

ECE 3040 Microelectronic Circuits

Exam 1

September 30, 2015

Dr. W. Alan Doolittle

Print your name clearly and largely:

Solutions

Instructions:

Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 sheet of notes (1 page front and back) as well as a calculator. There are 100 total points. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I cannot read it, it will be considered a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. A periodic table is supplied on the last page. Good luck!

Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

First 33% Multiple Choice and True/False
(Circle the letter of the most correct answer or answers)

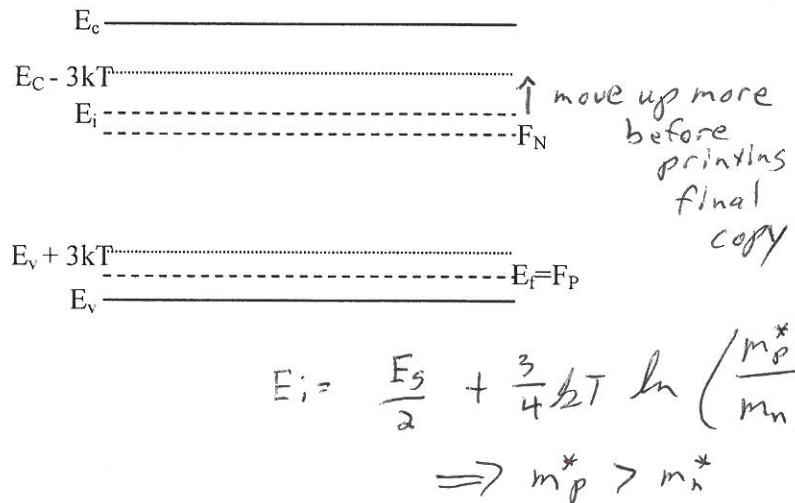
- 1.) (3-points) True or False: Valence electrons hold the crystal together and do not directly participate in conduction of electricity.
- 2.) (3-points) True or False: A high mobility (due to less frequent collisions with atoms) results from a low atomic density.
- 3.) (3-points) True or False: States that lie far below the fermi-energy are most likely filled.
- 4.) (3-points) True or False: $(Al_{0.1}In_{0.50}Ga_{0.40}N_{0.3}P_{0.4}As_{0.3})$ is not a valid semiconductor formula in standard semiconductor notation because it has too many atoms.
- 5.) (3-points) True or False: The probability of a hole existing in a state is mathematically described by one minus the fermi-distribution function evaluated at the energy of that state.
- 6.) (3-points) True or False: The density of states describes the likelihood of a state being occupied.
- 7.) (3-points) True or False: The fermi-energy can never be found inside the conduction band.

Select the **best** answer or answers for 8-10:

- 8.) (4-points) Which of the following are true about diffusion currents ...
 - a.) ... the equal the drift current in equilibrium
 - b.) ... they are driven by electric field
 - c.) ... they only happen when there is an imbalance (gradient) in carrier concentration
 - d.) ... they are the smaller of the three types of current flow
 - e.) ... they always balance (negate) the drift velocity
- 9.) (4-points) Which of the following are true about partial ionization.
 - a.) You rarely need to be concerned with this since impurities are always totally ionized
 - b.) The degeneracy factor for donors results from two electrons having the same momentum
 - c.) The degeneracy factor for donors results from two electrons having the same spin (quantum numbers)
 - d.) The further the ionization energy is toward the center of the bandgap, the higher the ionization probability
 - e.) The degeneracy factor for acceptors is larger than that for donors because there are more valance bands than conduction bands

- 10.) (4-points) The following energy band diagram indicates the material is:

- a.) In equilibrium
- b.) Degenerate and n-type
- c.) Degenerate and p-type
- d.) Non-degenerate n-type
- e.) Non-degenerate p-type
- f.) In low level injection
- g.) In high level injection
- h.) $m_n^* > m_p^*$
- i.) $m_n^* < m_p^*$
- j.) In steady state



Second 17% Short Answer ("Plug and Chug"):

For the following problems (11-12) use the following material parameters and assuming total ionization:

For InP:

$$n_i = 1.3e7 \text{ cm}^{-3} \quad N_D = 1e15 \text{ cm}^{-3} \text{ donors} \quad N_A = 2e15 \text{ cm}^{-3} \text{ acceptors} \quad m_p^* = 0.6m_0 \quad m_n^* = 0.08m_0$$

$$E_G = 1.344 \text{ eV} \quad \text{Electron mobility, } \mu_n = 5000 \text{ cm}^2/\text{Vsec} \quad \text{Hole mobility, } \mu_p = 150 \text{ cm}^2/\text{V-sec}$$

Temperature=27 degrees C

11.) (7-points) Where is the fermi energy (relative to the valence band which is referenced to zero energy)?

$$p = \frac{N_A - N_D}{2} + \sqrt{\frac{(N_A - N_D)^2}{4} + n_i^2} = 1e15 \text{ cm}^{-3} \quad n = \frac{n_i^2}{p} = \frac{(1.3e7)^2}{1e15} = 0.169 \text{ cm}^{-5}$$

$$E_i = E_g + \frac{3}{4}kT \ln\left(\frac{m_p^*}{m_n^*}\right) = 0.711 \text{ eV}$$

Several possible approaches

$$1) p = 1e15 = 1.3e7 e^{(E_F - E_A)/kT} \quad [E_A = 0.241 \text{ eV}]$$

$$2) n = 0.169 = 1.3e7 e^{(E_F - E_i)/kT} \quad [E_i = 0.241 \text{ eV}]$$

$$3) N_c = 2.51 \times 10^{19} \left(\frac{m_n^*}{m_0}\right)^{3/2} = 5.679 e17 \text{ cm}^{-3}$$

$$0.169 = N_c e^{(E_F - E_c)/kT} \quad [E_c = 0.239 \text{ eV}]$$

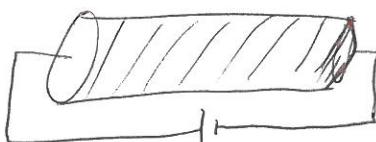
$$4) N_v = 2.59 \times 10^{19} \left(\frac{m_p^*}{m_0}\right)^{3/2}$$

$$1e15 = p = N_v e^{(E_v - E_F)/kT} \quad [E_v = 0.243 \text{ eV}]$$

12.) (10-points) A 10 um diameter x 500 um long cylindrical semiconductor resistor is made from the semiconductor from problem 11. It is biased on two opposing sides (longest dimension) with 1.5 volt battery. Determine both the electron and hole current flowing in the device.

$$A = \pi (5 \times 10^{-4} \text{ cm})^2 = 7.854e-7 \text{ cm}^2$$

$$L = 500 \times 10^{-4} \text{ cm}$$



$$R_n = \frac{p_n L}{A}$$

$$= 4.71e20 \Omega$$

massive

$$\boxed{I_n = \frac{V}{R_n} = 3.2e-21 \text{ A}}$$

practically zero!

$$R = \frac{\rho L}{q(\mu_n n + \mu_p p)} \quad R_p = \frac{\rho L}{q \mu_p p}$$

$$p_n = \frac{1}{q \mu_n n} \quad p_p = \frac{1}{q \mu_p p} = 41.66 \Omega \cdot \text{cm}$$

$$l_n = 7.4e15 \text{ cm}$$

$$R_p = \frac{p_p L}{A} = \frac{(41.66)(5 \times 10^{-2})}{7.854e-7}$$

$$R_p = 2.65e6 \Omega$$

$$\boxed{I_p = \frac{V}{R_p} = 0.565 \mu \text{A}}$$

Section 3 (more short answer)

13.) (10-points total) The material in problems 11 and 12 is exposed to the sun's light (like in a solar cell) that generates $2 \times 10^{16} \text{ cm}^{-3}$ extra minority carriers.

- a) (2 points) Is this low level or high level injection?

$$\Delta p = 2 \times 10^{16} > 1 \times 10^{15} \text{ so High Level}$$

$\uparrow p_0$

- b) (8 points) Draw the 1 dimensional energy band diagram showing the placement of both the quasi-fermi levels (numeric answer) relative to E_i , E_c , and E_v .

$$n = 0.162 + 2 \times 10^{16}$$

$$n = 2 \times 10^{16}$$

$$n = 1.3 \times 10^{17} e^{\frac{(E_F - E_i)}{kT}}$$

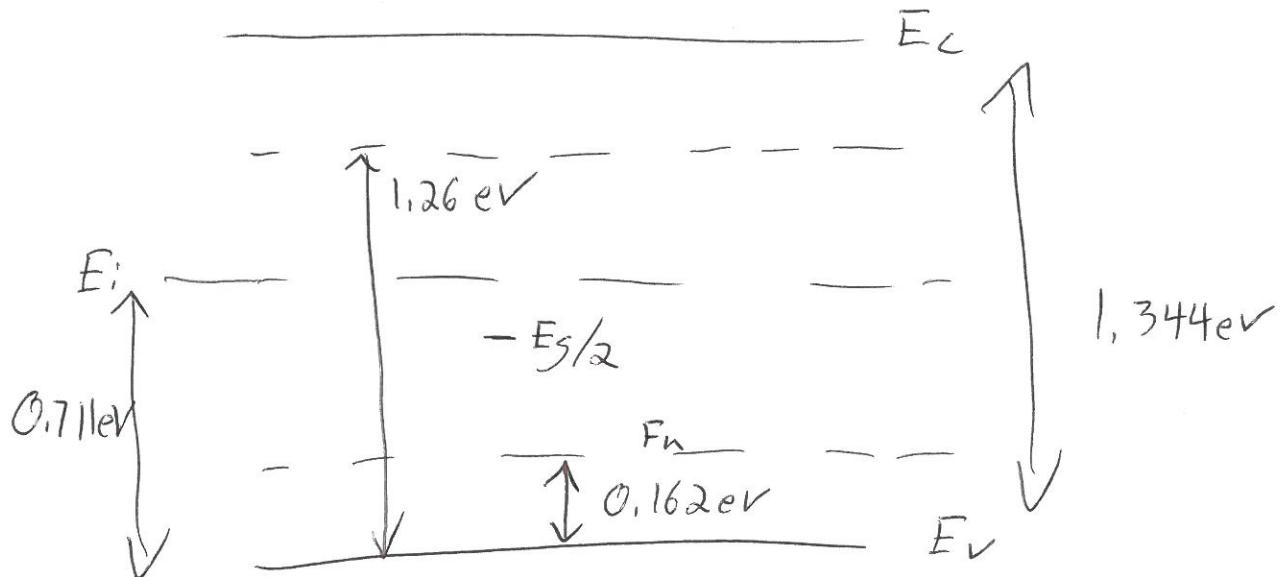
$$F_n = 1.26 \text{ eV}$$

$$p = 1 \times 10^{15} + 2 \times 10^{16}$$

$$p = 2.1 \times 10^{16}$$

$$p = 1.3 \times 10^{17} e^{\frac{(E_i - F_p)}{kT}}$$

$$F_p = 0.162 \text{ eV}$$



Pulling all the concepts together for a useful purpose:

14.) (40-points)

(Humor intended to Diffuse Test Tension. Apologies if the choice of "morons" offends.)

The world is made up of 4 types of particles; tiny electrons, protons, neutrons and gigantic morons. Morons are particles only found in government and have the ability to completely consume every other particle (electrons in this case). A 100 um length of a semiconductor named "TxPaYEr" has been constantly stuck between democrat morons and republican morons since February 3, 1913 when the 16th amendment was passed. The semiconductor is to be used in the presence of sunlight. The semiconductor is doped p-type with an acceptor concentration of $1e17 \text{ cm}^{-3}$ and has a minority carrier lifetime of $10^0 \text{ microseconds}$.

6v

The sunlight is absorbed uniformly in the semiconductor generating an excess minority carrier concentration rate of $10^{20} \text{ cm}^{-3}/\text{sec}$. At both ends of the semiconductor (at +50 and -50 um), the democrat and republican morons act to steal minority carriers from the semiconductor "TxPaYEr" resulting in the excess electron concentration being zero at the semiconductor boundaries, $\Delta n(x=+50)=\Delta n(x=-50)=0 \text{ cm}^{-3}$. If the semiconductor is held at room temperature (27 degrees C), determine the minority carrier diffusion current density at all positions in the semiconductor ($-50 \text{ um} \geq x \geq 50 \text{ um}$). Assume a minority carrier mobility of $200 \text{ cm}^2/\text{V sec}$ and the intrinsic concentration is $1e14 \text{ cm}^{-3}$.

M^

TBC Given, easy

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} - \frac{\Delta n_p}{\tau_n}$

General Solution is: $\Delta n_p(x) = Ae^{-x/L_n} + Be^{+x/L_n}$

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} - \frac{\Delta n_p}{\tau_n} + G_L$

General Solution is: $\Delta n_p(x) = Ae^{-x/L_n} + Be^{+x/L_n} + G_L \tau_n$

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2}$

General Solution is: $\Delta n_p(x) = A + Bx$

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} + G_L$

General Solution is: $\Delta n_p(x) = Ax^2 + Bx + C$

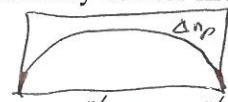
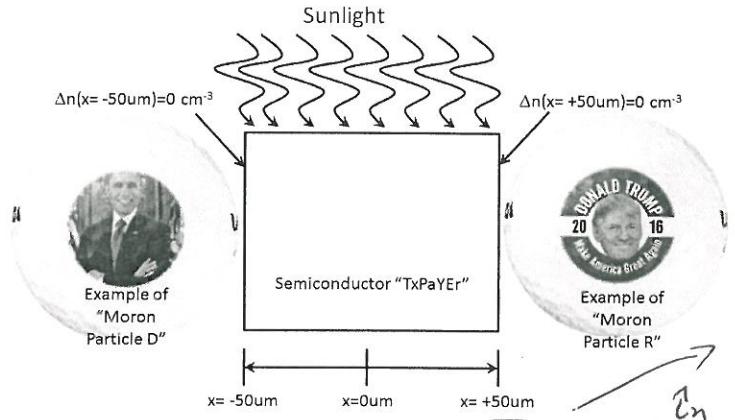
Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} + G_{LO} f(x)$ General Solution is: $\Delta n_p(x) = \left[-\frac{G_{LO}}{D_n} \int \int f(x) dx \right] + Bx + C$

Given: $\frac{d \Delta n_p}{dt} = -\frac{\Delta n_p}{\tau_n}$

General Solution is: $\Delta n_p(t) = \Delta n_p(t=0) e^{-t/\tau_n}$

Given: $0 = -\frac{\Delta n_p}{\tau_n} + G_L$

General Solution is: $\Delta n_p = G_L \tau_n$



Extra work can be done here, but clearly indicate which problem you are solving.

$$D_n = \mu n \left(\frac{2\pi}{q} \right) = 5.18 \text{ cm}^2/\text{sec}$$

$$L_n = \sqrt{D_n t_n} = \sqrt{5.18(100e-6)} = 227.6 \text{ nm}$$

$$G_L t_n = (10^{20}) (100e-6) = 1e16 \text{ cm}^{-3}$$

BC:

$$1) \Delta n(x=-50 \text{ nm}) = 0 = A e^{50/227.6} + B e^{-50/227.6} + 1e16$$

$$2) \Delta n(x=+50 \text{ nm}) = 0 = A e^{-50/227.6} + B e^{+50/227.6} + 1e16$$

Setting 1) = 2)

$$A e^{50/227.6} + B e^{-50/227.6} = A e^{-50/227.6} + B e^{50/227.6}$$

$$A(e^{50/227.6} - e^{-50/227.6}) = B(e^{50/227.6} - e^{-50/227.6})$$

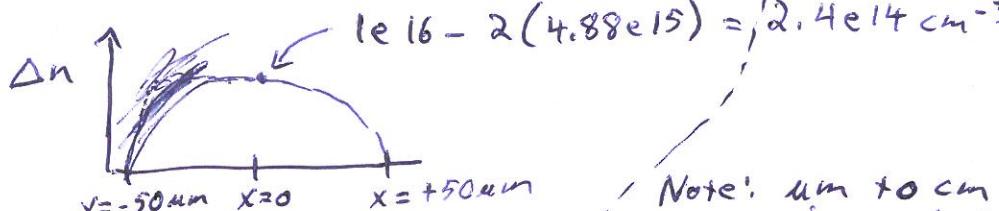
Subbing into 1)

$$A = B$$

$$0 = A(e^{50/227.6} + e^{-50/227.6}) + 1e16$$

$$A = B = -4.88 e^{15} \text{ cm}^{-3}$$

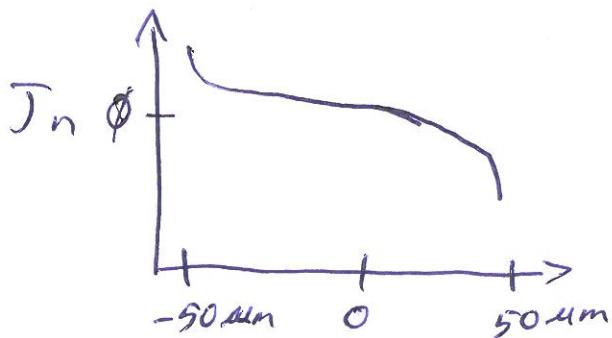
$$\boxed{\Delta n(x) = -4.88 e^{15} [e^{-x/227.6 \text{ nm}} + e^{+x/227.6 \text{ nm}}] + 1e16 \text{ cm}^{-3}}$$



$$J_n = q D_n \frac{d \Delta n(x)}{dx}$$

Note: nm to cm conversion when taking derivative

$$\boxed{J_n = 0.177 [e^{-x/227.6} - e^{+x/227.6}] \text{ A/cm}^2}$$



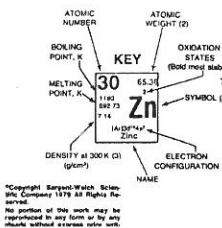
Extra work can be done here, but clearly indicate which problem you are solving.

PERIODIC TABLE OF THE ELEMENTS

Table of Selected Radioactive Isotopes

GROUP IA		Periodic Table of the Elements																																					
1	1.0076	H	IA	Periodic Table of the Elements		Periodic Table of the Elements																																	
20	20.106	Periodic Table of the Elements		Periodic Table of the Elements																																			
30	30.065	Periodic Table of the Elements		Periodic Table of the Elements																																			
1	Hydrogen	IIA	3	6.044	9.0121	20	20.106	30	30.065	40	40.072	50	50.079	60	60.087	70	70.095	80	80.103	90	90.111																		
16	Lithium	Be	17	7.016	10.019	21	21.023	31	31.029	41	41.036	51	51.043	61	61.050	71	71.057	81	81.064	91	91.071																		
16	19 ²⁹ Lithium	Beryllium	17	19 ³⁰ Be	20	21 ³¹ 20 ³⁰ 30	31	31 ³² 21 ³¹ 31	41	41 ³³ 21 ³² 31	51	51 ³⁴ 21 ³³ 31	61	61 ³⁵ 21 ³⁴ 31	71	71 ³⁶ 21 ³⁵ 31	81	81 ³⁷ 21 ³⁶ 31	91	91 ³⁸ 21 ³⁷ 31																			
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1	1 ³¹ 32 ⁷⁹ 29	2	2 ³² 33 ⁸⁰ 50 ³¹	3	3 ³³ 32 ⁸¹ 51 ³²	4	4 ³⁴ 31 ⁸² 51 ³³	5	5 ³⁵ 30 ⁸³ 51 ³⁴	6	6 ³⁶ 29 ⁸⁴ 51 ³⁵	7	7 ³⁷ 28 ⁸⁵ 51 ³⁶	8	8 ³⁸ 27 ⁸⁶ 51 ³⁷	9	9 ³⁹ 26 ⁸⁷ 51 ³⁸	10	10 ⁴⁰ 25 ⁸⁸ 51 ³⁹	11	11 ⁴¹ 25 ⁸⁹ 51 ³⁹	12	12 ⁴² 25 ⁹⁰ 51 ³⁹	13	13 ⁴³ 25 ⁹¹ 51 ³⁹	14	14 ⁴⁴ 25 ⁹² 51 ³⁹	15	15 ⁴⁵ 25 ⁹³ 51 ³⁹	16	16 ⁴⁶ 25 ⁹⁴ 51 ³⁹	17	17 ⁴⁷ 25 ⁹⁵ 51 ³⁹	18	18 ⁴⁸ 25 ⁹⁶ 51 ³⁹	19	19 ⁴⁹ 25 ⁹⁷ 51 ³⁹	20	20 ⁵⁰ 25 ⁹⁸ 51 ³⁹
1	1 ²⁹ 30 ⁷⁹ 29	2	2 ³⁰ 29 ⁸⁰ 50 ³¹	3	3 ³¹ 28 ⁸¹ 51 ³²	4	4 ³² 27 ⁸² 51 ³³	5	5 ³³ 26 ⁸³ 51 ³⁴	6	6 ³⁴ 25 ⁸⁴ 51 ³⁵	7	7 ³⁵ 24 ⁸⁵ 51 ³⁶	8	8 ³⁶ 23 ⁸⁶ 51 ³⁷	9	9 ³⁷ 22 ⁸⁷ 51 ³⁸	10	10 ³⁸ 21 ⁸⁸ 51 ³⁹	11	11 ³⁹ 20 ⁸⁹ 51 ³⁹	12	12 ⁴⁰ 19 ⁹⁰ 51 ³⁹	13	13 ⁴¹ 19 ⁹¹ 51 ³⁹	14	14 ⁴² 19 ⁹² 51 ³⁹	15	15 ⁴³ 19 ⁹³ 51 ³⁹	16	16 ⁴⁴ 19 ⁹⁴ 51 ³⁹	17	17 ⁴⁵ 19 ⁹⁵ 51 ³⁹	18	18 ⁴⁶ 19 ⁹⁶ 51 ³⁹	19	19 ⁴⁷ 19 ⁹⁷ 51 ³⁹	20	20 ⁴⁸ 19 ⁹⁸ 51 ³⁹
1	1 ²⁷ 28 ⁷⁹ 29	2	2 ²⁸ 27 ⁸⁰ 50 ³¹	3	3 ²⁹ 26 ⁸¹ 51 ³²	4	4 ³⁰ 25 ⁸² 51 ³³	5	5 ³¹ 24 ⁸³ 51 ³⁴	6	6 ³² 22 ⁸⁴ 51 ³⁵	7	7 ³³ 21 ⁸⁵ 51 ³⁶	8	8 ³⁴ 20 ⁸⁶ 51 ³⁷	9	9 ³⁵ 19 ⁸⁷ 51 ³⁸	10	10 ³⁶ 18 ⁸⁸ 51 ³⁹	11	11 ³⁷ 17 ⁸⁹ 51 ³⁹	12	12 ³⁸ 16 ⁹⁰ 51 ³⁹	13	13 ³⁹ 15 ⁹¹ 51 ³⁹	14	14 ⁴⁰ 14 ⁹² 51 ³⁹	15	15 ⁴¹ 13 ⁹³ 51 ³⁹	16	16 ⁴² 12 ⁹⁴ 51 ³⁹	17	17 ⁴³ 11 ⁹⁵ 51 ³⁹	18	18 ⁴⁴ 10 ⁹⁶ 51 ³⁹	19	19 ⁴⁵ 9 ⁹⁷ 51 ³⁹	20	20 ⁴⁶ 8 ⁹⁸ 51 ³⁹
1	1 ²⁵ 26 ⁷⁹ 29	2	2 ²⁶ 25 ⁸⁰ 50 ³¹	3	3 ²⁷ 24 ⁸¹ 51 ³²	4	4 ²⁸ 23 ⁸² 51 ³³	5	5 ²⁹ 22 ⁸³ 51 ³⁴	6	6 ³⁰ 20 ⁸⁴ 51 ³⁵	7	7 ³¹ 19 ⁸⁵ 51 ³⁶	8	8 ³² 17 ⁸⁶ 51 ³⁷	9	9 ³³ 16 ⁸⁷ 51 ³⁸	10	10 ³⁴ 15 ⁸⁸ 51 ³⁹	11	11 ³⁵ 14 ⁸⁹ 51 ³⁹	12	12 ³⁶ 13 ⁹⁰ 51 ³⁹	13	13 ³⁷ 12 ⁹¹ 51 ³⁹	14	14 ³⁸ 11 ⁹² 51 ³⁹	15	15 ³⁹ 10 ⁹³ 51 ³⁹	16	16 ⁴⁰ 9 ⁹⁴ 51 ³⁹	17	17 ⁴¹ 8 ⁹⁵ 51 ³⁹	18	18 ⁴² 7 ⁹⁶ 51 ³⁹	19	19 ⁴³ 6 ⁹⁷ 51 ³⁹	20	20 ⁴⁴ 5 ⁹⁸ 51 ³⁹
1	1 ²³ 24 ⁷⁹ 29	2	2 ²⁴ 23 ⁸⁰ 50 ³¹	3	3 ²⁵ 22 ⁸¹ 51 ³²	4	4 ²⁶ 21 ⁸² 51 ³³	5	5 ²⁷ 20 ⁸³ 51 ³⁴	6	6 ²⁸ 18 ⁸⁴ 51 ³⁵	7	7 ²⁹ 16 ⁸⁵ 51 ³⁶	8	8 ³⁰ 14 ⁸⁶ 51 ³⁷	9	9 ³¹ 13 ⁸⁷ 51 ³⁸	10	10 ³² 12 ⁸⁸ 51 ³⁹	11	11 ³³ 11 ⁸⁹ 51 ³⁹	12	12 ³⁴ 10 ⁹⁰ 51 ³⁹	13	13 ³⁵ 9 ⁹¹ 51 ³⁹	14	14 ³⁶ 8 ⁹² 51 ³⁹	15	15 ³⁷ 7 ⁹³ 51 ³⁹	16	16 ³⁸ 6 ⁹⁴ 51 ³⁹	17	17 ³⁹ 5 ⁹⁵ 51 ³⁹	18	18 ⁴⁰ 4 ⁹⁶ 51 ³⁹	19	19 ⁴¹ 3 ⁹⁷ 51 ³⁹	20	20 ⁴² 2 ⁹⁸ 51 ³⁹
1	1 ²¹ 22																																						

* Estimated Values



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58	140. 34	169. 34	140.3077 137.011 137.011	60	144. 34	61	145. 34	62	150. 32	63	151. 32	64	152. 32	65	154. 32	66	152. 32	67	164. 32	68	167. 32	69	168. 32	70	172. 32	
Ce	(¹⁴⁰ Pr) Ce	(¹⁶⁹ Pr) Pr	(¹⁴⁰ Pr) Pr	Pr	(¹⁴⁴ Nd) Nd	(¹⁶⁹ Pm) Pm	(¹⁴⁵ Nd) Nd	Pm	(¹⁵⁰ Eu) Eu	(¹⁵¹ Gd) Gd	(¹⁵² Tb) Tb	(¹⁵⁴ Dy) Dy	(¹⁵² Ho) Ho	(¹⁶⁷ Er) Er	(¹⁶⁸ Tm) Tm	(¹⁶⁹ Yb) Yb	(¹⁷² Lu) Lu	(¹⁶⁸ Lu) Lu	(¹⁷² Yb) Yb	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Yb) Yb	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Yb) Yb	(¹⁷⁴ Lu) Lu
(¹⁴⁰ Pr) Pr	(¹⁶⁹ Pr) Pr	(¹⁴⁰ Pr) Pr	(¹⁴⁰ Pr) Pr	(¹⁴⁴ Nd) Nd	(¹⁶⁹ Pm) Pm	(¹⁴⁵ Nd) Nd	(¹⁶⁹ Pm) Pm	(¹⁵⁰ Eu) Eu	(¹⁵¹ Gd) Gd	(¹⁵² Tb) Tb	(¹⁵⁴ Dy) Dy	(¹⁵² Ho) Ho	(¹⁶⁷ Er) Er	(¹⁶⁸ Tm) Tm	(¹⁶⁹ Yb) Yb	(¹⁷² Lu) Lu	(¹⁶⁸ Lu) Lu	(¹⁷² Yb) Yb	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Yb) Yb	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Yb) Yb	(¹⁷⁴ Lu) Lu	
(¹⁴⁰ Pr) Pr	(¹⁶⁹ Pr) Pr	(¹⁴⁰ Pr) Pr	(¹⁴⁰ Pr) Pr	(¹⁴⁴ Nd) Nd	(¹⁶⁹ Pm) Pm	(¹⁴⁵ Nd) Nd	(¹⁶⁹ Pm) Pm	(¹⁵⁰ Eu) Eu	(¹⁵¹ Gd) Gd	(¹⁵² Tb) Tb	(¹⁵⁴ Dy) Dy	(¹⁵² Ho) Ho	(¹⁶⁷ Er) Er	(¹⁶⁸ Tm) Tm	(¹⁶⁹ Yb) Yb	(¹⁷² Lu) Lu	(¹⁶⁸ Lu) Lu	(¹⁷² Yb) Yb	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Yb) Yb	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Lu) Lu	(¹⁷⁴ Yb) Yb	(¹⁷⁴ Lu) Lu	
90	237. 036	231. 035	92	236. 02	93	237. 045	94	244. 02	95	245. 02	96	247. 02	97	247. 02	98	251. 02	99	251. 02	100	251. 02	101	254. (258)	102	(259) No		
Th	(²³¹ Pa) Th	(²³⁰ Pa) Th	(²³¹ Pa) Th	Pa	(²³⁰ U) U	(²³¹ Pa) Pa	(²³⁰ U) U	U	(²³¹ Pa) Pa	(²³² Np) Np	(²³³ Pu) Pu	(²³⁴ Am) Am	(²³⁵ Bk) Bk	(²³⁸ Cf) Cf	(²⁴⁰ Es) Es	(²⁴² Fm) Fm	(²⁴⁴ Md) Md	(²⁴⁸ No) No	(²⁵⁰ Lr) Lr	(²⁵² No) No	(²⁵⁴ Lr) Lr	(²⁵⁶ No) No	(²⁵⁸ Lr) Lr	(²⁶⁰ No) No		
(²³¹ Pa) Th	(²³⁰ Pa) Th	(²³¹ Pa) Th	(²³¹ Pa) Th	Pa	(²³⁰ U) U	(²³¹ Pa) Pa	(²³⁰ U) U	U	(²³¹ Pa) Pa	(²³² Np) Np	(²³³ Pu) Pu	(²³⁴ Am) Am	(²³⁵ Bk) Bk	(²³⁸ Cf) Cf	(²⁴⁰ Es) Es	(²⁴² Fm) Fm	(²⁴⁴ Md) Md	(²⁴⁸ No) No	(²⁵⁰ Lr) Lr	(²⁵² No) No	(²⁵⁴ Lr) Lr	(²⁵⁶ No) No	(²⁵⁸ Lr) Lr	(²⁶⁰ No) No		
(²³¹ Pa) Th	(²³⁰ Pa) Th	(²³¹ Pa) Th	(²³¹ Pa) Th	Pa	(²³⁰ U) U	(²³¹ Pa) Pa	(²³⁰ U) U	U	(²³¹ Pa) Pa	(²³² Np) Np	(²³³ Pu) Pu	(²³⁴ Am) Am	(²³⁵ Bk) Bk	(²³⁸ Cf) Cf	(²⁴⁰ Es) Es	(²⁴² Fm) Fm	(²⁴⁴ Md) Md	(²⁴⁸ No) No	(²⁵⁰ Lr) Lr	(²⁵² No) No	(²⁵⁴ Lr) Lr	(²⁵⁶ No) No	(²⁵⁸ Lr) Lr	(²⁶⁰ No) No		

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