

EE 362 Electronic, Magnetic, & Opt. Prop. of Mat'ls Quiz 4 (Spring 2025)

Name KEY A

Instructions: Open book/notes. Place answers in indicated spaces and show all work for credit. Carry *at least 6* significant figures on constants/parameters in calculations. Give answers with **4-5** significant figures.

A sample of gallium arsenide (GaAs) has an intrinsic carrier concentration of $1.79 \times 10^6 \text{ \#/cm}^3$ and a band gap of 1.424 eV at 300 K. It is doped with tellurium at a concentration of $2 \times 10^{14} \text{ \#/cm}^3$. Is the sample a p-type or n-type extrinsic semiconductor? Find the conduction band electron concentration $n_0 \text{ (\#/cm}^3\text{)}$ and valence hole concentration $p_0 \text{ (\#/cm}^3\text{)}$. Calculate the **magnitude** of the difference between the intrinsic Fermi energy and the Fermi energy of the sample in eV, i.e., $\Delta E = |E_F - E_{Fi}|$. Is E_F bigger or smaller than E_{Fi} ?

Tellurium (Te) is a column to the right of arsenic (As) on periodic table $\Rightarrow$ donor $\Rightarrow$ **n-type**

Given that $N_d = 2 \times 10^{14} \text{ \#/cm}^3 \gg n_i = 1.79 \times 10^6 \text{ \#/cm}^3$ and $N_a = 0$, **$n_0 \cong N_d = 2 \times 10^{14} \text{ \#/cm}^3$** .

Or, can use (4.60),

$$n_0 = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2} = \frac{2 \times 10^{14} - 0}{2} + \sqrt{\left(\frac{2 \times 10^{14} - 0}{2}\right)^2 + (1.79 \times 10^6)^2} \text{ to get}$$

$$\Rightarrow \textbf{n_0 \cong N_d = 2 \times 10^{14} \#/cm^3}.$$

$$\text{Per (4.43), } n_i^2 = n_0 p_0 \Rightarrow p_0 = n_i^2 / n_0 = (1.79 \times 10^6)^2 / 2 \times 10^{14} \Rightarrow \textbf{p_0 = 0.0160205 \#/cm^3}.$$

$$\text{Per (4.65), } E_F - E_{Fi} = k_B T \ln\left(\frac{n_0}{n_i}\right) = 8.617333 \times 10^{-5} (300) \ln\left(\frac{2 \times 10^{14}}{1.79 \times 10^6}\right)$$

$$\Rightarrow \textbf{\Delta E = |E_F - E_{Fi}| = 0.47908 eV}.$$

p-type or **n-type** ? (circle correct) $n_0 = \textbf{N_d = 2 \times 10^{14} \#/cm^3}$ $p_0 = \textbf{0.0160205 \#/cm^3}$

$\Delta E = \textbf{0.47908 eV}$ **$E_F > E_{Fi}$** or $E_{Fi} > E_F$? (circle correct)

1 H Hydrogen 1.008																	2 He Helium 4.003																																														
3 Li Lithium 6.941	4 Be Beryllium 9.012															5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180																																										
11 Na Sodium 22.990	12 Mg Magnesium 24.305															13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948																																										
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 52.00	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.69	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.63	33 As Arsenic 74.922	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.8	37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.906	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.905	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.757	52 Te Tellurium 127.6	53 I Iodine 126.905	54 Xe Xenon 131.294																												
55 Cs Cesium 132.905	56 Ba Barium 137.327	57 La Lanthanum 138.905	58 Ce Cerium 140.12	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.930	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.222	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium 209	85 At Astatine 210	86 Rn Radon 222	87 Fr Francium 223	88 Ra Radium 226	89 Ac Actinium 227	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.07	97 Bk Berkelium 247.07	98 Cf Californium 251.08	99 Es Einsteinium 252.083	100 Fm Fermium 257.10	101 Md Mendelevium 258.10	102 No Nobelium 259.10	103 Lr Lawrencium 262.10	104 Rf Rutherfordium 261.10	105 Db Dubnium 262.10	106 Sg Seaborgium 266.10	107 Bh Bohrium 264.10	108 Hs Hassium 277.10	109 Mt Meitnerium 268.10	110 Ds Darmstadtium 271.10	111 Rg Roentgenium 272.10	112 Cn Copernicium 285.10	113 Nh Nihonium 284.10	114 Fl Flerovium 289.10	115 Mc Moscovium 288.10	116 Lv Livermorium 293.10	117 Ts Tennessine 294.10	118 Og Oganesson 294.10

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Instructions: Open book/notes. Place answers in indicated spaces and show all work for credit. Carry *at least 6* significant figures on constants/parameters in calculations. Give answers with **4-5** significant figures.

A sample of gallium arsenide (GaAs) has an intrinsic carrier concentration of $1.79 \times 10^6 \text{ \#/cm}^3$ and a band gap of 1.424 eV at 300 K. It is doped with cadmium at a concentration of $6 \times 10^{14} \text{ \#/cm}^3$. Is the sample a p-type or n-type extrinsic semiconductor? Find the conduction band electron concentration n_0 ($\text{\#/cm}^3$) and valence hole concentration p_0 ($\text{\#/cm}^3$). Calculate the **magnitude** of the difference between the intrinsic Fermi energy and the Fermi energy of the sample in eV, i.e., $\Delta E = |E_F - E_{Fi}|$. Is E_F bigger or smaller than E_{Fi} ?

Cadmium (Cd) is a column to the left of Gallium (Ga) on periodic table $\Rightarrow$ acceptor $\Rightarrow$ **p-type**

Given that $N_a = 6 \times 10^{14} \text{ \#/cm}^3 \gg n_i = 1.79 \times 10^6 \text{ \#/cm}^3$ and $N_d = 0$, $p_0 \cong N_a = 6 \times 10^{14} \text{ \#/cm}^3$.

Or, can use (4.62),

$$p_0 = \frac{N_a - N_d}{2} + \sqrt{\left(\frac{N_a - N_d}{2}\right)^2 + n_i^2} = \frac{6 \times 10^{14} - 0}{2} + \sqrt{\left(\frac{6 \times 10^{14} - 0}{2}\right)^2 + (1.79 \times 10^6)^2} \text{ to get}$$

$$\Rightarrow \underline{p_0 \cong N_a = 6 \times 10^{14} \text{ \#/cm}^3}.$$

Per (4.43), $n_i^2 = n_0 p_0 \Rightarrow n_0 = n_i^2 / p_0 = (1.79 \times 10^6)^2 / 6 \times 10^{14} \Rightarrow \underline{n_0 = 0.0053402 \text{ \#/cm}^3}.$

Per (4.68), $E_{Fi} - E_F = k_B T \ln\left(\frac{p_0}{n_i}\right) = 8.617333 \times 10^{-5} (300) \ln\left(\frac{6 \times 10^{14}}{1.79 \times 10^6}\right) = 0.50748055$

$$\Rightarrow \underline{\Delta E = |E_F - E_{Fi}| = 0.50748 \text{ eV}}.$$

p-type or n-type ? (circle correct) $n_0 = \underline{0.0053402 \text{ \#/cm}^3}$ $p_0 = \underline{6 \times 10^{14} \text{ \#/cm}^3}$

$\Delta E = \underline{0.50748 \text{ eV}}$ $E_F > E_{Fi}$ or **$E_{Fi} > E_F$** ? (circle correct)

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