ECE4904 Lecture 1

Administrative Information

Background Review

- ECE2201
- Fields
- Chemistry

Semiconductors (text Ch. 1)

Carrier Modeling (text Ch. 2)

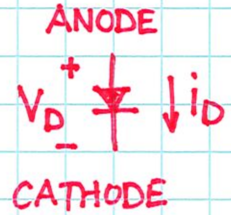
- Quantization
- Bonding Model
- Energy Band Model

Handouts

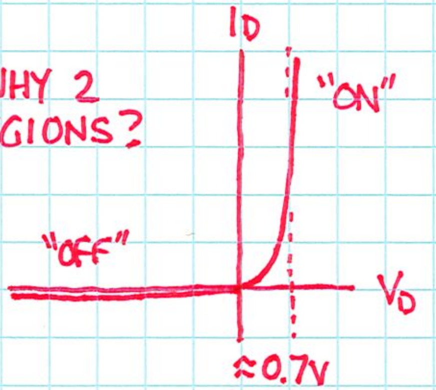
- Administrative Information
- Periodic Table + Textbook Figures
- HW 1 (online)

ECE2201 REVIEW "BLACK BOX" MODELS

DIODE



WHY 2 REGIONS?

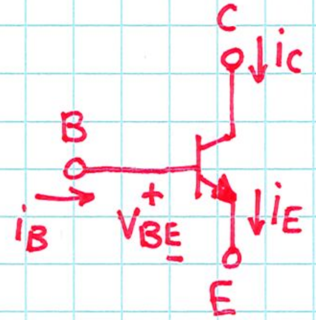


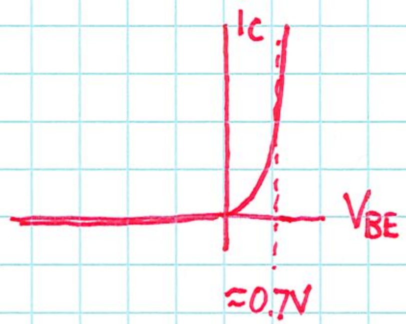
WHY 0.7V?

$$\underbrace{i_D = \underbrace{I_S}_{\text{SCALE CURRENT}} e^{V_D / \underset{\uparrow\ \approx 2}{n} \underbrace{V_T}_{\frac{kT}{q}}}}_{\text{WHY?}}$$

$\frac{kT}{q}$ = 26mV @T=300K

BJT (ACTIVE REGION)





$$i_C = I_S e^{V_{BE}/V_T}$$

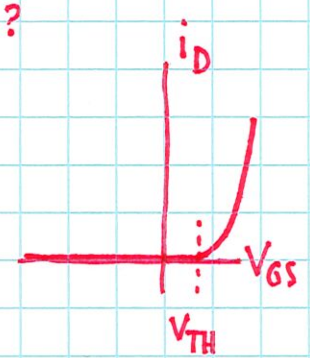
$$\underbrace{\text{V BASE} \Rightarrow \text{I COLLECTOR}}_{\text{HOW?}}$$

$i_B = \frac{i_C}{\beta}$ } CURRENT GAIN

WHY?

HOW $\beta\uparrow$?

MOSFET



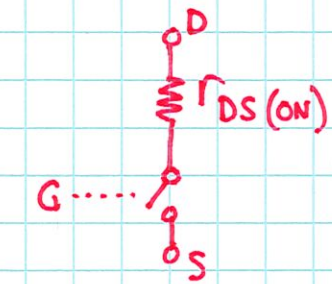
"THRESHOLD VOLTAGE" } ?

FOR $V_{GS} > V_{TH}$

$i_D = \underbrace{K}_{\left[\frac{A}{V^2}\right]} (V_{GS} - V_{TH})^2$ } WHY?

WHY?

SWITCH



$$\underbrace{r_{DS(ON)} = \frac{1}{K(V_{GS} - V_{TH})}}_{\text{WHY?}}$$

$$\underbrace{\text{IDEAL: } r_{DS} \to 0}_{\text{HOW?}}$$

FIELDS "REVIEW" 

ELECTRIC FIELD $\mathcal{E}$ ....

- FORCE ON A CHARGED PARTICLE
- SEPARATION OF CHARGE
- EXTENDS INFINITELY → FARTHER ~ WEAKER
- $\underbrace{\text{POTENTIAL}}_{\text{ENERGY}}$ OF PARTICLES IN FIELD IS $\underbrace{\text{VOLTAGE}}_{\text{[AMP-OHMS]}}$

ENERGY

CAN STORE ENERGY IN $\mathcal{E}$ FIELD

$[V] = \left[\frac{\text{Joule}}{\text{coulomb}}\right]$

[AMP-OHMS]

- IF THERE IS A MATERIAL, DIELECTRIC CONSTANT AFFECTS STRENGTH

UNITS OF $\mathcal{E}$ FIELD $F = Q\,\mathcal{E}$

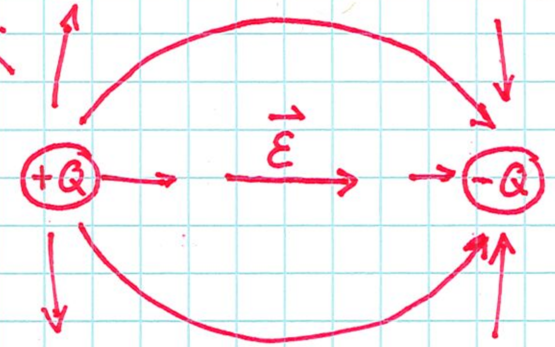
$\underset{N}{F} = \underset{\text{coul}}{Q}\,\underset{\left[\frac{N}{\text{coul}}\right]}{\mathcal{E}}$

$$\boxed{\text{VOLTAGE: } [\mathcal{E}] = \frac{V}{m}}$$

$$\mathcal{E} = \frac{V_c}{d}$$

$V = IR$

$\cancel{\frac{Q_1 Q_2}{\varepsilon r^2}}$



"LINES OF FORCE"

$$\underbrace{\vec{F}}_{} = Q\,\vec{\mathcal{E}}$$

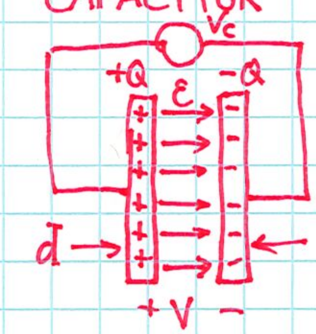
FORCE THAT Q EXPERIENCES

$\boxed{\text{TELLS YOU WHICH WAY A + CHARGE WOULD MOVE}}$

LINES:
ALWAYS START ON +
ALWAYS END ON −

$\boxed{\text{KEEP TRACK OF CHARGE CONSERVATION!}}$

PARALLEL PLATE CAPACITOR



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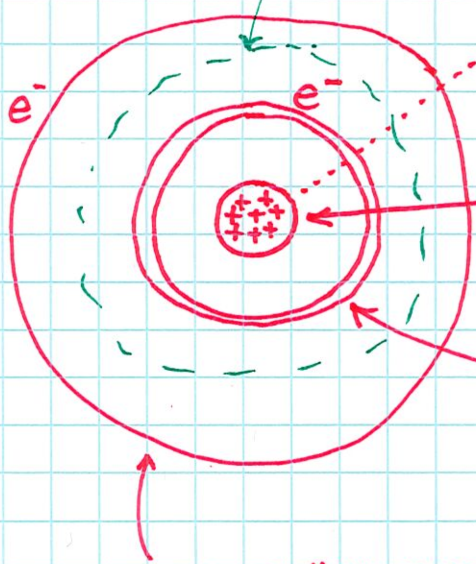
CHEMISTRY

ATOM

NOT MOVING

INCREASING
e^- ENERGY



NUCLEUS (+ CHARGE)

INNER SHELL e^-
TIGHTLY BOUND

OUTER "VALENCE" e^-

- NOT AS TIGHTLY BOUND
- CAN BE SHARED IN A CHEMICAL BOND
- MAY BECOME FREE (IONIZATION)
  - RANDOM THERMAL ENERGY
  - $\mathcal{E}$ FIELD APPLIED VOLTAGE

METALS | NONMETALS

TRANSITION METALS

OF VALENCE e^-

PERIODS	I A	II A	III B	IV B	V B	VI B	VII B	VIII	VIII	VIII	I B	II B	III A	IV A	V A	VI A	VII A	0
1 0	1.0079 H [1] 1																1.0079 H [1] 1	4.00260 He[2] 2
2 2	6.941 Li [3] 1	9.01218 Be[4] 2											10.81 B [5] 3	12.011 C [6] 4	14.0067 N [7] 5	15.9994 O [8] 6	18.9984 F [9] 7	20.179 Ne[10] 8
3 2, 8	22.9898 Na[11] 1	24.305 Mg[12] 2											26.9815 Al[13] 3	28.086 Si [14] 4	30.9738 P [15] 5	32.06 S [16] 6	35.453 Cl [17] 7	39.948 Ar[18] 8
4 2, 8	39.098 K [19] 8, 1	40.08 Ca[20] 8, 2	44.9559 Sc [21] 9, 2	47.90 Ti [22] 10, 2	50.9414 V [23] 11, 2	51.996 Cr[24] 13, 1	54.9380 Mn[25] 13, 2	55.847 Fe[26] 14, 2	58.9332 Co[27] 15, 2	58.71 Ni [28] 16, 2	63.546 Cu[29] 18, 1	65.38 Zn[30] 18, 2	69.72 Ga[31] 18, 3	72.59 Ge[32] 18, 4	74.9216 As[33] 18, 5	78.96 Se[34] 18, 6	79.904 Br[35] 18, 7	83.80 Kr[36] 18, 8
5 2, 8, 18	85.4678 Rb[37] 8, 1	87.62 Sr [38] 8, 2	88.9059 Y [39] 9, 2	91.22 Zr [40] 10, 2	92.9064 Nb[41] 12, 1	95.94 Mo[42] 13, 1	98.9062 Tc[43] 14, 1	101.07 Ru[44] 15, 1	102.9055 Rh[45] 16, 1	106.4 Pd[46] 18	107.868 Ag[47] 18, 1	112.40 Cd[48] 18, 2	114.82 In[49] 18, 3	118.69 Sn[50] 18, 4	121.75 Sb[51] 18, 5	127.60 Te[52] 18, 6	126.9045 I [53] 18, 7	131.30 Xe[54] 18, 8
6 2, 8, 18	132.9054 Cs [55] 18, 8, 1	137.34 Ba[56] 18, 8, 2	[57-71] *	178.49 Hf[72] 32, 10, 2	180.9479 Ta[73] 32, 11, 2	183.85 W [74] 32, 12, 2	186.2 Re[75] 32, 13, 2	190.2 Os[76] 32, 14, 2	192.22 Ir [77] 32, 15, 2	195.09 Pt [78] 32, 17, 1	196.9665 Au[79] 32, 18, 1	200.59 Hg[80] 32, 18, 2	204.37 Tl[81] 32, 18, 3	207.2 Pb[82] 32, 18, 4	208.9804 Bi [83] 32, 18, 5	(210) Po[84] 32, 18, 6	(210) At[85] 32, 18, 7	(222) Rn[86] 32, 18, 8
7 2,8,18,32	(223) Fr [87] 18, 8, 1	226.0254 Ra[88] 18, 8, 2	[89-103] †	[104] 32, 10, 2	[105] 32, 11, 2	[106]	[107]	[108]										

* LANTHANIDE SERIES	138.9055 La[57] 18, 9, 2	140.12 Ce[58] 20, 8, 2	140.9077 Pr[59] 21, 8, 2	144.24 Nd[60] 22, 8, 2	(145) Pm[61] 23, 8, 2	150.4 Sm[62] 24, 8, 2	151.96 Eu[63] 25, 8, 2	157.25 Gd[64] 25, 9, 2	158.9254 Tb[65] 27, 8, 2	162.50 Dy[66] 28, 8, 2	164.9304 Ho[67] 29, 8, 2	167.26 Er[68] 30, 8, 2	168.9342 Tm[69] 31, 8, 2	173.04 Yb[70] 32, 8, 2	174.97 Lu[71] 32, 9, 2
† ACTINIDE SERIES	(227) Ac[89] 18, 9, 2	232.0381 Th[90] 18, 10, 2	231.0359 Pa[91] 20, 9, 2	238.029 U [92] 21, 9, 2	237.0482 Np[93] 23, 8, 2	(242) Pu[94] 24, 8, 2	(243) Am[95] 25, 8, 2	(245) Cm[96] 25, 9, 2	(245) Bk[97] 26, 9, 2	(248) Cf [98] 28, 8, 2	(253) Es[99] 29, 8, 2	(254) Fm[100] 30, 8, 2	(256) Md[101] 31, 8, 2	(253) No[102] 32, 8, 2	(257) Lr [103] 32, 9, 2

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TYPES OF MATERIALS

CONDUCTORS

(EX: COPPER)

LOTS OF $\underbrace{\text{FREE}}_{}$ e^-

NOT USED
IN COVALENT BOND

"SEA OF ELECTRONS"

$$R = \frac{V \;\}\; \mathcal{E}\text{ FIELD}}{I \;\}\; \text{HIGH CURRENT}}$$

→ LOW
RESISTANCE

SEMICONDUCTORS

EX: SILICON
GERMANIUM
GaAs

AT T=300K, ALMOST
ALL e^- USED IN
COVALENT BOND

SOME e^- CAN MOVE
(RANDOM THERMAL
IONIZATION)

$$R = \frac{V \;\}\; \mathcal{E}\text{ FIELD}}{I \;\}\; \text{SOME}}$$

MIDDLEISH RESISTANCE

TAILOR V, I, R WITH
IMPURITY ATOMS
"DOPANTS" < 1 $\underbrace{\text{ppb}}$

1E-9 BILLION

INSULATORS

GLASS, CERAMICS

ALL e^- TIGHTLY
BOUND

$$R = \frac{V \;\}\; \text{HIGH } \vec{\mathcal{E}}}{I \;\}\; \text{SMALL (NO } e^- \text{ MOVING)}}$$

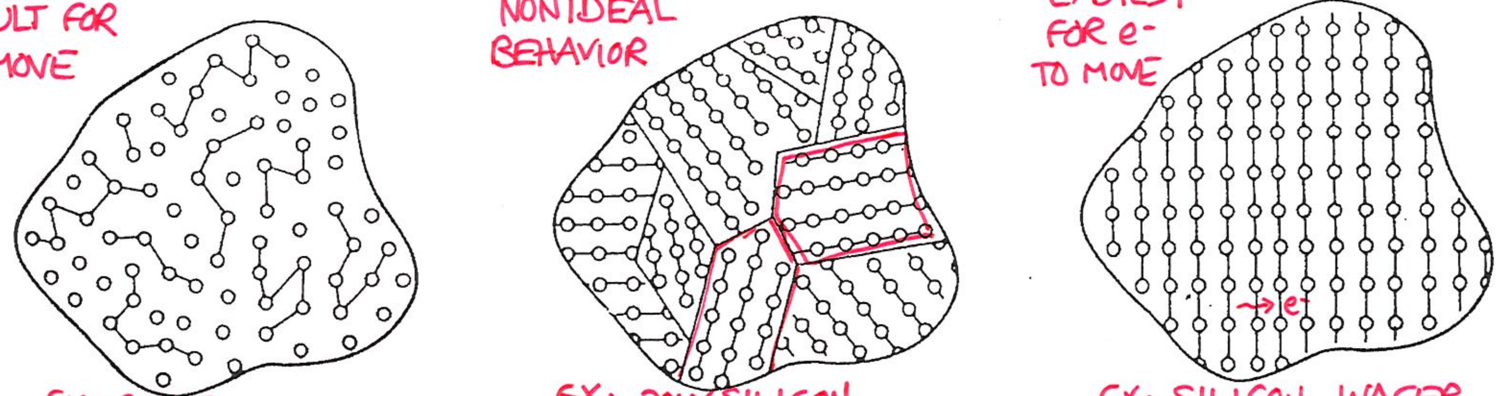
→ HIGH RESISTANCE

BEST DEVICE PERFORMANCE

DIFFICULT FOR e^- TO MOVE

CAN LEAD TO NONIDEAL BEHAVIOR

EASIEST FOR e^- TO MOVE



EX: GLASS	EX: POLYSILICON	EX: SILICON WAFER
(a) Amorphous	(b) Polycrystalline	(c) Crystalline
No recognizable long-range order	Completely ordered in segments	Entire solid is made up of atoms in an orderly array

Figure 1.1 General classification of solids based on the degree of atomic order: (a) amorphous, (b) polycrystalline, and (c) crystalline.

CRYSTAL AS "CONTAINER" FOR CARRIERS:

- ALL NUCLEI } FIXED LOCATIONS
- MOST e^-

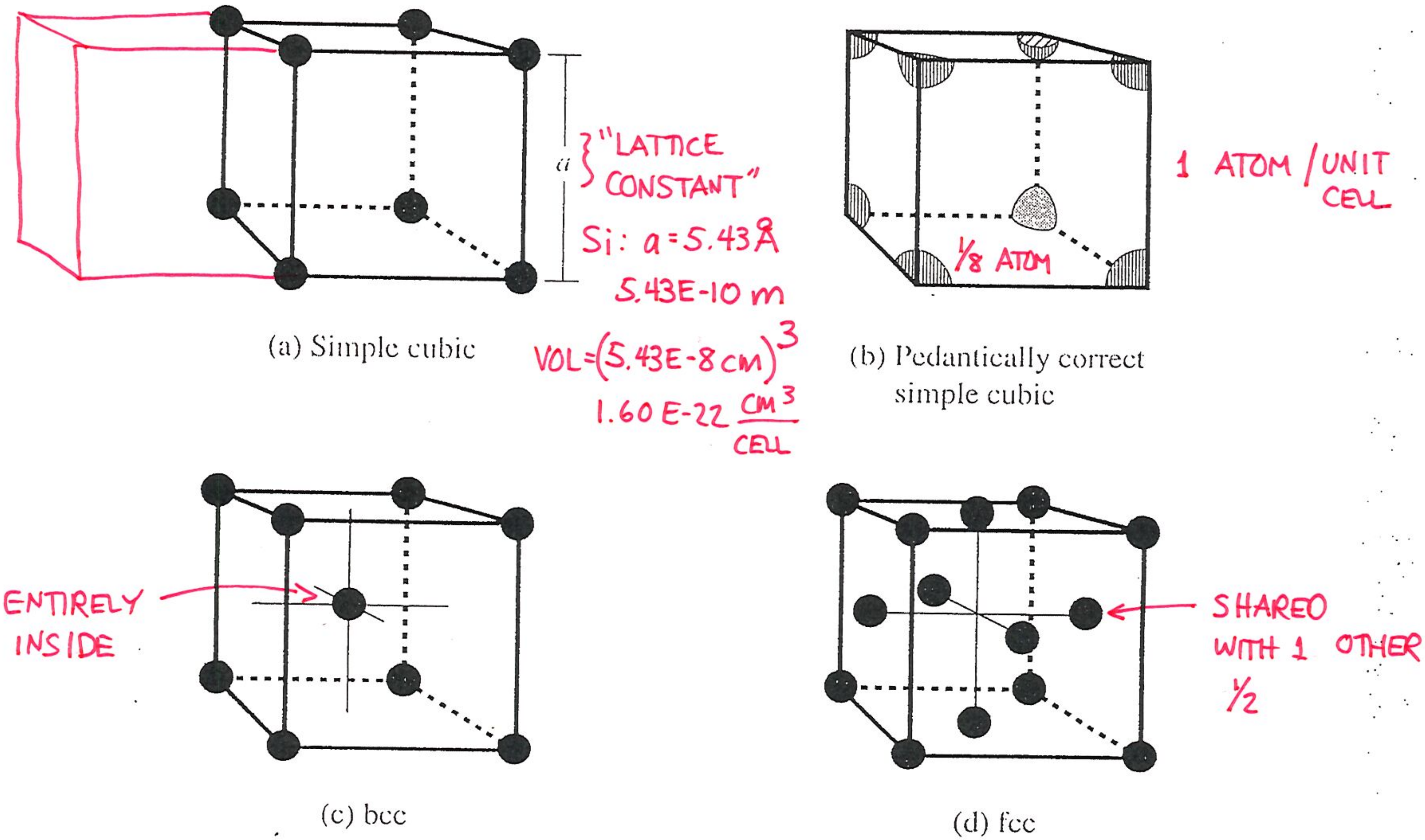


Figure 1.3 Simple three-dimensional unit cells. (a) Simple cubic unit cell. (b) Pedantically correct simple cubic unit cell including only the fractional portion (1/8) of each corner atom actually within the cell cube. (c) Body centered cubic unit cell. (d) Face centered cubic unit cell.

REPEATING PATTERN } SIZE = a

HOW MANY ATOMS / CELL?

$$\left(8\ \frac{\text{ATOM}}{\text{CELL}}\right)\left(\frac{1}{1.60\text{E-}22\ \frac{\text{CM}^3}{\text{CELL}}}\right) = \underbrace{5\text{E+}22\ \frac{\text{ATOM}}{\text{CM}^3}}_{\text{A LOT!}}$$

WE WILL BE SUBSTITUTING DOPANT ATOMS FOR Si ATOM

CORNERS

$8 \times \frac{1}{8} = 1$

FACES

$6 \times \frac{1}{2} = 3$

INSIDE

$4 \times 1 = 4$

$\frac{\text{8 ATOMS}}{\text{UNIT CELL}}$

1 ppb = 1E-9

$$\boxed{\text{DOPANT ATOM CONCENTRATION } 5\text{E+}13\ \frac{\text{ATOM}}{\text{CM}^3}}$$

N

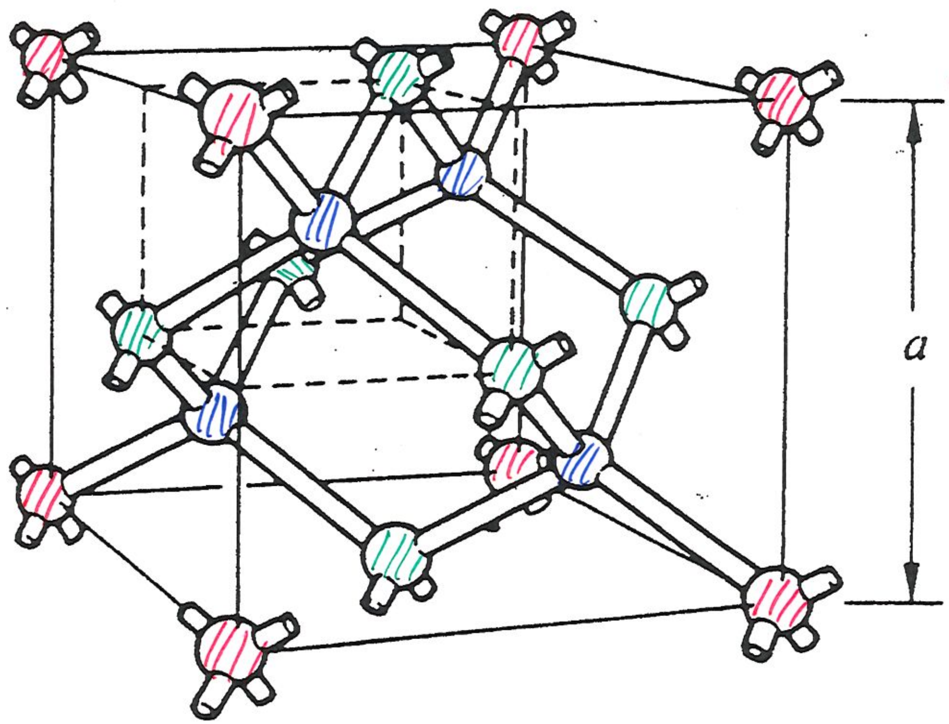
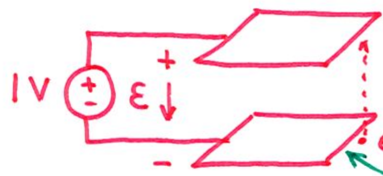


Figure 1.4 (a) Diamond lattice unit cell.

"eV" ELECTRON VOLT
AS UNIT OF ENERGY

$1eV = \underbrace{1.6E\text{-}19}$ JOULE

$1e^- = 1.6E\text{-}19$ COUL



ENERGY ALWAYS RELATIVE
NEED TO DEFINE Ø REFERENCE

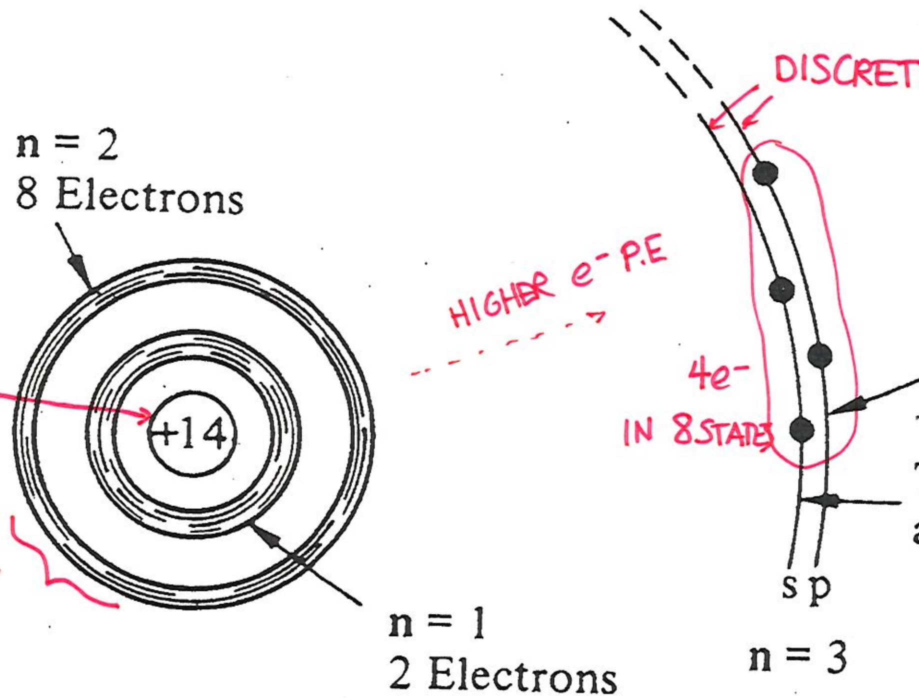


Figure 2.2 Schematic representation of an isolated Si atom.

WHAT HAPPENS
IN CRYSTAL?

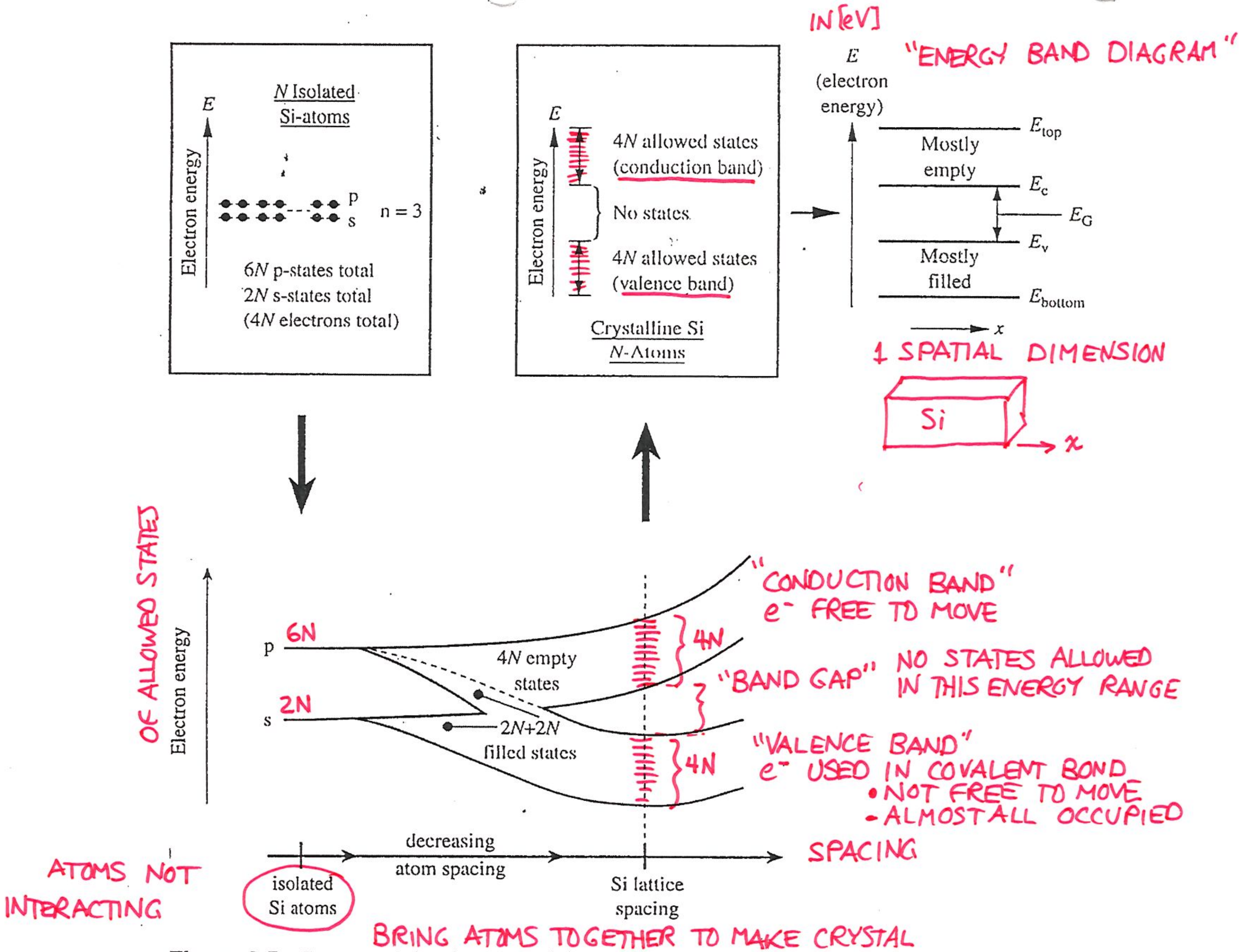


Figure 2.5 Conceptual development of the energy band model starting with N isolated Si atoms on the top left and concluding with a "dressed-up" version of the energy band model on the top right.