University of KwaZulu-Natal

School of Electrical, Electronic and Computer Engineering

Main Examinations: November 2015

Nuclear and Semiconductor Physics (ENEL2NP H2)

Duration: 2 hours

Examiners: Internal: Dr A.L.L. Jarvis
Dr J. Govender
External: Dr J. Poole

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. Please 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.**

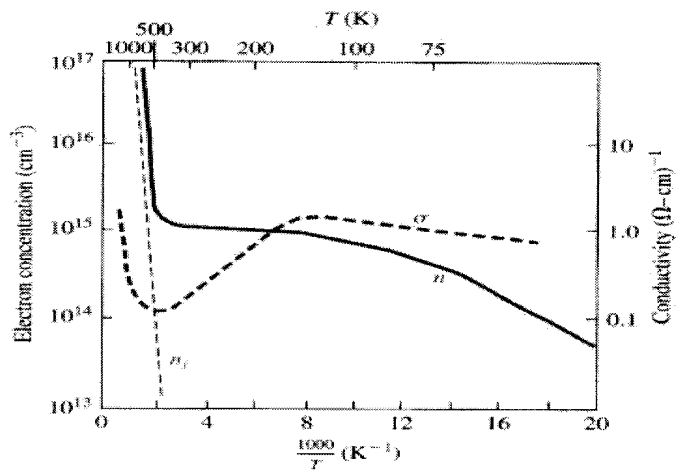
Section A (60 marks)

Question 1 [15]

(a) Explain the semiconductor term doping. (3)

(b) How does one 'create' an n-type semiconductor? (2)

(c) Using the figure below, explain the conductivity curve and name three important conductivity regions. (5)



(d) Draw a well labelled Band diagram of an n-type semiconductor, clearly showing the Fermi energy levels present.

(3)

(e) Explain how charge can flow without an applied electric field.

(2)

Question 2: [15]

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)

$$n_0 = \frac{(N_d - N_a)}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2} \qquad p_0 = \frac{N_a - N_d}{2} + \sqrt{\left(\frac{N_a - N_d}{2}\right)^2 + n_i^2}$$

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

(c) If the temperature is raised to T=450 K, and the observed dependency of the intrinsic carrier concentration on temperature obeys $T^{3/2}$, calculate part (a) again, and comment on the result. (5)

(d) Discuss the term 'hole charge carrier'.

(5)

Question 3: [10]

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

(5)

(b) Draw the voltage versus current (+ and – current flow) relationship for a diode.

(5)

Question 4: [10]

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

(5)

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

(5)

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 and should be answered on the attached answer sheet provided. **Tear off Page 11 (MCQ sheet) now, and fill in your student number in the space provided.** Place a cross (X) on the letter corresponding to the answer that you think is correct for each of the 20 questions. Each question counts 3 marks. There are no negative marks for incorrect answers. Place the this 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 ${}^{1}_{1}p$: $M(p) = 1.007276\ \mathrm{u}$

mass of neutron ${}^{1}_{0}n$: $M(n) = 1.008665\ \mathrm{u}$

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

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

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

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

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

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

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

$a_0 = 0.0529\ \mathrm{nm}$

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

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

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

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

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

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

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

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

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

---

1. The energy of the $n = 2$ state in the Bohr model of the hydrogen atom is

   A) −13.6 eV

   B) −4.5 eV

   C) −1.7 eV

   D) −6.8 eV

   E) −3.4 eV

2. If the principle quantum number of an electron is $n = 5$, which one of the following is NOT an allowed magnetic quantum number m_ℓ for the electron?

   A) 0

   B) 5

   C) 4

   D) 3

   E) 2

3. Which one of the following atomic transitions of the hydrogen atom results in the release of a photon with the largest wavelength?

   A) $n = 2$ to $n = 1$

   B) $n = 3$ to $n = 2$

   C) $n = 4$ to $n = 3$

   D) $n = 3$ to $n = 1$

   E) $n = 4$ to $n = 2$

4. A certain nucleus containing 8 protons and 7 neutrons has a radius R. Which one of the following values would be closest to the expected value of the radius of a nucleus having 51 protons and 69 neutrons?

A) 6.38 R B) 2.00 R C) 1.85 R D) 2.14 R E) 8.00 R

5. The total binding energy per nucleon of $^{7}_{3}\mathrm{Li}$ is approximately

($M(^{7}_{3}\mathrm{Li})$ = 7.016003 u)

A) 0.04215 MeV
B) 0.00602 MeV
C) 5.606 MeV
D) 6.593 MeV
E) 0.00590 MeV

6. A radioactive sample decays by β- emission with a half-life of 1.0 min. During the first 1.0 min, a particular sample emits 1000 β particles. During the next 1.0 min, the number of β particles emitted by this sample is closest to

A) 2000
B) 250
C) 1500
D) 1000
E) 500

7. Rutherfordium-261 has a half-life of 1.08 min. Approximately how long will it take for a sample of Rutherfordium to lose one-third $\left(\frac{1}{3}\right)$ of its nuclei?

A) 0.632 min
B) 3.24 min
C) 1.62 min
D) 2.70 min
E) 1.02 min

8. An archaeologist finds the ^{14}C in a sample of 3.4 g of material to be decaying at 107 counts per second. A modern 1.00-g sample of the same material decays at 151 counts per second. The half-life of ^{14}C is 5730 y. Approximately how old is the sample?

A) 13000 y
B) 8990 y
C) 27500 y
D) 17200 y
E) None of the answers given

9. The radioactive nucleus $^{234}_{90}\mathrm{Th}$ decays through a series of alpha and beta minus emissions to an unstable nucleus $^{214}_{83}\mathrm{Bi}$. 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 7 beta minus particles.
C) 5 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.

10. A radioactive nuclide of atomic number Z 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) $Z+1$

B) $Z+2$

C) $Z-2$

D) $Z-1$

E) $Z-3$

11. The expression $((M(\mathrm{X})-M(\mathrm{Y})-M(\mathrm{He}))\times 931.5$ MeV represents

A) the binding energy of the nucleus X.

B) the binding energy of the nucleus Y.

C) the energy released when X undergoes alpha decay.

D) the energy absorbed when X undergoes alpha decay.

E) the energy released when X undergoes nuclear fission.

12. The *Q*-value of the reaction

$$^{13}_{6}\mathrm{C}+{}^{1}_{1}\mathrm{H}\rightarrow {}^{1}_{0}\mathrm{n}+{}^{13}_{7}N$$

($M(^{13}\mathrm{C})$ =13.003355 u, $M(^{13}\mathrm{N})$ = 13.005739 u)

is approximately

A) 10.56 MeV

B) 7.56 MeV

C) −7.56 MeV

D) 3.00 MeV

E) −3.00 MeV

13. 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.

14. A proton strikes a $^{18}_{8}\mathrm{O}$ nucleus producing $^{18}_{9}\mathrm{F}$ and another particle. What is the other particle?

A) a gamma ray
B) β^- particle
C) a neutron
D) β^+ particle
E) α particle

15. Neutrons produced in the fission of uranium are rapidly moving projectiles and must be slowed before they can produce more fission. If the neutrons collide elastically, hydrogen is effective in slowing them down because

A) hydrogen atoms repel neutrons.
B) a hydrogen atom is much more massive than a neutron.
C) a hydrogen atom and a neutron have about the same mass.
D) a neutron is much more massive than a hydrogen atom.
E) hydrogen atoms attract neutrons.

16. The uranium used in a nuclear reactor is 3% enriched with $^{235}\mathrm{U}$, with each fission reaction producing 200 MeV of energy. $M(^{235}\mathrm{U} = 235.043922\ \mathrm{u})$. If the nuclear plant is 30% efficient and produces 1000 MW of power per day, the mass of uranium used in one day is closest to

A) 3.20 kg
B) 3.54 kg
C) 10.6 kg
D) 106.7 kg
E) 117.9 kg

17. In choosing a material as the moderator in nuclear reactors, which one of the following is NOT a requirement? The material must

A) have a low mass number.
B) have high probability of scattering neutrons.
C) have low probability of absorbing neutrons.
D) be in greater quantity than the fissile medium.
E) be a good conductor of thermal energy.

18. 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 $M(^{3}\mathrm{He} = 3.016049\ \mathrm{u})$, $M(^{4}\mathrm{He} = 4.002604\ \mathrm{u})$

$M(^{7}\mathrm{Be} = 7.016930\ \mathrm{u})$. 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.

19. In an experimental inertial-confinement fusion reactor, the confinement duration is $\tau = 5.0 \times 10^{-10}$ s. The density of the fusible material needed to meet Lawson's criterion must be greater than

A) 2.0×10^{24} particles / cm^3

B) 2.0×10^{23} particles / cm^3

C) 2.0×10^{10} particles / cm^3

D) 5.0×10^{23} particles / cm^3

E) 2.0×10^{29} particles/cm^3

20. A 63-kg researcher absorbs 4.2×10^8 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) 4.9

B) 49

C) 3.1

D) 1.5

E) 15

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	