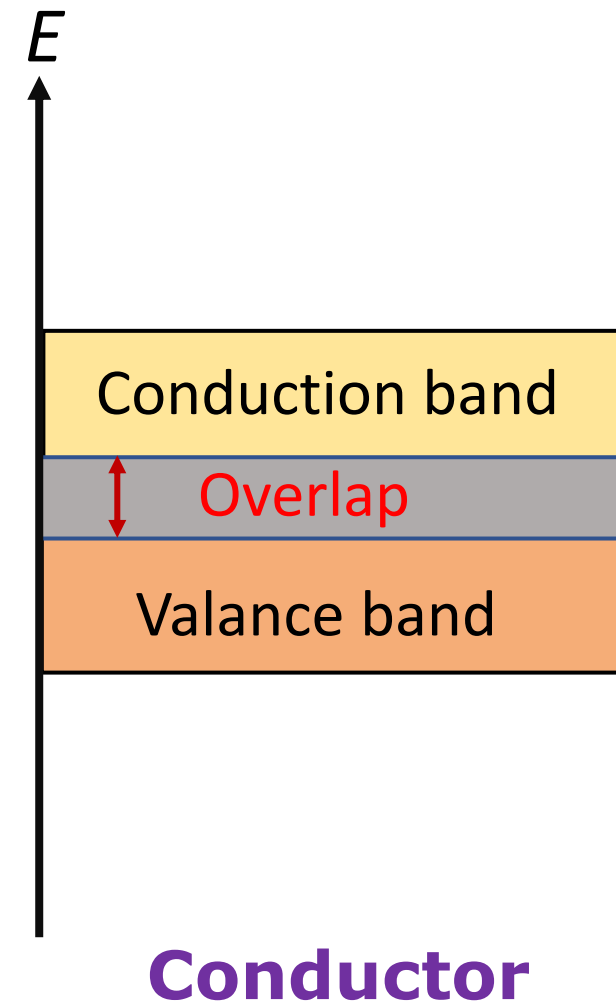
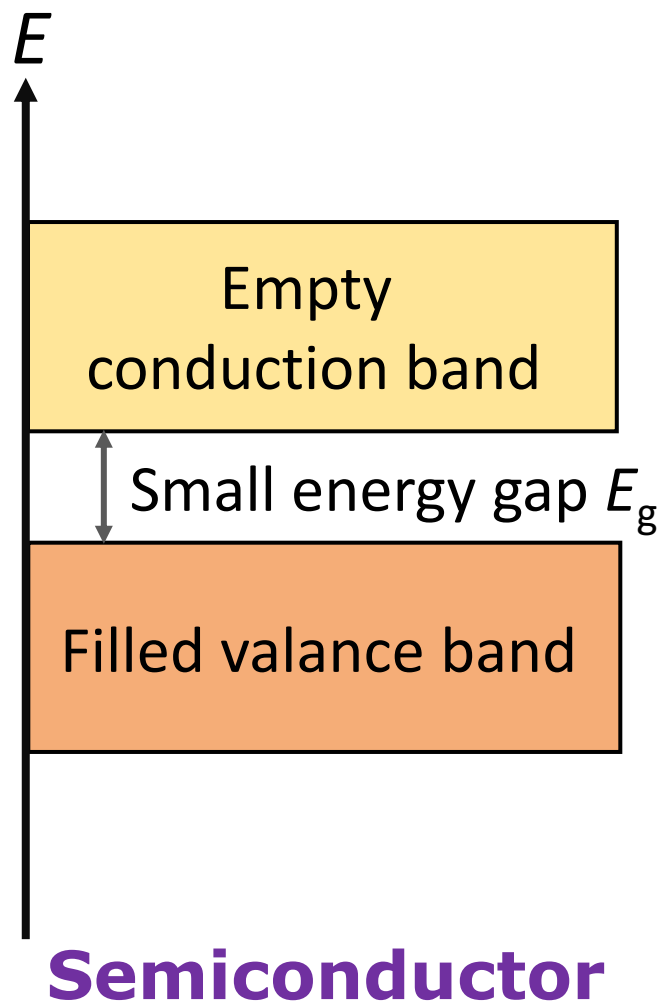
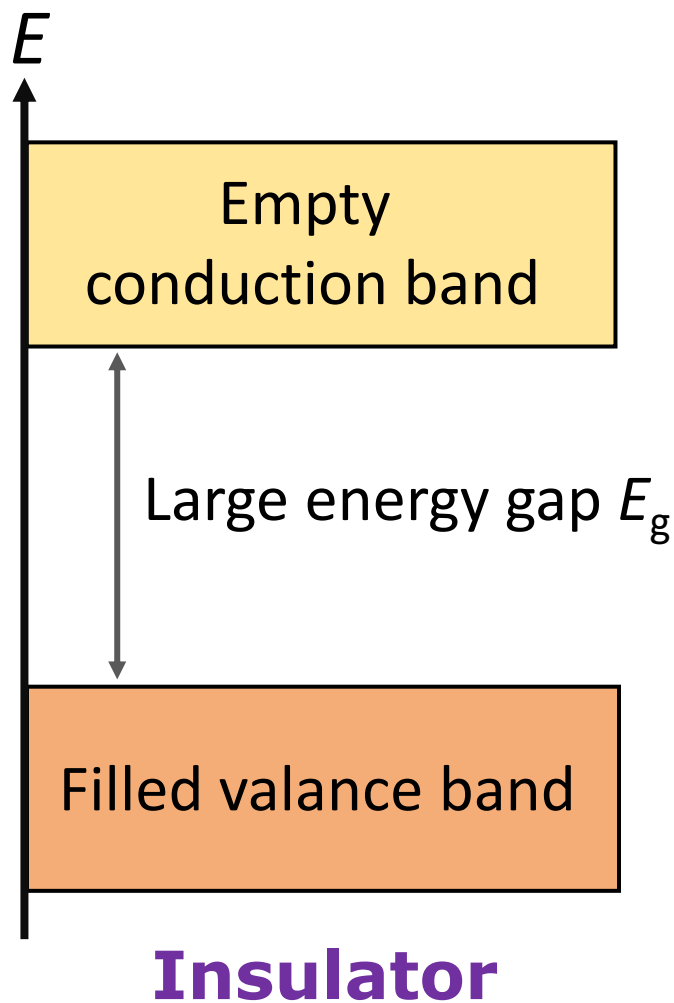


# Intrinsic and extrinsic semiconductors

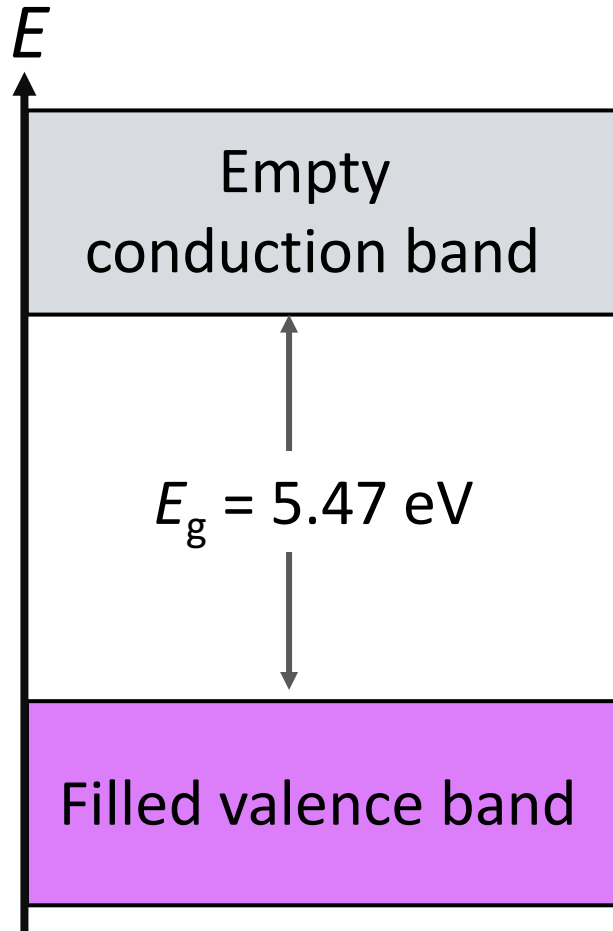
Dr Mohammad Abdur Rashid



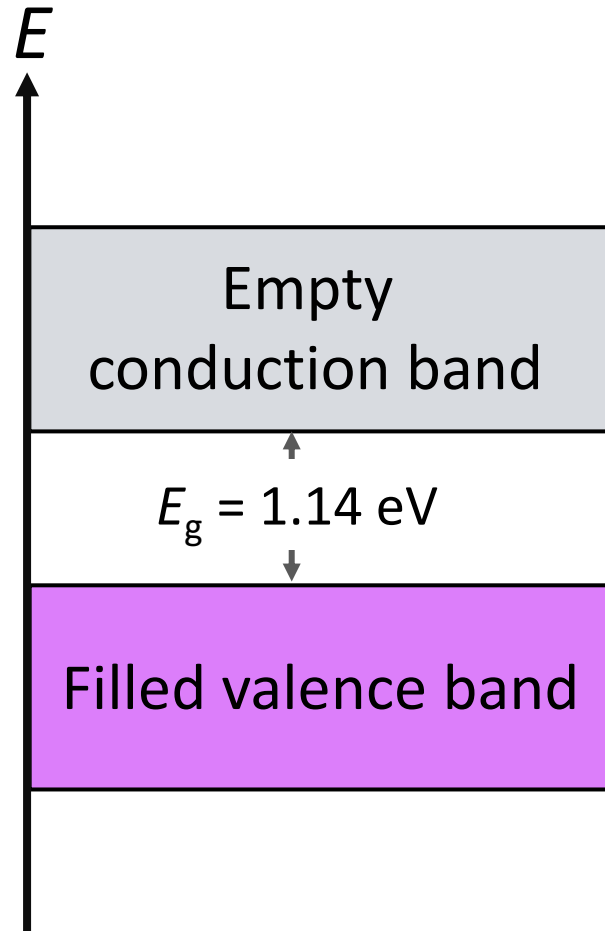
# Energy Bands for Solids



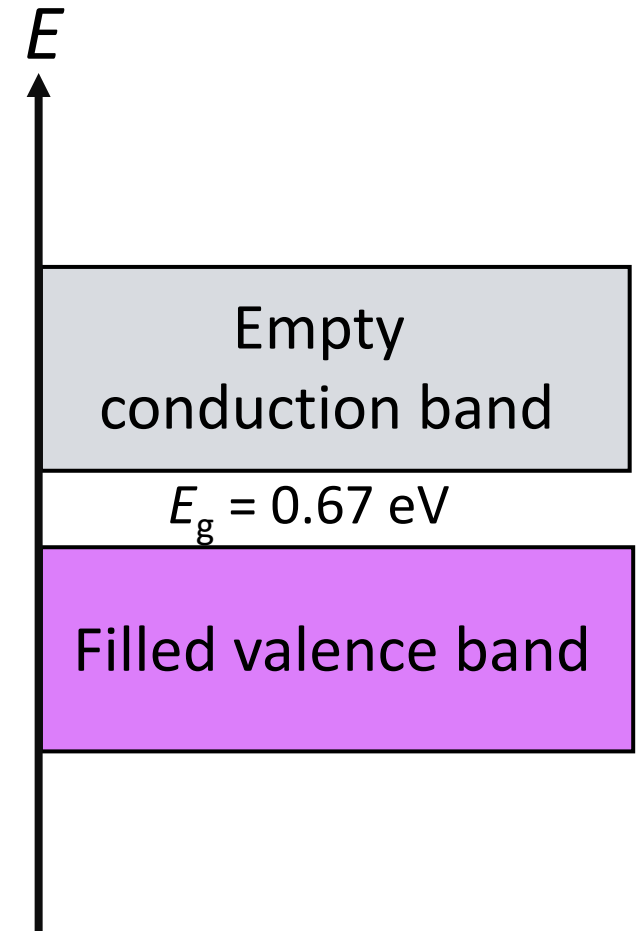
# Semiconductor



**Diamond**



**Silicon**



**Germanium**

# Semiconductor

| Semiconductor | InSb | GaAs | GaP  | ZnSe |
|---------------|------|------|------|------|
| $E_g$ (eV)    | 0.18 | 1.42 | 2.25 | 2.7  |

$$E = k_B T$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$300 \text{ K} \approx 0.026 \text{ eV}$$



# Periodic Table of the Elements

|  |  |                                       |  |  |   |   |  |   |   |  |  |  |  |  |  |   |  |
|--|--|---------------------------------------|--|--|---|---|--|---|---|--|--|--|--|--|--|---|--|
| 1<br>1IA<br>1A                         |  |                                       |  |  |   |   |  |   |   |  |  |  |  |  |  |   | 18<br>VIIIA<br>8A                      |
| 1<br><b>H</b><br>Hydrogen<br>1.008     |  |                                       |  |  |   |   |  |   |   |  | 13<br>IIIA<br>3A                         | 14<br>IVA<br>4A                        | 15<br>VA<br>5A                         | 16<br>VIA<br>6A                        | 17<br>VIIA<br>7A                         | 2<br><b>He</b><br>Helium<br>4.003       |  |
| 3<br><b>Li</b><br>Lithium<br>6.941     | 4<br><b>Be</b><br>Beryllium<br>9.012   |                                       |  |  |   |   |  |   |   |  |  | 5<br><b>B</b><br>Boron<br>10.811       | 6<br><b>C</b><br>Carbon<br>12.011      | 7<br><b>N</b><br>Nitrogen<br>14.007    | 8<br><b>O</b><br>Oxygen<br>15.999        | 9<br><b>F</b><br>Fluorine<br>18.998     | 10<br><b>Ne</b><br>Neon<br>20.180      |
| 11<br><b>Na</b><br>Sodium<br>22.99     | 12<br><b>Mg</b><br>Magnesium<br>24.305 | 3<br>IIIB<br>3B                       | 4<br>IVB<br>4B                             | 5<br>VB<br>5B                          | 6<br>VIB<br>6B                          | 7<br>VIIB<br>7B                         | 8<br>VIII<br>8                         | 9<br>VIII<br>8                          | 10<br>VIII<br>8                           | 11<br>IB<br>1B                           | 12<br>IIB<br>2B                          | 13<br><b>Al</b><br>Aluminum<br>26.982  | 14<br><b>Si</b><br>Silicon<br>28.086   | 15<br><b>P</b><br>Phosphorus<br>30.974 | 16<br><b>S</b><br>Sulfur<br>32.066       | 17<br><b>Cl</b><br>Chlorine<br>35.453   | 18<br><b>Ar</b><br>Argon<br>39.948     |
| 19<br><b>K</b><br>Potassium<br>39.098  | 20<br><b>Ca</b><br>Calcium<br>40.078   | 21<br><b>Sc</b><br>Scandium<br>44.956 | 22<br><b>Ti</b><br>Titanium<br>47.867      | 23<br><b>V</b><br>Vanadium<br>50.942   | 24<br><b>Cr</b><br>Chromium<br>51.996   | 25<br><b>Mn</b><br>Manganese<br>54.938  | 26<br><b>Fe</b><br>Iron<br>55.845      | 27<br><b>Co</b><br>Cobalt<br>58.933     | 28<br><b>Ni</b><br>Nickel<br>58.693       | 29<br><b>Cu</b><br>Copper<br>63.546      | 30<br><b>Zn</b><br>Zinc<br>65.38         | 31<br><b>Ga</b><br>Gallium<br>69.723   | 32<br><b>Ge</b><br>Germanium<br>72.631 | 33<br><b>As</b><br>Arsenic<br>74.922   | 34<br><b>Se</b><br>Selenium<br>78.971    | 35<br><b>Br</b><br>Bromine<br>79.904    | 36<br><b>Kr</b><br>Krypton<br>83.789   |
| 37<br><b>Rb</b><br>Rubidium<br>85.468  | 38<br><b>Sr</b><br>Strontium<br>87.62  | 39<br><b>Y</b><br>Yttrium<br>88.906   | 40<br><b>Zr</b><br>Zirconium<br>91.224     | 41<br><b>Nb</b><br>Niobium<br>92.906   | 42<br><b>Mo</b><br>Molybdenum<br>95.95  | 43<br><b>Tc</b><br>Technetium<br>98.907 | 44<br><b>Ru</b><br>Ruthenium<br>101.07 | 45<br><b>Rh</b><br>Rhodium<br>102.906   | 46<br><b>Pd</b><br>Palladium<br>106.42    | 47<br><b>Ag</b><br>Silver<br>107.868     | 48<br><b>Cd</b><br>Cadmium<br>112.414    | 49<br><b>In</b><br>Indium<br>114.818   | 50<br><b>Sn</b><br>Tin<br>118.711      | 51<br><b>Sb</b><br>Antimony<br>121.760 | 52<br><b>Te</b><br>Tellurium<br>127.6    | 53<br><b>I</b><br>Iodine<br>126.904     | 54<br><b>Xe</b><br>Xenon<br>131.294    |
| 55<br><b>Cs</b><br>Cesium<br>132.905   | 56<br><b>Ba</b><br>Barium<br>137.328   | 57-71                                 | 72<br><b>Hf</b><br>Hafnium<br>178.49       | 73<br><b>Ta</b><br>Tantalum<br>180.948 | 74<br><b>W</b><br>Tungsten<br>183.84    | 75<br><b>Re</b><br>Rhenium<br>186.207   | 76<br><b>Os</b><br>Osmium<br>190.23    | 77<br><b>Ir</b><br>Iridium<br>192.217   | 78<br><b>Pt</b><br>Platinum<br>195.085    | 79<br><b>Au</b><br>Gold<br>196.967       | 80<br><b>Hg</b><br>Mercury<br>200.592    | 81<br><b>Tl</b><br>Thallium<br>204.383 | 82<br><b>Pb</b><br>Lead<br>207.2       | 83<br><b>Bi</b><br>Bismuth<br>208.980  | 84<br><b>Po</b><br>Polonium<br>[208.982] | 85<br><b>At</b><br>Astatine<br>209.987  | 86<br><b>Rn</b><br>Radon<br>222.018    |
| 87<br><b>Fr</b><br>Francium<br>223.020 | 88<br><b>Ra</b><br>Radium<br>226.025   | 89-103                                | 104<br><b>Rf</b><br>Rutherfordium<br>[261] | 105<br><b>Db</b><br>Dubnium<br>[262]   | 106<br><b>Sg</b><br>Seaborgium<br>[266] | 107<br><b>Bh</b><br>Bohrium<br>[264]    | 108<br><b>Hs</b><br>Hassium<br>[269]   | 109<br><b>Mt</b><br>Meitnerium<br>[278] | 110<br><b>Ds</b><br>Darmstadtium<br>[281] | 111<br><b>Rg</b><br>Roentgenium<br>[280] | 112<br><b>Cn</b><br>Copernicium<br>[285] | 113<br><b>Nh</b><br>Nihonium<br>[286]  | 114<br><b>Fl</b><br>Flerovium<br>[289] | 115<br><b>Mc</b><br>Moscovium<br>[286] | 116<br><b>Lv</b><br>Livermorium<br>[293] | 117<br><b>Ts</b><br>Tennessine<br>[294] | 118<br><b>Og</b><br>Oganesson<br>[294] |

Lanthanide Series

|   |                                      |  |   |  |                                       |  |   |                                       |  |                                       |                                      |                                       |   |  |
|---|--------------------------------------|--|---|--|---------------------------------------|--|---|---------------------------------------|--|---------------------------------------|--------------------------------------|---------------------------------------|---|--|
| 57<br><b>La</b><br>Lanthanum<br>138.905 | 58<br><b>Ce</b><br>Cerium<br>140.116 | 59<br><b>Pr</b><br>Praseodymium<br>140.908 | 60<br><b>Nd</b><br>Neodymium<br>144.243 | 61<br><b>Pm</b><br>Promethium<br>144.913 | 62<br><b>Sm</b><br>Samarium<br>150.36 | 63<br><b>Eu</b><br>Europium<br>151.964 | 64<br><b>Gd</b><br>Gadolinium<br>157.25 | 65<br><b>Tb</b><br>Terbium<br>158.925 | 66<br><b>Dy</b><br>Dysprosium<br>162.500 | 67<br><b>Ho</b><br>Holmium<br>164.930 | 68<br><b>Er</b><br>Erbium<br>167.259 | 69<br><b>Tm</b><br>Thulium<br>168.934 | 70<br><b>Yb</b><br>Ytterbium<br>173.055 | 71<br><b>Lu</b><br>Lutetium<br>174.967 |
|---|--------------------------------------|--|---|--|---------------------------------------|--|---|---------------------------------------|--|---------------------------------------|--------------------------------------|---------------------------------------|---|--|

Actinide Series

|  |                                       |  |                                      |   |   |   |                                      |   |   |   |  |  |   |   |
|--|---------------------------------------|--|--------------------------------------|---|---|---|--------------------------------------|---|---|---|--|--|---|---|
| 89<br><b>Ac</b><br>Actinium<br>227.028 | 90<br><b>Th</b><br>Thorium<br>232.038 | 91<br><b>Pa</b><br>Protactinium<br>231.036 | 92<br><b>U</b><br>Uranium<br>238.029 | 93<br><b>Np</b><br>Neptunium<br>237.048 | 94<br><b>Pu</b><br>Plutonium<br>244.064 | 95<br><b>Am</b><br>Americium<br>243.061 | 96<br><b>Cm</b><br>Curium<br>247.070 | 97<br><b>Bk</b><br>Berkelium<br>247.070 | 98<br><b>Cf</b><br>Californium<br>251.080 | 99<br><b>Es</b><br>Einsteinium<br>[254] | 100<br><b>Fm</b><br>Fermium<br>257.095 | 101<br><b>Md</b><br>Mendelevium<br>258.1 | 102<br><b>No</b><br>Nobelium<br>259.101 | 103<br><b>Lr</b><br>Lawrencium<br>[262] |
|--|---------------------------------------|--|--------------------------------------|---|---|---|--------------------------------------|---|---|---|--|--|---|---|

**SCIENCE NOTES**  
Learn Science Do Science

|              |                |                  |             |           |          |         |           |            |          |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|
| Alkali Metal | Alkaline Earth | Transition Metal | Basic Metal | Semimetal | Nonmetal | Halogen | Noble Gas | Lanthanide | Actinide |
|--------------|----------------|------------------|-------------|-----------|----------|---------|-----------|------------|----------|

©2017 Todd Helmenstein  
todd@twinkl.com



# Silicon



ChemistryLearner.com

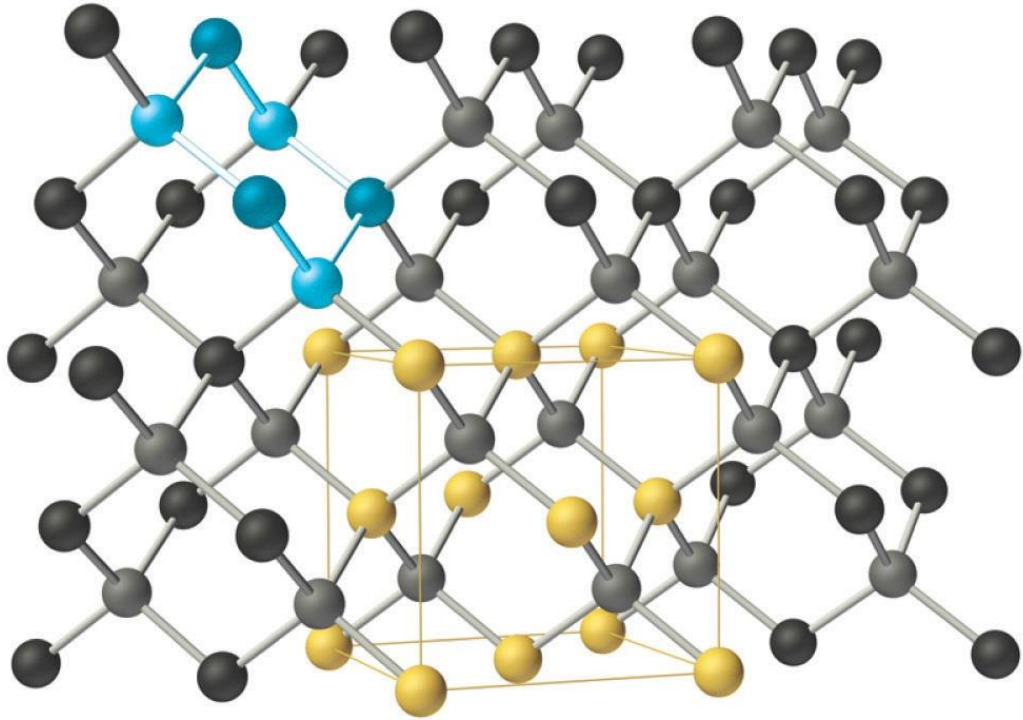


WIKIPEDIA  
The Free Encyclopedia



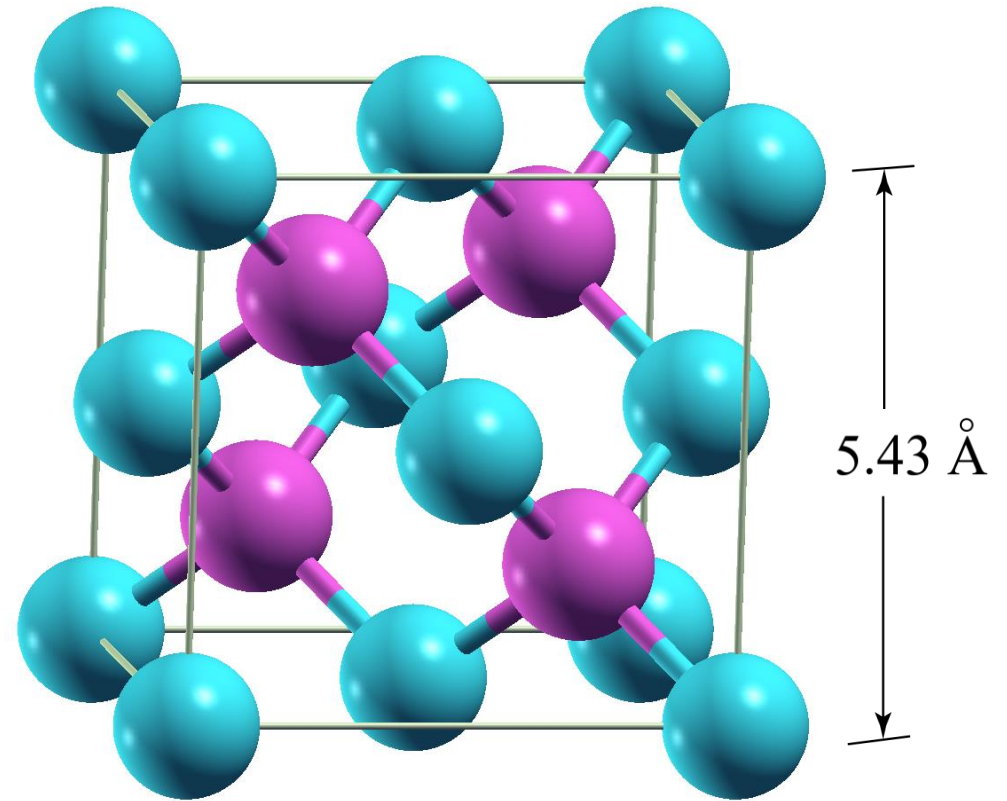


# Crystal Silicon



[chem.libretexts.org](http://chem.libretexts.org)

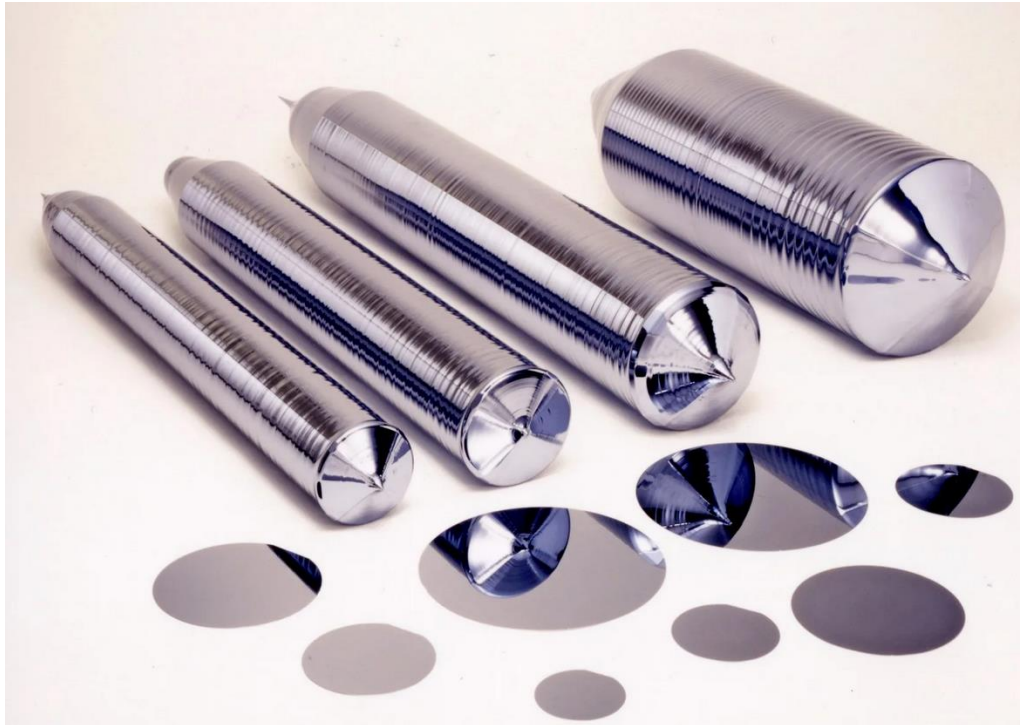
3sp tetrahedral bond



2.35 Å

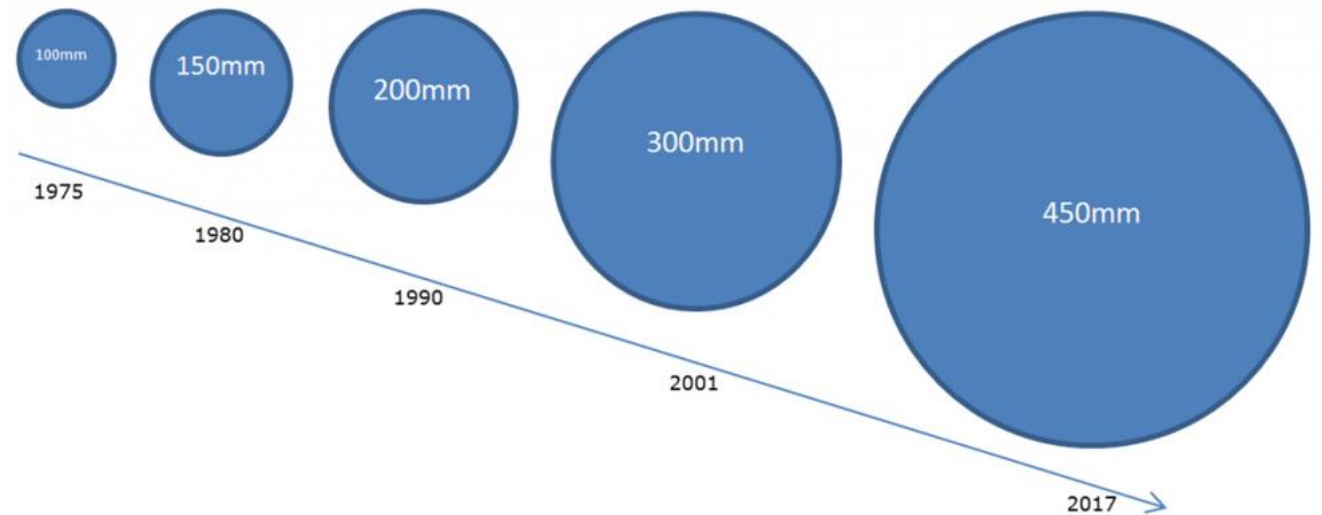


# Silicon ingot



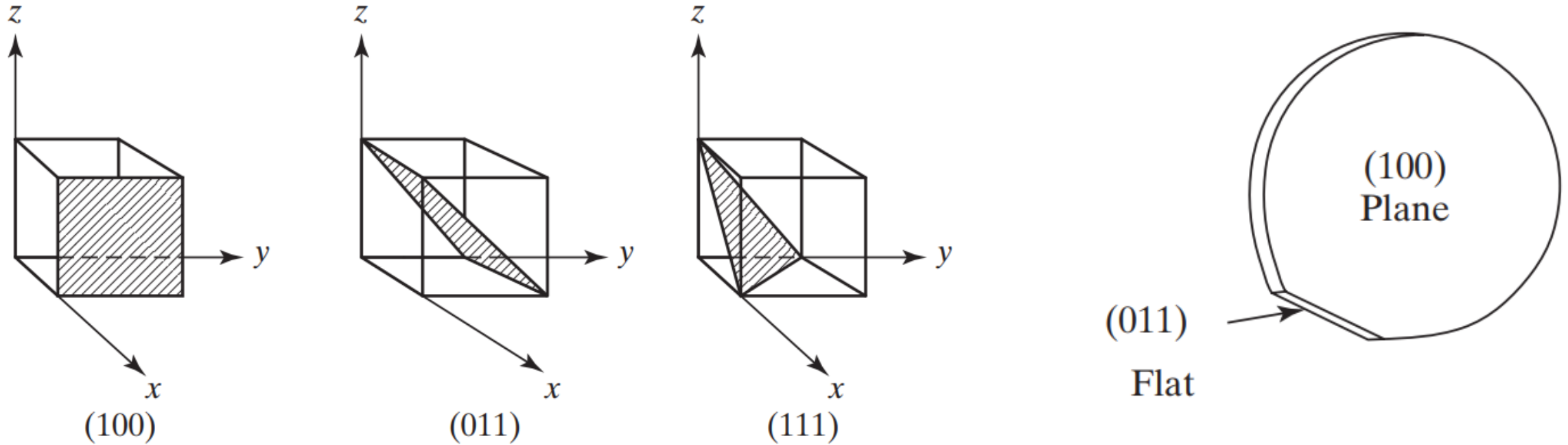
[asia.nikkei.com](http://asia.nikkei.com)

[techdesignforums.com](http://techdesignforums.com)





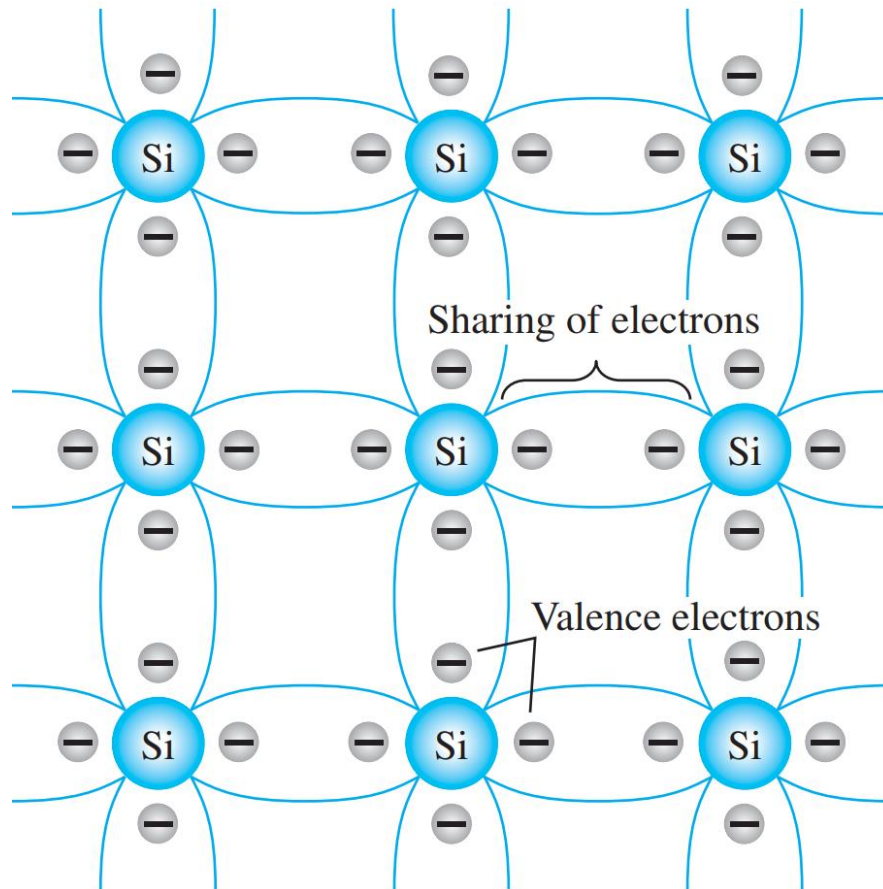
# Silicon wafers



Modern Semiconductor Devices for Integrated Circuits – C. Hu



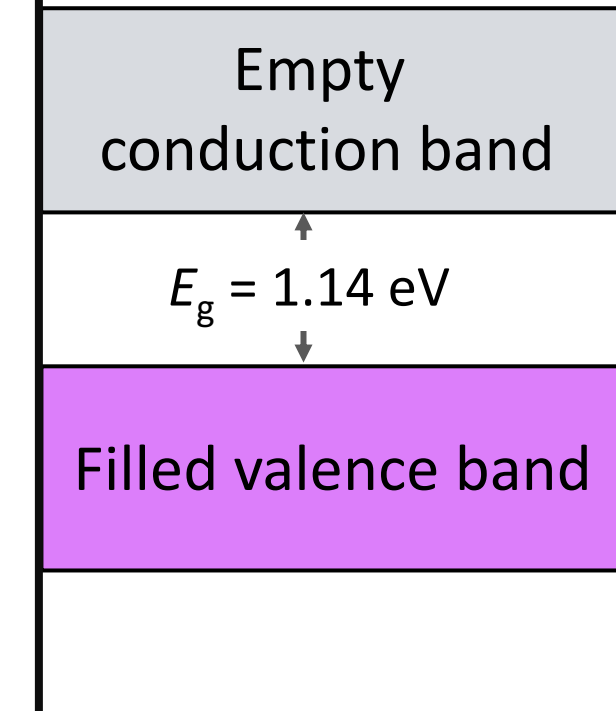
# Covalent bonding of the silicon atom



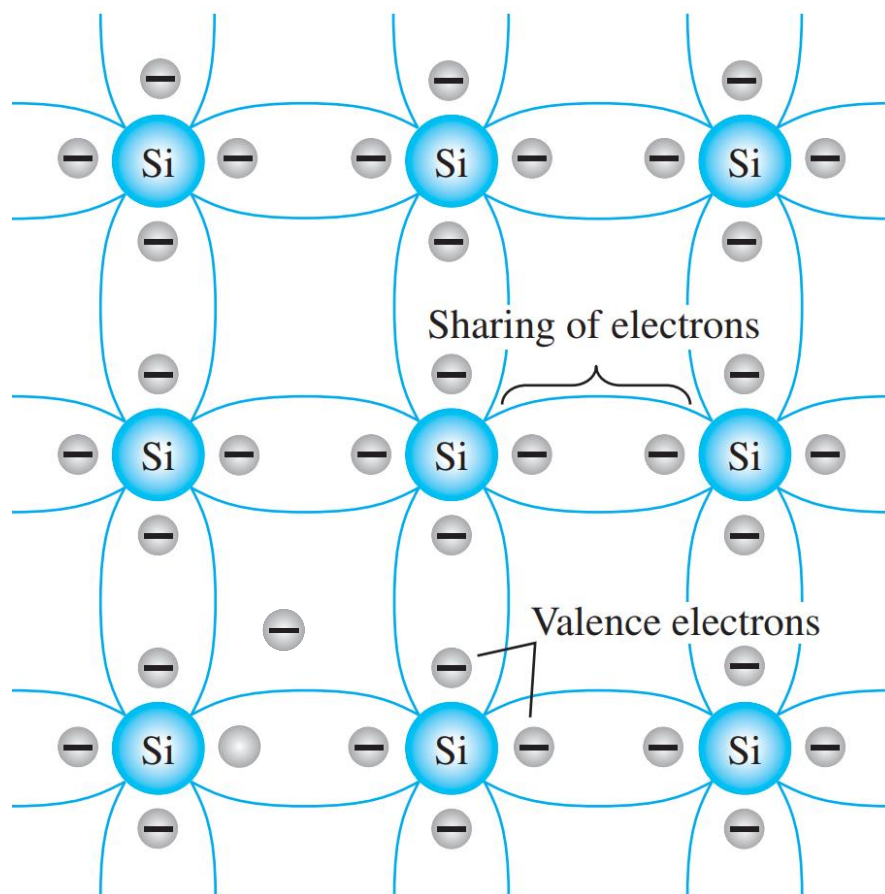
Electronic Devices and Circuit Theory – Boylestad, Nashelsky

$E$

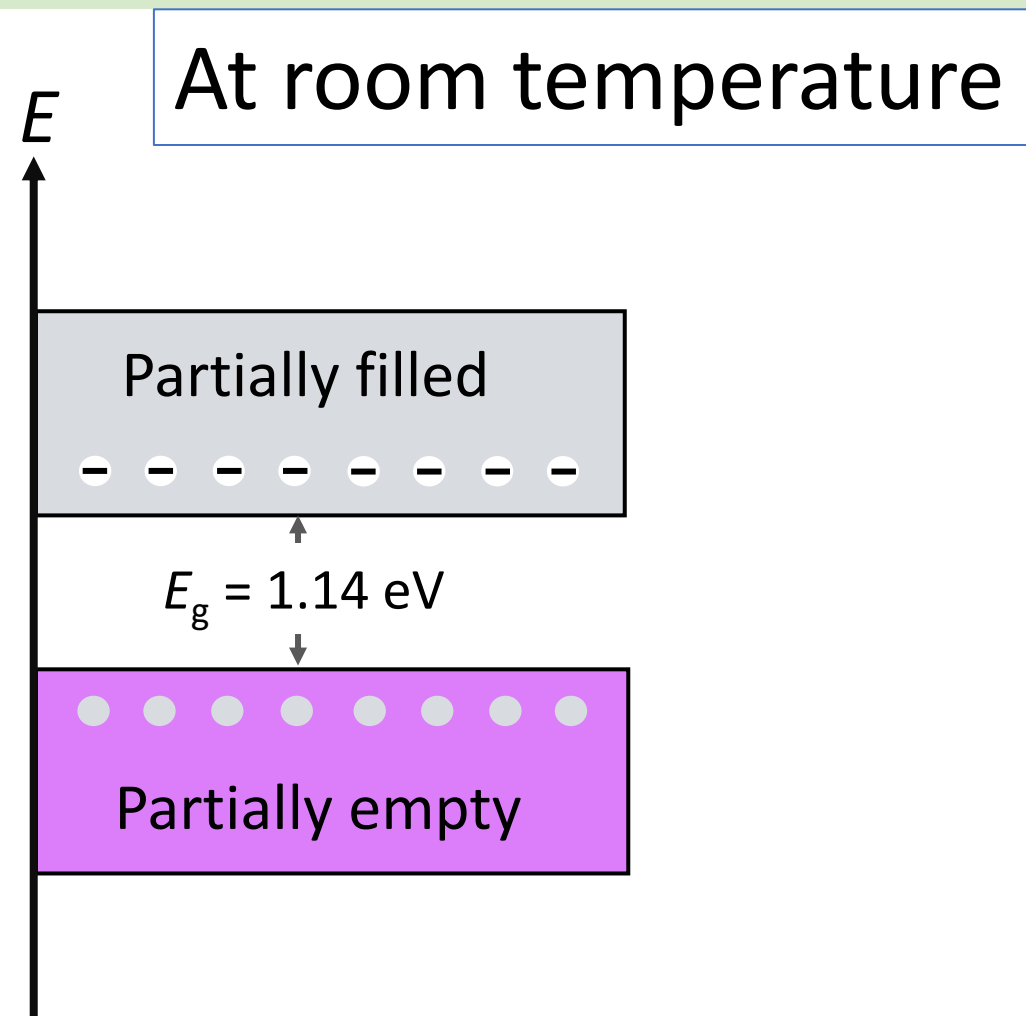
At  $T = 0$  K



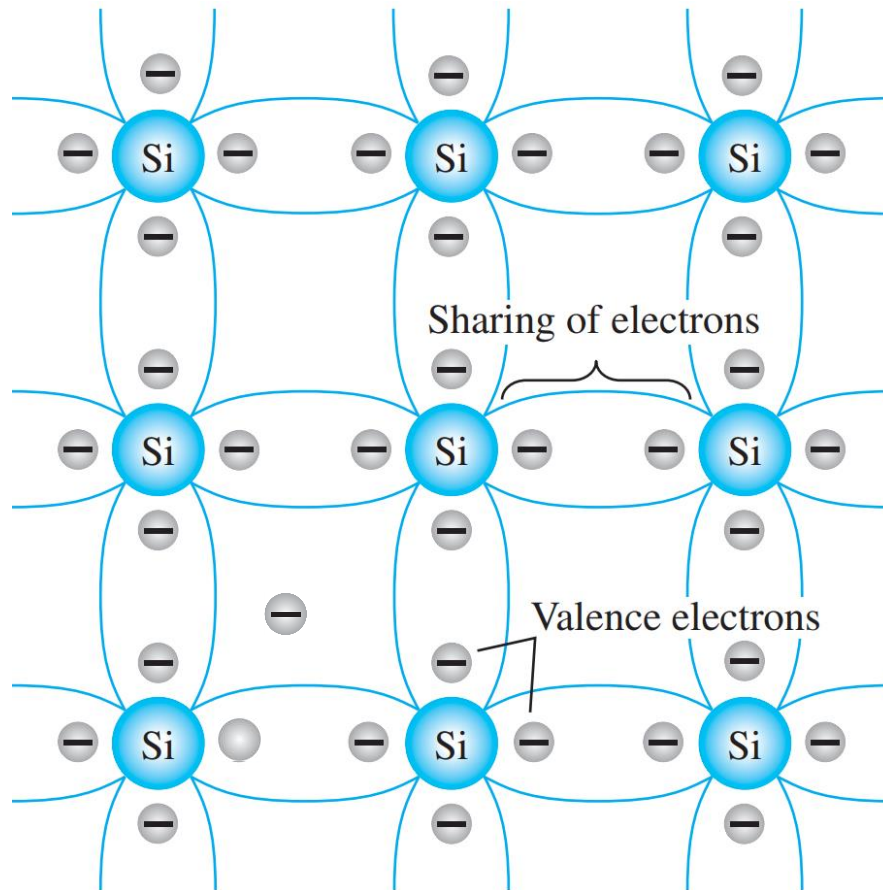
# Electron and Hole in intrinsic silicon



Electronic Devices and Circuit Theory – Boylestad, Nashelsky



# Electron and Hole in intrinsic silicon

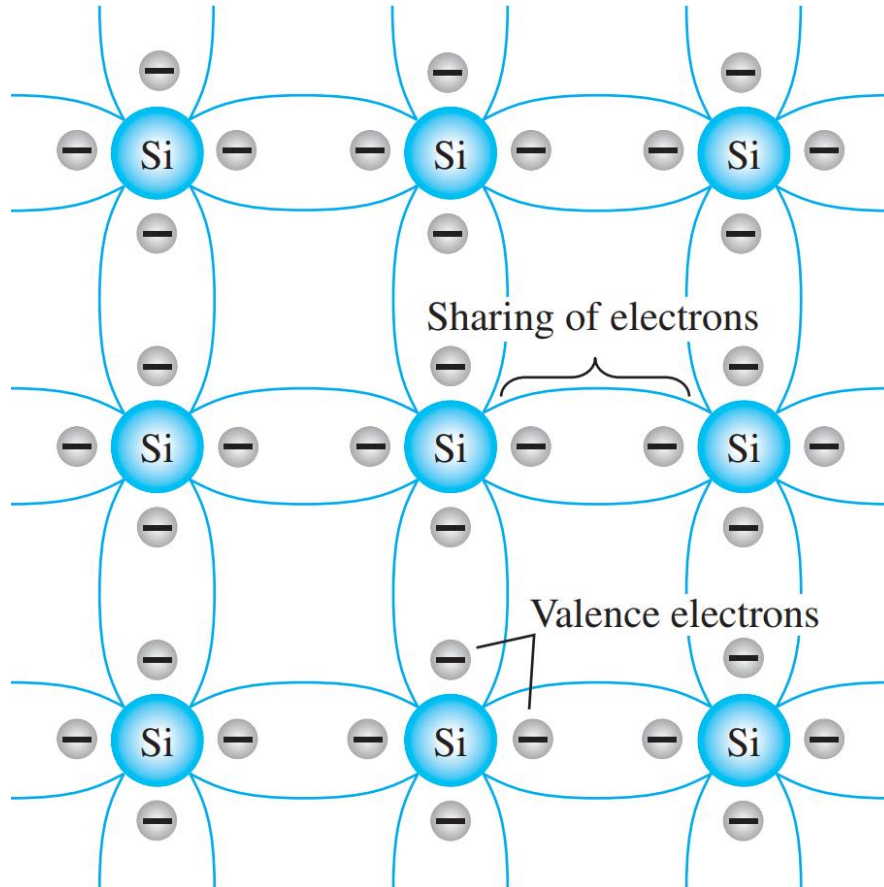


Electronic Devices and Circuit Theory – Boylestad, Nashelsky

The external causes include effects such as light energy in the form of photons and thermal energy (heat) from the surrounding medium.

At room temperature there are approximately  $1.5 \times 10^{10}$  free carriers in  $1 \text{ cm}^3$  of *intrinsic* silicon.

# Extrinsic semiconductor



Electronic Devices and Circuit Theory – Boylestad, Nashelsky

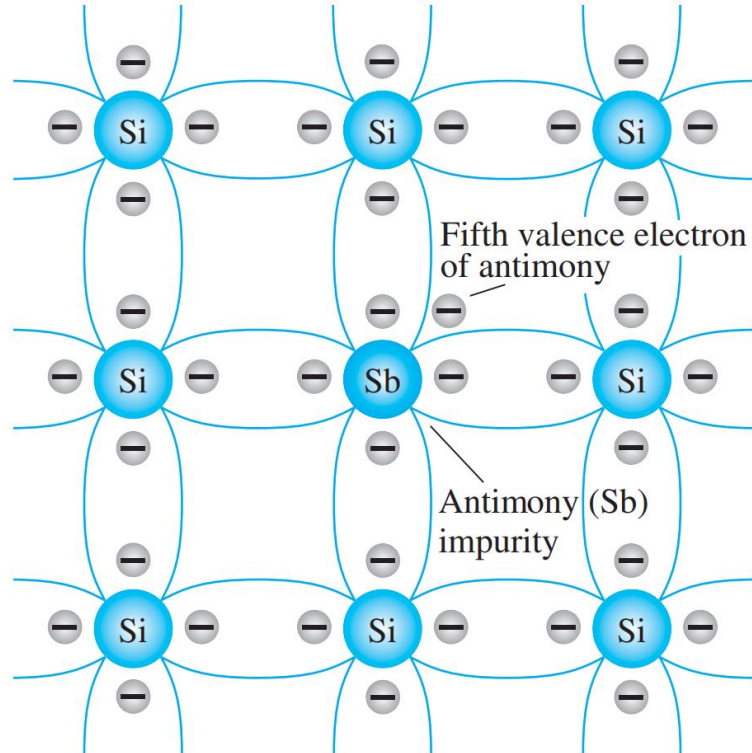
|     | IIIA     | IVA      | VA       | VIA      |
|-----|----------|----------|----------|----------|
|     | 5<br>B   | 6<br>C   | 7<br>N   | 8<br>O   |
|     | 13<br>Al | 14<br>Si | 15<br>P  | 16<br>S  |
| IIB | 30<br>Zn | 31<br>Ga | 32<br>Ge | 33<br>As |
|     | 34<br>Se |          |          |          |
|     | 48<br>Cd | 49<br>In | 50<br>Sn | 51<br>Sb |
|     |          |          |          | 52<br>Te |



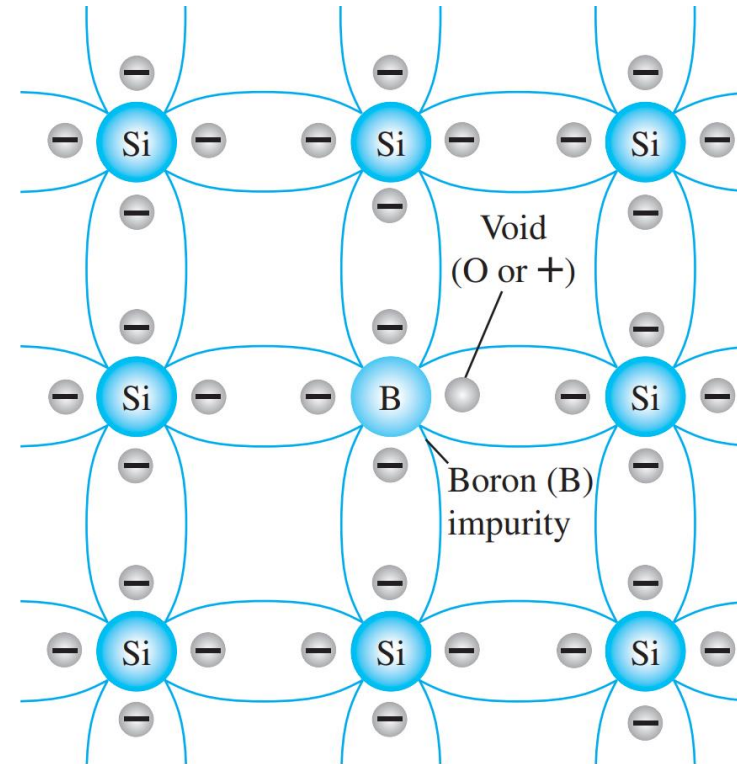


# Extrinsic semiconductor

n-type material



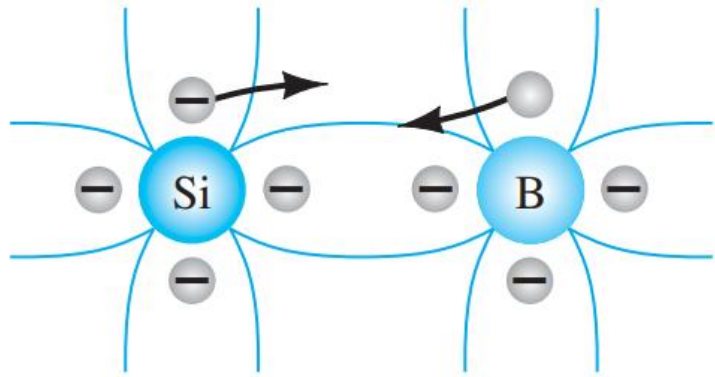
p-type material



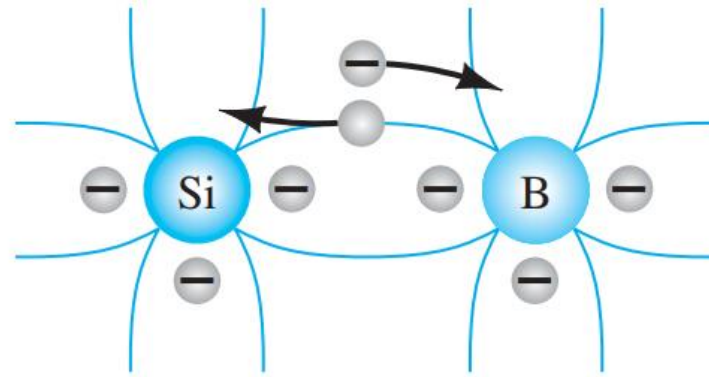
Electronic Devices and Circuit Theory – Boylestad, Nashelsky



# Electron versus Hole Flow

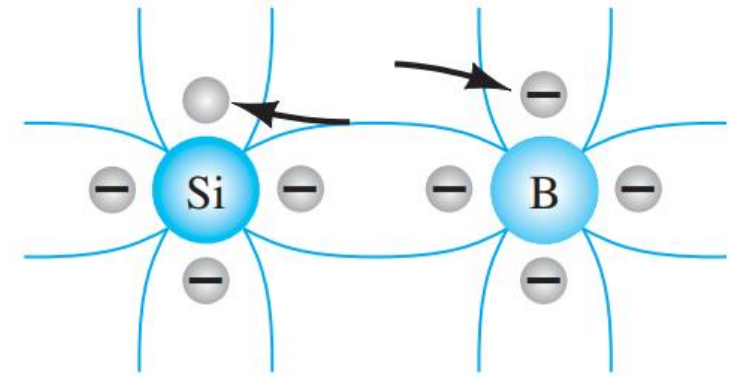


(a)



Hole flow  
Electron flow

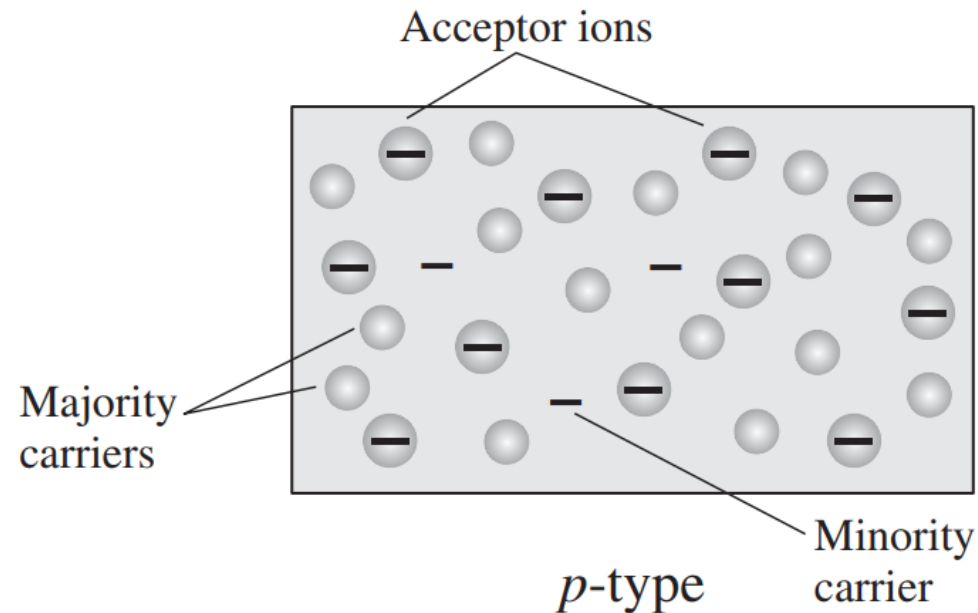
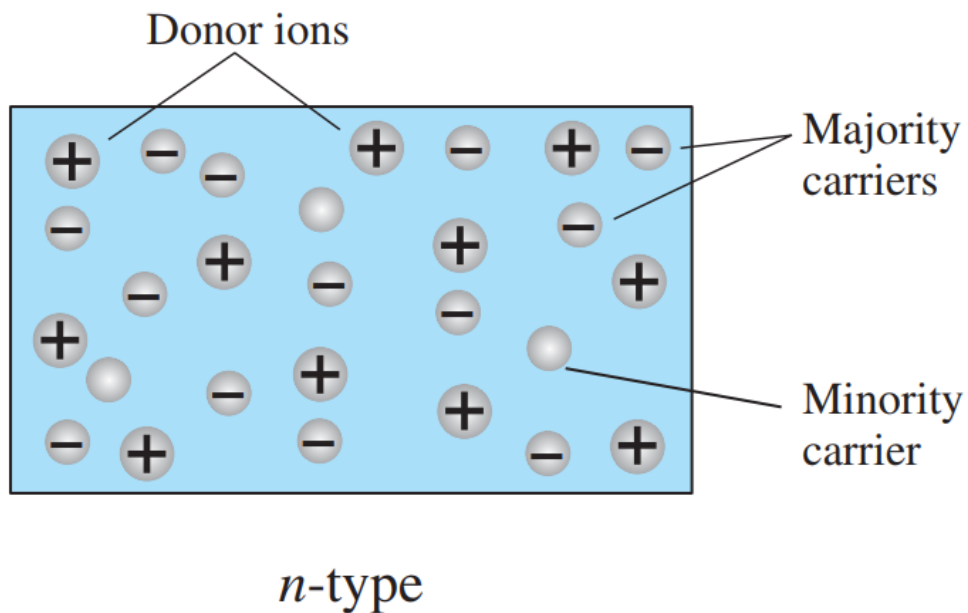
(b)



(c)

Electronic Devices and Circuit Theory – Boylestad, Nashelsky

# Majority and Minority Carriers



Electronic Devices and Circuit Theory – Boylestad, Nashelsky