
B) When the electron is in an allowed stable orbit, it does not radiate electromagnetic energy
C) Can calculate spectral line energies but not intensities.
D) All of the above
E) None of the above are correct

Q3. The Thompson "plum-pudding" model failed because

A) It did not explain large scattering angles observed

B) It did not explain electron orbits

C) Only small scattering angles were observed

D) It postulated the atom had a net positive charge

E) None of the above

Q4. Which of the following is true?

A) The Thompson model considered an atom as Z protons uniformly distributed in a sphere filled with a positively charged mist

B) Rutherford concluded that most of matter is empty with atoms centred by a positively charged nucleus that carried half the mass of the atom

C) Rutherford's model stating that electrons orbit the nucleus conflicted with classical electromagnetic theory stating that accelerating charged particles lose energy and decay into the center of their orbit.

D) Bohr postulated that electrons existed in states where the electron does emit radiation whilst in a specific orbit.

E) All of the above

Q5. The Bohr radius of the hydrogen atom in the ground state is 0.529×10^{-10} m. The radius of the n = 3 state of the hydrogen atom is approximately

A) 0.143×10^{-10} m

B) 4.761×10^{-10} m

C) 1.158×10^{-10} m

D) 0.0441×10^{-10} m

E) 1.578×10^{-10} m

Q6. Suppose that an electron within a hydrogen atom moves from the fourth energy level to the second energy level. What is the wavelength of the photon emitted during this process?

A) 487.5 nm
B) 445.9 nm
C) 817.4 nm
D) 345.5 nm
E) none of the above

Q7. How many protons, neutrons, and electrons are there in a nucleus of the isotope of Bismuth, $^{209}_{83}\ Bi^{2+}$, respectively?

A) 209, 126, 207

B) 83, 126, 81

C) 85, 209, 87

D) 83, 81, 207

E) none of the above

Q8. The most common kind of iron nucleus has mass number A = 56. Find the radius, approximate mass, and approximate density of the nucleus

A) $2.3fm$, $10.3x10^{-26}kg$, $3.3x10^{17}\ kg/m^3$
B) $4.6fm$, $9.3x10^{-26}kg$, $3.3x10^{17}\ kg/m^3$
C) $4.6fm$, $9.3x10^{-26}kg$, $2.3x10^{17}\ kg/m^3$

D) $2.3fm$, $9.3x10^{-26}kg$, $2.3x10^{17}\ kg/m^3$

E) none of the above

Q9. The most common isotope of uranium, $^{238}_{92}U$, has atomic mass 238.050783 u. Calculate the binding energy per nucleon.

A) 7.37 MeV

B) 112 MeV

C) 46 MeV

D) 11 MeV

E) 72.5 MeV

Q10. What nuclide is produced in the radioactive decay β⁺ decay of $^{140}_{56}Ba$

A) $^{12}_{24}Mg$

B) $^{140}_{58}Ce$

C) $^{10}_{5}B$

D) $^{6}_{12}C$

E) $^{140}_{55}Cs$

Q11. A hydrogen atom is in a state with energy −0.85 eV. In the Bohr model, what is the angular momentum of the electron in the atom, with respect to an axis at the nucleus?

A) 2ħ

B) 3ħ

C) 4ħ

D) 5ħ

E) 6ħ

Q12. A radioactive sample has a half-life of ten minutes. What fraction of the sample is left after forty minutes?

A) 1/2

B) 1/4

C) 1/8

D) 1/16

E) 1/32

Q13. Consider the nuclear reaction

$^{2}_{1}H + {}^{9}_{4}Be \rightarrow X + {}^{4}_{2}He$, where X is a nuclide.

The values of Z and A for the nuclide X as well as how much energy is liberated, respectively, are

A) 7, 3, and 7.152 MeV

B) 3, 7, and 3.071 MeV

C) 7, 3, and 3.071 MeV

D) 3, 7, and 7.152 MeV

E) none of the above

Q14. Scandium $^{44}_{21}Sc$ decays by emitting a positron. What are the products of the decay?

A) $^{45}_{20}Ca + \beta^{-} + \nu$

B) $^{45}_{20}Ca + \beta^{+} + \nu$

C) $^{44}_{20}Ca + \beta^{+} + \nu$

D) $^{43}_{20}Ca + \beta^{+} + \nu$

E) $^{44}_{21}Ca + \beta^{+} + \nu$

Q15. The isotope ^{57}Co decays by electron capture to ^{57}Fe with a half-life of 272 days. The ^{57}Fe nucleus is produced in an excited state, and it almost instantaneously emits gamma rays that we can detect. Find the mean lifetime for ^{57}Co.

A) 1.24×10^{7} s

B) 7.66×10^{7} s

C) 3.39×10^7 s

D) 5.69×10^7 s

E) None of the above

Q16. How long will it take for 90 % of the radioactive gas tritium to become non-radioactive after being accidentally spilled into the atmosphere, if it has a half-life of 12.3 years?

A) 4.6 years

B) 123. Years

C) 40.86 years

D) 111 years

E) 725 years

Q17. Why is it necessary to accelerate positively charged nuclei to high kinetic energies for fusion?

A) To result in high amount of energy in short period of time

B) To create the isobars and isotopes required for fusion

C) To overcome electrical repulsive forces

D) To achieve a sustainable reaction

E) All of the above

Q18. The purpose of fuel enrichment in a nuclear reactor is to

A) Increase the amount of neutrons

B) Increase the amount of fissible material within the fuel

C) Increase the amount of non-fissible material in the fuel to increase the reaction rate

D) Decrease the amount of fissible material within the fuel

E) None of the above

Q19. Which of the following concerning the coolant is true?

A) Most reactors use water or helium under high pressure

B) The coolant transports the fission heat to external heat exchangers

C) The coolant may be heated to several hundred Kelvin above its initial temperature

D) The coolant forms steam that drives turbines to generate electricity

E) All of the above

Q20. During a diagnostic x-ray examination, a 1.2-kg portion of a broken leg receives an equivalent dose of 0.40 mSv. If the x-ray energy is 50 keV, how many x-ray photons are absorbed?

A) $4.5 \times 10^{10} photons$

B) $0.3 \times 10^{10} photons$

C) $9.8 \times 10^{10} photons$

D) $6.0 \times 10^{10} photons$

E) None of the above

Student Number: _____

ANSWER SHEET: Place a large cross (X) on the letter of your choice.

1.	**A**	**B**	**C**	**D**	**E**	
2.	**A**	**B**	**C**	**D**	**E**	
3.	**A**	**B**	**C**	**D**	**E**	
4.	**A**	**B**	**C**	**D**	**E**	
5.	**A**	**B**	**C**	**D**	**E**	
6.	**A**	**B**	**C**	**D**	**E**	
7.	**A**	**B**	**C**	**D**	**E**	
8.	**A**	**B**	**C**	**D**	**E**	
9.	**A**	**B**	**C**	**D**	**E**	
10.	**A**	**B**	**C**	**D**	**E**	
11.	**A**	**B**	**C**	**D**	**E**	
12.	**A**	**B**	**C**	**D**	**E**	
13.	**A**	**B**	**C**	**D**	**E**	
14.	**A**	**B**	**C**	**D**	**E**	
15.	**A**	**B**	**C**	**D**	**E**	
16.	**A**	**B**	**C**	**D**	**E**	
17.	**A**	**B**	**C**	**D**	**E**	
18.	**A**	**B**	**C**	**D**	**E**	
19.	**A**	**B**	**C**	**D**	**E**	
20.	**A**	**B**	**C**	**D**	**E**	
					Total	