University of KwaZulu-Natal

School of Electrical, Electronic and Computer Engineering

Main Examinations: December 2016

Nuclear and Semiconductor Physics (ENEL2NP H2)

Duration: 2 hours

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General Instructions:

1. PUT YOUR STUDENT NUMBER ON THE MULTPILE CHOICE (MCQ) SHEET ON PAGE 11
2. Full marks are equal to 120 marks
3. Follow the instructions carefully
4. Answer ALL questions for sections A and B
5. Keep answers neat and concise. Take note of the mark assignment.
6. The use of any calculator is permitted
7. **Answer Sections A in the booklet provided, then put the MCQ Sheet (Page 11) in the booklet.**
8. **Note there is a choice between Question 4 and Question 5 (10 Marks)**

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,	2.8×10^{19}	4.7×10^{17}	1.04×10^{19}

(cm^{-3})			
Effective density of states in valence band, N_v, (cm^{-3})	1.04 x 10^{19}	7.0x10^{18}	6.0x10^{18}
Intrinsic carrier concentration (cm^{-3})	1.5 x 10^{10}	1.8x10^{6}	2.4x10^{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	μ_0 = 4π 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 [25]

(a) How does one 'create' a p-type semiconductor? (4)

(b) Draw and explain the electron concentration, *n*, curve of an n-type semiconductor versus the temperature range 20 K to 1000 K. Discuss the three important regions. (12)

(c) Draw a well labelled band diagram of a p-type semiconductor, clearly showing all the important energy levels. (5)

(d) Explain how charge can flow without an applied electric field (drift). (4)

Question 2: [10]

At T = 300 K, silicon has an intrinsic concentration of 1.5 x 10^{10} cm^{-3} with $N_a = 10^{13}$ cm^{-3} and $N_d = 10^{14}$ cm^{-3}

(a) Calculate the thermal equilibrium concentration of p_0 and n_0 (3)

(b) Is this material n-type, p-type, or neither? (2)

(c) Discuss the term 'hole charge carrier'. (5)

Question 3: [15]

(a) In a pn junction diode, (i) explain how the space charge region forms and (ii) why is this device known as a diffusion device (6)

(b) Draw the voltage versus current relationship for a pn diode. (5)

(c) Discuss with the help of a drawing, a limiting factor that limits the switching speed of a diode. (4)

Choose Question 4 or Question 5

Question 4: [10]

(a) Describe the electron flow in an NPN bipolar transistor biased in the forward active mode. (6)

(b) Draw the symbol for a NPN bipolar transistor label the three legs. (4)

Question 5: [10]

(a) What physical change is made to a MOSFET to make it a power device? (2)

(b) MOSFET: Draw the drain current versus voltage drain source voltage for different gate source voltages and explain what 'pinch off' refers to. (8)

Section B (60 Marks)

Instructions:

All questions in this section are multiple-choice. Answer all questions on the MCQ answer sheet provided. Each question counts 3 marks. There are no negative marks for incorrect answers. Place the MCQ answer sheet with your Section A booklet.

Constants and Conversions

mass of ${}^1_1\mathrm{H}$: $M({}^1\mathrm{H}) = 1.007825\ \mathrm{u}$

mass of proton ${}^1_1p$: $M(p) = 1.007276\ \mathrm{u}$

mass of neutron ${}^1_0n$: $M(n) = 1.008665\ \mathrm{u}$

mass of electron ${}^0_0e$: $M(e) = 5.486 \times 10^{-4}\ \mathrm{u} = 9.1 \times 10^{-31}\ \mathrm{kg}$

mass of alpha particle ${}^4_2\mathrm{He}^{2+}$: $M({}^4_2\mathrm{He}^{2+}) = 4.002603\ \mathrm{u}$

$e = 1.602 \times 10^{-19}\ \mathrm{C}$

$h = 6.626 \times 10^{-34}\ \mathrm{J.s} = 4.1357 \times 10^{-15}\ \mathrm{eV.s}$

$N_A = 6.02 \times 10^{23}\ \mathrm{atoms/mol.}$

$hc = 1240\ \mathrm{eV.nm}$

$E_n = -13.6\left(\frac{Z}{n}\right)^2\ \mathrm{eV}$

$a_0 = 0.0529\ \mathrm{nm}$

$R_H = 1.09678 \times 10^7\ \mathrm{m}^{-1}$

$\frac{e^2}{4\pi\epsilon_0} = 1.440\ \mathrm{eV.nm}$

$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/N.m^2}$

$c = 2.998 \times 10^8\ \mathrm{m/s}$

$1\ u = 931.5\ \mathrm{MeV/c^2}$

$1\ \mathrm{Ci} = 3.70 \times 10^{10}\ \mathrm{decays/s} = 3.70 \times 10^{10}\ \mathrm{Bq}$

$1\ \mathrm{eV} = 1.602 \times 10^{-19}\ \mathrm{J}$

$1\ \mathrm{rad} = 0.01\ \mathrm{Gy} = 10^{-2}\ \mathrm{J/kg}$

$1\ \mathrm{rem} = 0.01\ \mathrm{Sv}$

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1. What is the energy of an electron occupying an orbital described by the principal quantum number $n = 3$ in the Bohr model of the hydrogen atom?

   A) –13.6 eV

   B) –4.5 eV

   C) –1.5 eV

   D) –6.8 eV

   E) –3.4 eV

2. If the radius of the $^{54}_{26}\mathrm{Fe}$ nucleus is $3R$, what is the radius of the $^{16}_{8}\mathrm{O}$ nucleus?

A) 2.00 R B) 1.50 R C) R D) 3.78 R E) 0.50 R

3. An electron in the first excited state of the hydrogen atom absorbs a photon and transitions into the state described by the principal quantum number $n = 3$, what is the wavelength of the photon absorbed?

A) 122 nm
B) 486 nm
C) 656 nm
D) 1875 nm
E) 410 nm

4. What is the electron binding energy of the ground state of the hydrogen atom?

A) 13.6 eV

B) -0.85 eV

C) -13.6 eV

D) 0.85 eV

E) 3.4 eV

5. The total binding energy of the $^{235}_{92}\mathrm{U}$ nuclide is approximately

($M(^{235}_{92}\mathrm{U})$ = 235.043923 u)

A) 1.784 GeV

B) 0.00759 MeV

C) 7.591 MeV

D) 6.593 MeV

E) 0.00590 MeV

6. The following process:

$$ {}_{0}^{1}\mathrm{n} + {}_{90}^{234}\mathrm{Th} \rightarrow {}_{90}^{233}\mathrm{Th}^{*} \xrightarrow{\gamma,\beta^{-}} {}_{91}^{233}\mathrm{Pa} \xrightarrow{\beta^{-}} {}_{92}^{233}\mathrm{U} $$

Is an example of a nuclear process called

A) nuclear fission
B) nuclear fusion
C) binding
D) breeding
E) transmutation

7. The ^{14}C radioisotope decays into the stable ^{14}N isotope. Given that the initial ratio of ^{14}C to ^{14}N nuclei in an isolated system is 3:2, approximately how long will it take until there is an equal number of ^{14}C and ^{14}N nuclei? [The half-life of ^{14}C is 5730 years]

A) 13000 years
B) 5730 years
C) 1510 years
D) 3885 years
E) None of the answers given

8. The radioactive ${}_{88}^{226}\mathrm{Ra}$ nucleus decays through a series of alpha and beta minus emissions to a stable ${}_{82}^{206}\mathrm{Pb}$ nucleus. The number of alpha particles and the number of beta minus particles emitted during the entire process are

A) 10 alpha particles and 7 beta minus particles.
B) 5 alpha particles and 4 beta minus particles.
C) 6 alpha particles and 3 beta minus particles.
D) 5 alpha particles and 2 beta minus particles.
E) 10 alpha particles and 3 beta minus particles.

9. A radioactive nuclide with neutron number N decays by emitting a positron, and the daughter nuclide emits a gamma ray. What is the atomic number of the resulting nuclide after both processes?

A) $N+1$
B) $N+2$
C) $N-2$
D) $N-1$
E) N

10. The Q-value of the following:

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

[$M(^{238}\mathrm{U})$ =238.050788 u, $M(^{13}\mathrm{N})$ = 234.043601 u]

is approximately

A) 4.68 MeV

B) 4.27 MeV

C) −7.56 MeV

D) 3.00 MeV

E) −3.00 MeV

11. The unifying concepts in physics are the conservation laws. To preserve these laws in nuclear processes, it became necessary to postulate the existence of

A) the positron.

B) particle spin.

C) space quantization.

D) the neutrino.

E) the neutron.

12. Most of the energy released in a fission reaction is

A) the kinetic energy of alpha particles.

B) the kinetic energy of fission fragments.

C) the kinetic energy of fission neutrons.

D) the energy of gamma rays.

E) The kinetic energy of beta particles.

13. The purpose of a moderator in a nuclear reactor is to

A) repel neutrons with electrostatic force.

B) control the temperature of the core.

C) slow down neutrons thereby increasing the reaction rate.

D) absorb gamma radiation.

E) absorb neutrons thereby slowing down the reaction rate.

14. The purpose of control rods in a nuclear reactor is to

A) repel neutrons with electrostatic force.

B) control the temperature of the core.

C) slow down neutrons thereby increasing the reaction rate.

D) absorb gamma radiation.

E) absorb neutrons thereby slowing down the reaction rate.

15. Uranium-235 is used in a nuclear fission reactor with each fission reaction producing 200 MeV of energy. If the nuclear power plant is 30% efficient and produces 1.440×10^6 kWh of electricity per day, the number of uranium-235 nuclei which fission in one day is closest to

A) 6.25×10^{18}

B) 1.6×10^{19}

C) 5.4×10^{23}

D) 2.75×10^{18}

E) 6.25×10^{18}

16. The following fusion reaction occurs in the sun:

$$^{3}_{2}\mathrm{He} + ^{4}_{2}\mathrm{He} \rightarrow ^{7}_{4}\mathrm{Be}$$

The masses of the nuclei are $M(^{3}\mathrm{He}$ = 3.016049 u), $M(^{4}\mathrm{He}$ = 4.002604 u)

$M(^{7}\mathrm{Be}$ = 7.016930 u). The energy absorbed or released in the reaction is

A) 920 MeV, absorbed.

B) 1.6 MeV, absorbed.

C) 920 MeV, released.

D) 1.6 MeV, released.

E) 270 MeV, released.

17. A 65-kg researcher absorbs 5.0×10^{8} neutrons in a workday. The energy of the neutrons is 4.6 MeV. The relative biological efficiency (RBE) for fast neutrons is 10. What is the equivalent dosage of the radiation exposure, in mrem, of this worker?

A) 5.8

B) 4.9

C) 3.1

D) 1.5

E) 11.7

18. Neutrons are effective particles for penetrating the nucleus because they have

A) a small mass

B) no spin

C) small speeds

D) no charge

E) a small size

19. In the nuclear reaction $^{1}_{0}n + ^{235}_{92}\mathrm{U} \rightarrow ^{143}_{54}\mathrm{Xe} + ^{90}_{38}\mathrm{Sr} + ?$

the missing product is

A) $2\,^{1}_{0}n$ B) $3\,^{1}_{0}n$ C) $2\,^{1}_{1}p$ D) $3\,^{1}_{1}p$ E) $^{1}_{1}\mathrm{H}$

20. The radioactive ^{199}Pt has a half-life of 30.8 minutes. A sample is prepared that has an initial activity of 7.56×10^{11} Bq. How many nuclei are present in the sample?

A) 1.4×10^{15}

B) 3.4×10^{13}

C) 2.0×10^{15}

D) 7.6×10^{11}

E) 7.6×10^{13}

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	