NAME ____________ UCID ____________

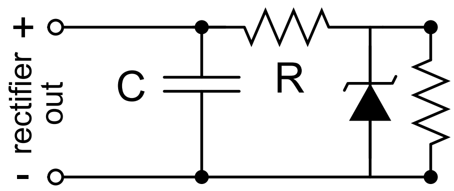
1. Answer all four questions. Maximum mark is 18.
2. Show your work as much as possible, within time and space constraints.

1. *(2 marks)* An element has the following electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^4$

(a) There are ______ electrons in the outer-most shell.

(b) Based on the electron configuration, the element should be a conductor/insulator (strike out one).

2. *(2 marks)* Consider the regulator shown below. R and C were chosen to satisfy all the constraints. After 10 days of operation, the connection to the capacitor breaks (essentially there is no more capacitor in the circuit).



(a) The maximum regulator output
(i) Increases (ii) Decreases (iii) Stays the same

(b) The minimum regulator output
(i) Increases (ii) Decreases (iii) Stays the same

3. *(2 marks)* Itsocoldium is a semiconductor with a bandgap of 0.6 eV. In the space below, draw the energy band diagram of acceptor-doped itsocoldium showing the Fermi level and the bandgap. The grid lines are 0.1 eV apart.

4. *(12 marks)* Recall that the Fermi level is halfway in the bandgap in an intrinsic material.
(a) Using the Boltzmann approximation ($E - E_F >> kT$ for electrons and $E_F - E >> kT$ for holes) show that if the probability of finding an electron at the bottom of the conduction band is equal to the probability of finding a hole at the top of the valence band, the material must be intrinsic.
(b) You have a sample of silicon where the Fermi level is $10kT$ above the intrinsic silicon Fermi level. How (type and concentration of dopant) should this sample be doped to move the Fermi level $10kT$ below the intrinsic silicon Fermi level.
(c) If you dope the material as required in (b), what is the final minority carrier concentration?

$$
\begin{aligned}
n &= \frac{N_D - N_A}{2} + \sqrt{\left(\frac{N_D - N_A}{2}\right)^2 + n_i^2} \\
&= N_D - N_A \text{ if } N_D - N_A > 10n_i \\
p &= \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2} \\
&= N_A - N_D \text{ if } N_A - N_D > 10n_i \\
np &= n_i^2 \\
n &= N_C e^{-(E_C - E_F)/kT} \\
p &= N_V e^{-(E_F - E_V)/kT} \\
N_C &= 2\left(\frac{2\pi m_n kT}{h^2}\right)^{3/2} \\
N_V &= 2\left(\frac{2\pi m_p kT}{h^2}\right)^{3/2}
\end{aligned}
$$

$$
\begin{aligned}
D_C(E) &= \frac{8\pi m_n \sqrt{2m_n(E - E_C)}}{h^3} \\
D_V(E) &= \frac{8\pi m_p \sqrt{2m_p(E_V - E)}}{h^3} \\
f(E) &= \frac{1}{1 + e^{(E - E_F)/kT}}
\end{aligned}
$$

Constants

$$
\begin{aligned}
k &= 1.38 \times 10^{-23}\ J/K \\
h &= 6.63 \times 10^{-34}\ Js \\
q &= 1.60 \times 10^{-19}\ C
\end{aligned}
$$

@300K

$$
\begin{aligned}
kT &= 26\ meV \\
\frac{kT}{q} &= 26\ mV
\end{aligned}
$$

Silicon@300K

$$
\begin{aligned}
N_C &= 2.8 \times 10^{19}/cm^3 \\
N_V &= 1.0 \times 10^{19}/cm^3 \\
n_i &= 1.0 \times 10^{10}/cm^3 \\
E_g &= 1.1\ eV
\end{aligned}
$$

Germanium@300K

$$
\begin{aligned}
N_C &= 1.0 \times 10^{19}/cm^3 \\
N_V &= 6.0 \times 10^{18}/cm^3 \\
n_i &= 2.0 \times 10^{13}/cm^3 \\
E_g &= 0.67\ eV
\end{aligned}
$$