

# EE 362 Electronic, Magnetic, & Optical Properties of Materials

## Examination #1 (Spring 2025)

Name **KEY B**

Instructions: Closed book. Put answers in indicated spaces, use notation as given in class & show all work for credit.  
Insert equation sheet in exam. Answers should have 4-5 significant figures (use more for constants).

- 1) Copper (Cu) has a face-centered cubic crystal structure with a lattice constant of 3.615 Å. Find the atomic weight, number of atoms per unit cell, and unit cell volume ( $\text{cm}^3$ ) for copper. Next, compute the atomic volume density  $avd_{\text{Cu}}$  (#/ $\text{cm}^3$ ) and mass density  $md_{\text{Cu}}$  ( $\text{g}/\text{cm}^3$ ) of copper.

From periodic table, the atomic weight of copper is  $A_{r,\text{Cu}} = 63.546$ .

# atoms/unit cell = 8 corners (1/8 atoms/corner) + 6 faces (1/2 atom/face) = 4 atoms.

$$\text{volume} = a^3 = (3.615 \times 10^{-10})^3 = 4.7241633 \times 10^{-29} \text{ m}^3 \Rightarrow \text{volume} = \underline{\underline{7.72416 \times 10^{-23} \text{ cm}^3}}.$$

$$avd_{\text{Sr}} = (\# \text{ atoms}/\text{unit cell})/\text{volume} = 4 / (3.615 \times 10^{-10})^3 = 8.46711 \times 10^{28} \text{ atoms}/\text{m}^3 \\ \Rightarrow \underline{\underline{avd_{\text{Cu}} = 8.46711 \times 10^{22} \text{ atoms}/\text{cm}^3}}.$$

The mass density strontium is

$$md_{\text{Cu}} = (avd_{\text{Cu}}) (\underline{\underline{A_{r,\text{Cu}}}}) / N_A = 8.46711 \times 10^{22} \text{ atoms}/\text{cm}^3 (63.546) / 6.02214076 \times 10^{23} \\ \Rightarrow \underline{\underline{md_{\text{Cu}} = 8.93454 \text{ g}/\text{cm}^3}}.$$

atomic weight =  $63.546$     # of atoms/unit cell =  $4$     volume =  $7.72416 \times 10^{-23} \text{ cm}^3$

$avd_{\text{Cu}} = \underline{\underline{8.4671 \times 10^{22} \text{ atoms}/\text{cm}^3}} \qquad md_{\text{Cu}} = \underline{\underline{8.9345 \text{ g}/\text{cm}^3}}$

- 2) An electron, near the surface of lithium (work function 2.93 eV), is simultaneously struck at one point by photons A ( $\lambda_A = 680 \text{ nm}$ ) and B ( $\lambda_B = 560 \text{ nm}$ ). First, find the frequency (Hz), momentum (kg·m/s), and kinetic energy (J and eV) of each photon. Assuming 100% energy transfer from the photons to the electron, will there be a photoelectron? If so, determine the maximum kinetic energy (J and eV), momentum (kg·m/s), velocity (m/s), and de Broglie wavelength (Å) of the photoelectron.

Photon A:

$$v = f = c/\lambda = 2.99792458 \times 10^8 / 680 \times 10^{-9} \Rightarrow v_A = f_A = 4.40871 \times 10^{14} \text{ Hz.}$$

$$(2.2) \ p = h/\lambda = 6.62607015 \times 10^{-34} / 680 \times 10^{-9} \Rightarrow p_A = 9.74422 \times 10^{-28} \text{ kg}\cdot\text{m/s.}$$

$$(\text{text p. 27}) \ KE_A = h v_A = 6.62607015 \times 10^{-34} (4.408713 \times 10^{14})$$

$$\Rightarrow KE_A = 2.921244 \times 10^{-19} \text{ J} = 1.8233 \text{ eV.}$$

Photon B:

$$v = f = c/\lambda = 2.99792458 \times 10^8 / 560 \times 10^{-9} \Rightarrow v_B = f_B = 5.353436 \times 10^{14} \text{ Hz.}$$

$$(2.2) \ p = h/\lambda = 6.62607015 \times 10^{-34} / 560 \times 10^{-9} \Rightarrow p_B = 1.183227 \times 10^{-27} \text{ kg}\cdot\text{m/s.}$$

$$(\text{text p. 27}) \ KE_B = h v_B = 6.62607015 \times 10^{-34} (5.353436 \times 10^{14})$$

$$\Rightarrow KE_B = 3.547225 \times 10^{-19} \text{ J} = 2.2140 \text{ eV.}$$

Photoelectron:

$$(2.1) \ KE = 0.5mv^2 = h\nu - \Phi = (1.8233 + 2.214) - 2.93 \\ \Rightarrow KE_e = 1.1073 \text{ eV} = 1.77409 \times 10^{-19} \text{ J.}$$

$$KE = 0.5mv^2 \Rightarrow v_e = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{2(1.77409 \times 10^{-19})}{9.1093837 \times 10^{-31}}} \Rightarrow v_e = 624,106.0 \text{ m/s.}$$

$$p_e = mv = (9.1093837 \times 10^{-31}) 624,106 \Rightarrow p_e = 5.68522 \times 10^{-25} \text{ kg}\cdot\text{m/s}$$

$$(2.3) \ \lambda_e = h/p_e = 6.62607015 \times 10^{-34} / 5.68522 \times 10^{-25} = 1.16549 \times 10^{-9} \text{ m} \\ \Rightarrow \lambda_e = 11.6549 \text{ Å.}$$

$$\text{A: } f_A = 4.4087 \times 10^{14} \text{ Hz} \quad p_A = 9.7442 \times 10^{-28} \text{ kg}\cdot\text{m/s} \quad KE_A = 2.9212 \times 10^{-19} \text{ J} = 1.8233 \text{ eV}$$

$$\text{B: } f_B = 5.3534 \times 10^{14} \text{ Hz} \quad p_B = 1.1832 \times 10^{-27} \text{ kg}\cdot\text{m/s} \quad KE_B = 3.5472 \times 10^{-19} \text{ J} = 2.2140 \text{ eV}$$

photoelectron?  Yes / No (circle correct answer)  $KE_e = 1.7741 \times 10^{-19} \text{ J} = 1.1073 \text{ eV}$

$$e^-: \text{mom}_e = 5.68522 \times 10^{-25} \text{ kg}\cdot\text{m/s} \quad \text{vel.}_e = 624,106 \text{ m/s} \quad \lambda_e = 11.6549 \text{ Å}$$

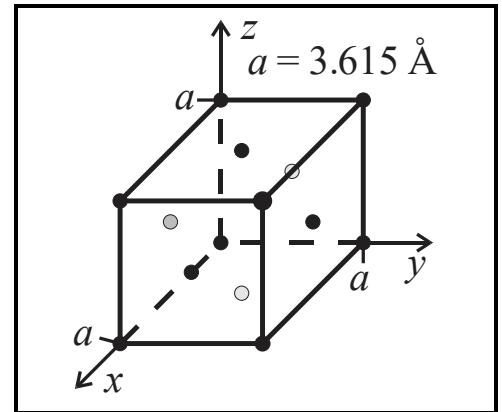
- 3) Copper (Cu) has a face-centered cubic crystal structure with a lattice constant of 3.615 Å. Sketch the lattice structure in box provided (align to Cartesian axes w/ back left corner at origin). Next, find the number of atoms, Miller indices, and atomic surface density  $asd$  (#/cm<sup>2</sup>) for the top surface as well as the diagonal surface connecting the left top and right bottom edges.

### Top

# atoms/top surface = 4 corners (1/4 atom/corner)  
+ 1 face (1 atom/face) = 2 atoms.

Miller indices

- $x$ -intercept is  $\infty$ ,  $y$ -intercept is  $\infty$ , &  $z$ -intercept is  $a$ .
- triplet  $(1/\infty, 1/\infty, 1/a) = (0, 0, 1/a)$
- $a (0, 0, 1/a) = (0, 0, 1) \Rightarrow \underline{(0\ 0\ 1)}$



$$\text{area} = a^2 = (3.615 \times 10^{-10})^2 = 1.3068225 \times 10^{-19} \text{ m}^2$$

$$\begin{aligned} asd = (\# \text{ atoms}/\text{top})/\text{area} &= 2 / (3.615 \times 10^{-10})^2 = 1.53043 \times 10^{19} \text{ atoms/m}^2 \\ &\Rightarrow \underline{asd = 1.53043 \times 10^{15} \text{ atoms/cm}^2}. \end{aligned}$$

### Diagonal

# atoms/diagonal surface = 4 corners (1/4 atom/corner) + 2 faces (1/2 atom/face) = 2 atoms.

Miller indices

- $x$ -intercept is  $\infty$ ,  $y$ -intercept is  $a$ , &  $z$ -intercept is  $a$ .
- triplet  $(1/\infty, 1/a, 1/a) = (0, 1/a, 1/a)$
- $a (0, 1/a, 1/a) = (0, 1, 1) \Rightarrow \underline{(0\ 1\ 1)}$

$$\text{area} = a (a^2 + a^2)^{0.5} = \sqrt{2}a^2 = \sqrt{2} (3.615 \times 10^{-10})^2 = 1.848126 \times 10^{-19} \text{ m}^2$$

$$\begin{aligned} asd = (\# \text{ atoms}/\text{top})/\text{area} &= 2 / 1.848126 \times 10^{-19} = 1.082177 \times 10^{19} \text{ atoms/m}^2 \\ &\Rightarrow \underline{asd = 1.082177 \times 10^{15} \text{ atoms/cm}^2}. \end{aligned}$$

**Top:** # atoms = 2      Miller indices = (0 0 1)       $asd = \underline{1.53043 \times 10^{15} \text{ atoms/cm}^2}$

**Diag:** # atoms = 2      Miller indices = (0 1 1)       $asd = \underline{1.08218 \times 10^{15} \text{ atoms/cm}^2}$

- 4) An electron is confined in a 1D infinite potential well where  $V = 0$  for  $0 < x < a = 2.8 \text{ \AA}$  and  $V \rightarrow \infty$  elsewhere. For the first two possible states, find the wave number, kinetic energy (eV & J), and probability density function of the confined electron as well as the probability (%) of finding the electron in  $0 < x < a/4$ . [Hint:  $\sin^2(A) = 0.5 - 0.5 \cos(2A)$  and  $\cos^2(A) = 0.5 + 0.5 \cos(2A)$ .]

Per (2.33),  $k_n = n\pi/a$ . For  $n=1$ ,  $k_1 = \pi/2.8 \times 10^{-10} \Rightarrow k_1 = 1.1219975 \times 10^{10} \text{ rad/m}$ .

For  $n=2$ ,  $k_2 = 2\pi/2.8 \times 10^{-10} \Rightarrow k_2 = 2.2439948 \times 10^{10} \text{ rad/m}$ .

Per (2.38), the kinetic energy

$$E_n = \frac{\hbar^2 n^2 \pi^2}{2ma^2} = \frac{(1.054571817 \times 10^{-34})^2 \pi^2 n^2}{(2)9.1093837 \times 10^{-31} (2.8 \times 10^{-10})^2} = \frac{(1.054571817 \times 10^{-34})^2 \pi^2 n^2}{(2)9.1093837 \times 10^{-31} (2.8 \times 10^{-10})^2}$$

$$= 7.684524736 \times 10^{-19} n^2 (\text{J}) = 4.796303 n^2 (\text{eV})$$

For  $n=1$ , the kinetic energy is  $\Rightarrow E_1 = 7.68452 \times 10^{-19} \text{ J} = 4.7963 \text{ eV}$ .

For  $n=2$ , the kinetic energy is  $\Rightarrow E_2 = 3.07381 \times 10^{-18} \text{ J} = 19.18521 \text{ eV}$ .

Per (2.36), the wave function is  $\psi(x) = \sqrt{\frac{2}{a}} \sin(k_n x) = \sqrt{\frac{2}{a}} \sin\left(\frac{n\pi}{a} x\right) \text{ m}^{-0.5} \quad n = 1, 2, 3, \dots$

Per (2.17),  $|\Psi(x,t)|^2 = |\psi(x)|^2 = \frac{2}{a} \sin^2\left(\frac{n\pi}{a} x\right) = \frac{2}{2.8 \times 10^{-10}} \sin^2\left(\frac{n\pi}{2.8 \times 10^{-10}} x\right)$ .

For  $n=1$ , the prob. density function is  $|\Psi_1(x)|^2 = 7.14286 \times 10^9 \sin^2(1.122 \times 10^{10} x) \text{ m}^{-1}$ .

For  $n=2$ , the prob. density function is  $|\Psi_2(x)|^2 = 7.14286 \times 10^9 \sin^2(2.244 \times 10^{10} x) \text{ m}^{-1}$ .

$$\int_0^{a/4} |\Psi(x)|^2 dx = \int_0^{a/4} \frac{2}{a} \sin^2\left(\frac{n\pi}{a} x\right) dx = \frac{2}{a} \int_0^{a/4} \left[ 0.5 - 0.5 \cos\left(\frac{2n\pi}{a} x\right) \right] dx$$

$$= \frac{1}{a} \int_0^{a/4} \left[ 1 - \cos\left(\frac{2n\pi}{a} x\right) \right] dx = \frac{1}{a} \left[ x - \sin\left(\frac{2n\pi}{a} x\right) / \left(\frac{2n\pi}{a}\right) \right]_0^{a/4}$$

$$= \frac{1}{a} \left[ \frac{a}{4} - a \sin\left(\frac{2n\pi}{a} \frac{a}{4}\right) / (2n\pi) \right] = \frac{1}{4} - \sin\left(\frac{n\pi}{2}\right) / (2n\pi)$$

The probability is

$$\text{For } n=1, \int_0^{a/4} |\Psi_1(x)|^2 dx = \frac{1}{4} - \sin\left(\frac{\pi}{2}\right) / (2\pi) = \frac{1}{4} - \frac{1}{2\pi} = 0.09084506 = 9.084506\%$$

$$\text{For } n=2, \int_0^{a/4} |\Psi_2(x)|^2 dx = \frac{1}{4} - \sin\left(\frac{2\pi}{2}\right) / (2\pi) = \frac{1}{4} - 0 = 0.25 = 25\%$$

**State 1:** wave number =  $1.1220 \times 10^{10} \text{ rad/m}$  KE =  $4.7963 \text{ eV} = 7.68452 \times 10^{-19} \text{ J}$

Prob. density function =  $7.14286 \times 10^9 \sin^2(1.122 \times 10^{10} x) \text{ m}^{-1}$  Prob'ty ( $0 < x < a/4$ ) =  $9.8045 \%$

**State 2:** wave number =  $2.2440 \times 10^{10} \text{ rad/m}$  KE =  $19.18521 \text{ eV} = 3.07381 \times 10^{-18} \text{ J}$

Prob. density function =  $7.14286 \times 10^9 \sin^2(2.244 \times 10^{10} x) \text{ m}^{-1}$  Probability ( $0 < x < a/4$ ) =  $25 \%$

## PERIODIC TABLE OF THE ELEMENTS

<b>1</b>	<b>H</b> Hydrogen 1.008	<b>2</b>	<b>He</b> Helium 4.003	<b>3</b>	<b>Li</b> Lithium 6.941	<b>4</b>	<b>Be</b> Boron 9.012	<b>5</b>	<b>B</b> Boron 10.811	<b>6</b>	<b>C</b> Carbon 12.011	<b>7</b>	<b>N</b> Nitrogen 14.007	<b>8</b>	<b>O</b> Oxygen 15.999	<b>9</b>	<b>F</b> Fluorine 18.998	<b>10</b>	<b>Ne</b> Neon 20.183																								
<b>11</b>	<b>Na</b> Sodium 22.99	<b>12</b>	<b>Mg</b> Magnesium 24.365	<b>13</b>	<b>K</b> Potassium 39.09	<b>14</b>	<b>Ca</b> Calcium 40.08	<b>15</b>	<b>Sc</b> Scandium 44.956	<b>16</b>	<b>Ti</b> Titanium 47.867	<b>17</b>	<b>V</b> Vanadium 50.92	<b>18</b>	<b>Cr</b> Chromium 51.996	<b>19</b>	<b>Mn</b> Manganese 54.938	<b>20</b>	<b>Fe</b> Iron 55.847	<b>21</b>	<b>Co</b> Cobalt 58.931	<b>22</b>	<b>Ni</b> Nickel 58.693	<b>23</b>	<b>Cu</b> Copper 63.546	<b>24</b>	<b>Zn</b> Zinc 65.401	<b>25</b>	<b>Ga</b> Gallium 69.721	<b>26</b>	<b>Ge</b> Germanium 72.611	<b>27</b>	<b>As</b> Arsenic 74.921	<b>28</b>	<b>Se</b> Selenium 78.955	<b>29</b>	<b>Br</b> Bromine 80.005	<b>30</b>	<b>Kr</b> Krypton 83.812	<b>31</b>	<b>Xe</b> Xenon 131.334		
<b>32</b>	<b>Rb</b> Rubidium 85.468	<b>33</b>	<b>Sr</b> Strontium 87.62	<b>34</b>	<b>Zr</b> Zirconium 91.224	<b>35</b>	<b>Tc</b> Technetium 95.95	<b>36</b>	<b>Nb</b> Niobium 95.96	<b>37</b>	<b>Ru</b> Ruthenium 101.07	<b>38</b>	<b>Pd</b> Palladium 106.42	<b>39</b>	<b>Ag</b> Silver 107.868	<b>40</b>	<b>Cd</b> Cadmium 112.412	<b>41</b>	<b>Fe</b> Iron 114.816	<b>42</b>	<b>Co</b> Cobalt 115.851	<b>43</b>	<b>Ni</b> Nickel 117.412	<b>44</b>	<b>Cu</b> Copper 118.711	<b>45</b>	<b>Zn</b> Zinc 119.412	<b>46</b>	<b>Ga</b> Gallium 120.891	<b>47</b>	<b>Ge</b> Germanium 121.762	<b>48</b>	<b>As</b> Arsenic 122.855	<b>49</b>	<b>Se</b> Selenium 123.934	<b>50</b>	<b>Br</b> Bromine 126.904	<b>51</b>	<b>Kr</b> Krypton 132.934	<b>52</b>	<b>Xe</b> Xenon 135.934		
<b>53</b>	<b>Cs</b> Cesium 132.915	<b>54</b>	<b>Ba</b> Barium 137.356	<b>55</b>	<b>Hf</b> Hafnium 178.495	<b>56</b>	<b>Ta</b> Tantalum 180.958	<b>57</b>	<b>Re</b> Rhenium 190.227	<b>58</b>	<b>Os</b> Osmium 190.227	<b>59</b>	<b>Pt</b> Platinum 195.09	<b>60</b>	<b>Au</b> Gold 196.967	<b>61</b>	<b>Hg</b> Mercury 200.59	<b>62</b>	<b>Tl</b> Thallium 204.424	<b>63</b>	<b>Pb</b> Lead 207.207	<b>64</b>	<b>Bi</b> Bismuth 208.977	<b>65</b>	<b>Po</b> Polonium 209.907	<b>66</b>	<b>Rn</b> Radium 222.007	<b>67</b>	<b>At</b> Astatine 223.007	<b>68</b>	<b>Rn</b> Radium 223.007	<b>69</b>	<b>At</b> Astatine 223.007	<b>70</b>	<b>Rn</b> Radium 223.007	<b>71</b>	<b>At</b> Astatine 223.007	<b>72</b>	<b>Rn</b> Radium 223.007				
<b>73</b>	<b>Fr</b> Francium 223.02	<b>74</b>	<b>Ra</b> Radium 226.02	<b>75</b>	<b>Rf</b> Rutherfordium 261.02	<b>76</b>	<b>Db</b> Dubnium 262.02	<b>77</b>	<b>Sg</b> Sovietium 263.02	<b>78</b>	<b>Bh</b> Bohrium 264.02	<b>79</b>	<b>Hs</b> Hassium 265.02	<b>80</b>	<b>Mt</b> Meitnerium 268.02	<b>81</b>	<b>Rg</b> Roentgenium 269.02	<b>82</b>	<b>Ts</b> Tennessine 269.02	<b>83</b>	<b>Lv</b> Livermorium 269.02	<b>84</b>	<b>Mc</b> Moscovium 269.02	<b>85</b>	<b>Nh</b> Nhastium 269.02	<b>86</b>	<b>Fl</b> Florium 269.02	<b>87</b>	<b>Cl</b> Clarkeium 269.02	<b>88</b>	<b>Lv</b> Livermorium 269.02	<b>89</b>	<b>Ts</b> Tennessine 269.02	<b>90</b>	<b>Mc</b> Moscovium 269.02	<b>91</b>	<b>Nh</b> Nhastium 269.02	<b>92</b>	<b>Fl</b> Clarkeium 269.02	<b>93</b>	<b>Cl</b> Livermorium 269.02	<b>94</b>	<b>Lu</b> Lutetium 174.967
<b>95</b>	<b>La</b> Lanthanum 138.95	<b>96</b>	<b>Ce</b> Cerium 140.136	<b>97</b>	<b>Pr</b> Praseodymium 141.032	<b>98</b>	<b>Nd</b> Neodymium 144.243	<b>99</b>	<b>Pm</b> Promethium 146.93	<b>100</b>	<b>Sm</b> Samarium 150.36	<b>101</b>	<b>Eu</b> Europium 151.964	<b>102</b>	<b>Gd</b> Gadolinium 157.05	<b>103</b>	<b>Tb</b> Terbium 158.925	<b>104</b>	<b>Dy</b> Dysprosium 162.566	<b>105</b>	<b>Ho</b> Holmium 164.936	<b>106</b>	<b>Er</b> Erbium 167.239	<b>107</b>	<b>Tm</b> Thulium 168.936	<b>108</b>	<b>Yb</b> Ytterbium 173.052	<b>109</b>	<b>Lu</b> Lutetium 174.967														
<b>110</b>	<b>Ac</b> Actinium 225.026	<b>111</b>	<b>Th</b> Thorium 232.036	<b>112</b>	<b>Pa</b> Protactinium 231.036	<b>113</b>	<b>U</b> Uranium 238.036	<b>114</b>	<b>Np</b> Neptunium 232.036	<b>115</b>	<b>Pu</b> Plutonium 234.036	<b>116</b>	<b>Am</b> Americium 243.036	<b>117</b>	<b>Cm</b> Curium 247.036	<b>118</b>	<b>Bk</b> Berkelium 247.036	<b>119</b>	<b>Cf</b> Californium 247.036	<b>120</b>	<b>Es</b> Einsteinium 252.036	<b>121</b>	<b>Fm</b> Fermium 257.036	<b>122</b>	<b>Md</b> Mendelevium 257.036	<b>123</b>	<b>No</b> Nobelium 253.171	<b>124</b>	<b>Lr</b> Lawrencium 257.036														