

# Working Principle of a Semiconductor Based Solar Cell

## Band Gap I - Electrons in Atoms

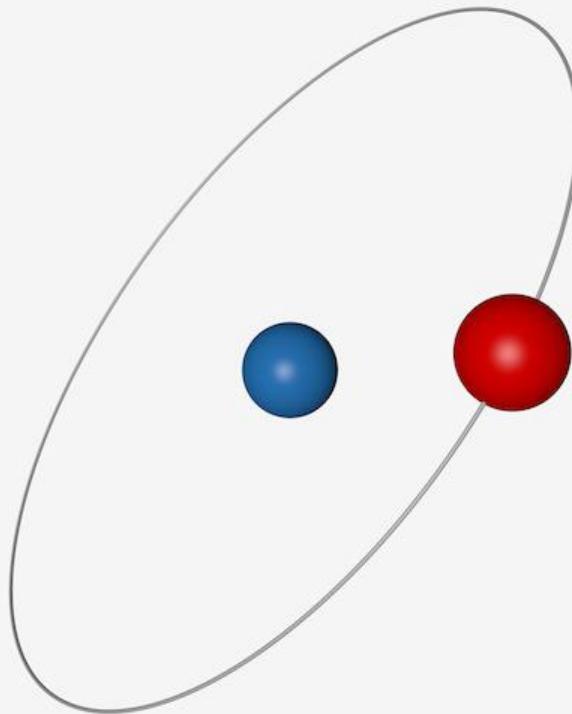
*Week 2.2.1*

Arno Smets



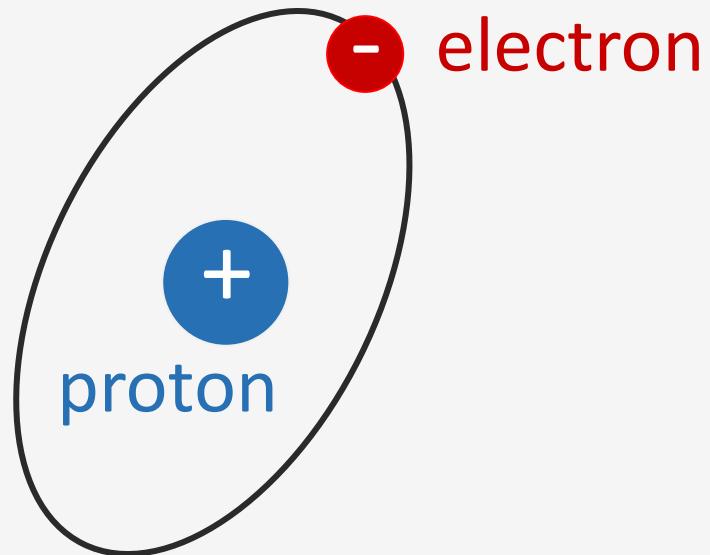
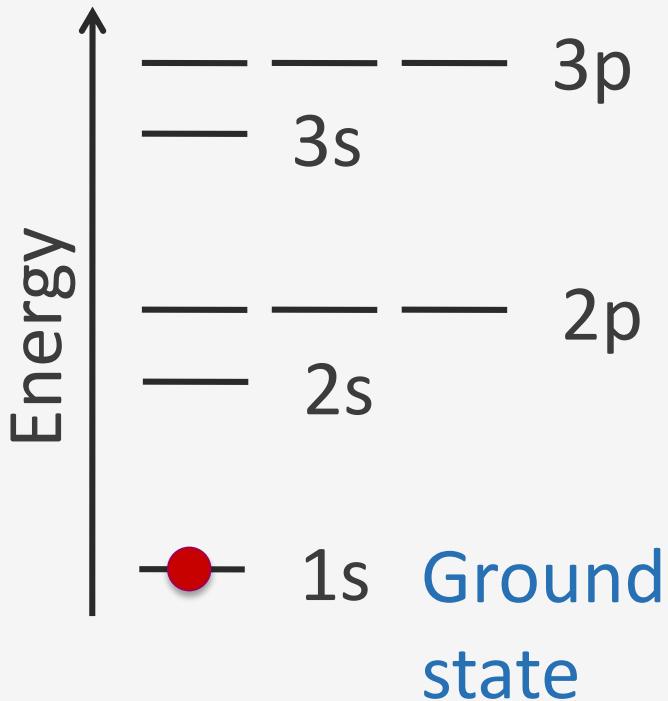
Challenge the future

# Hydrogen

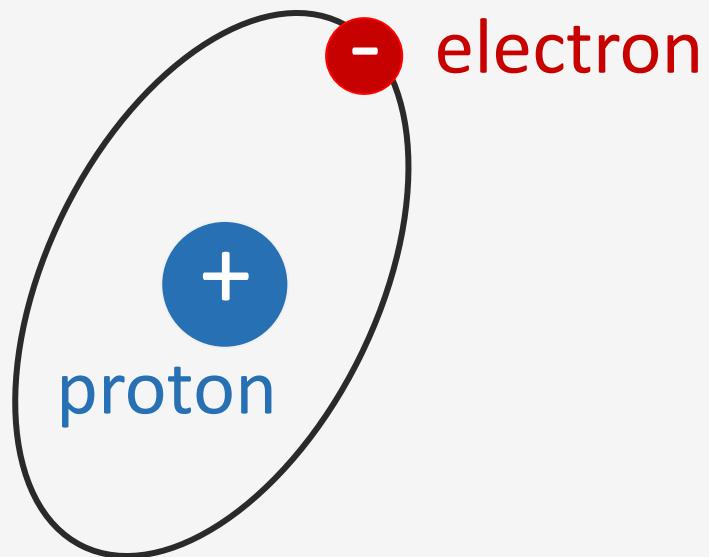
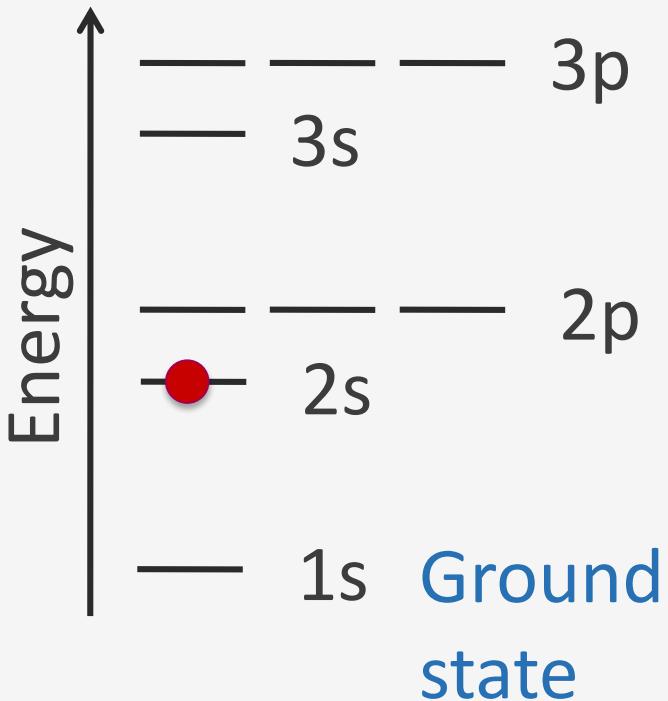


- Proton (+)
- Electron (-)

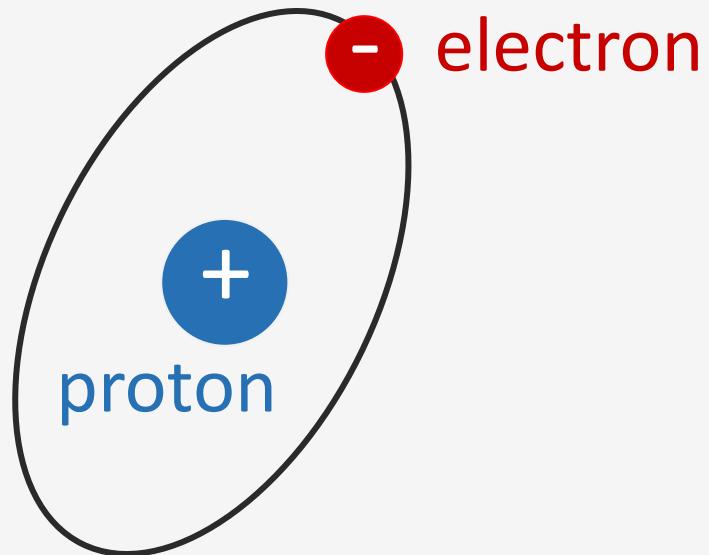
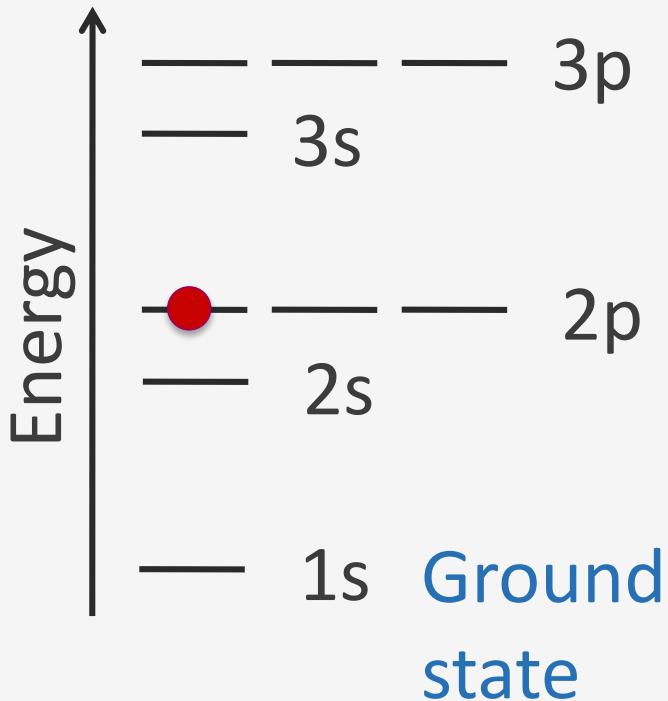
# How strong are electrons bonded: the H atom



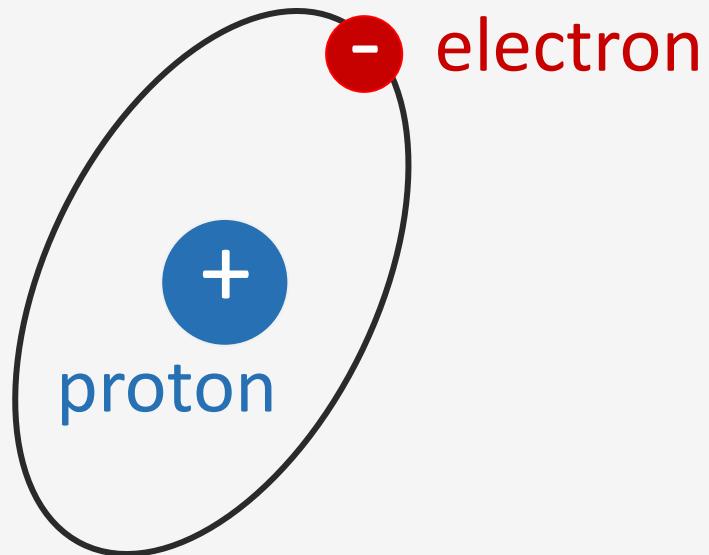
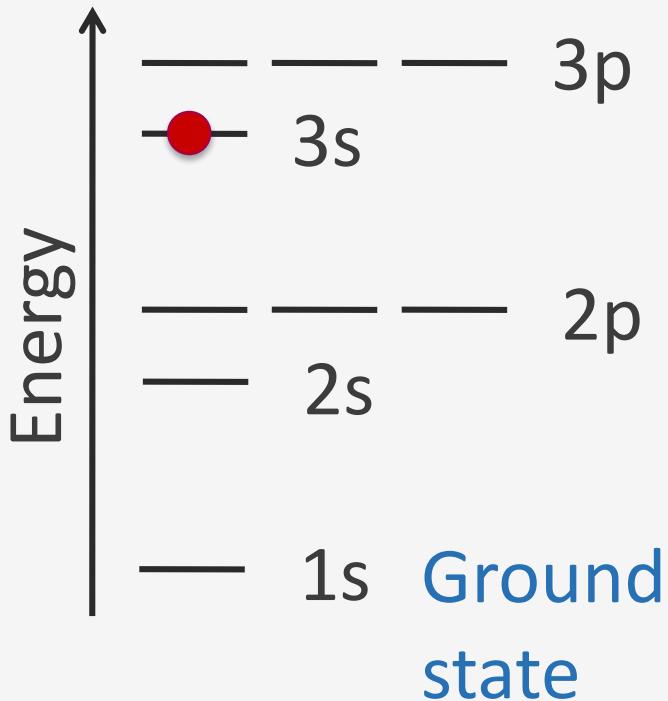
# How strong are electrons bonded: the H atom



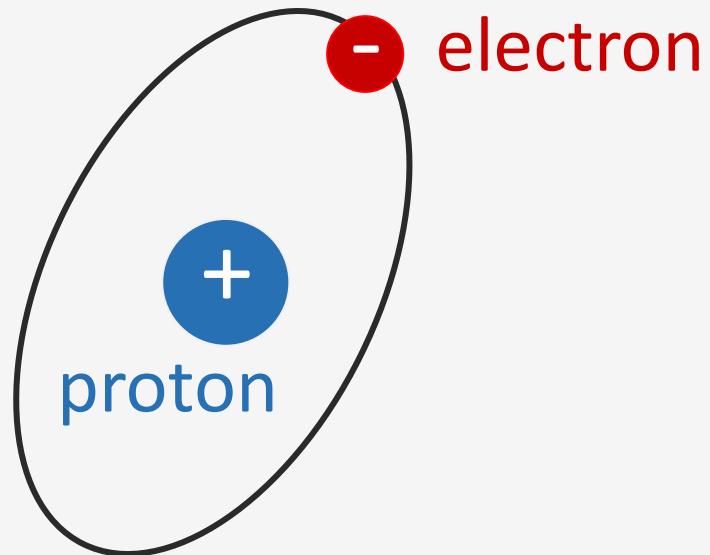
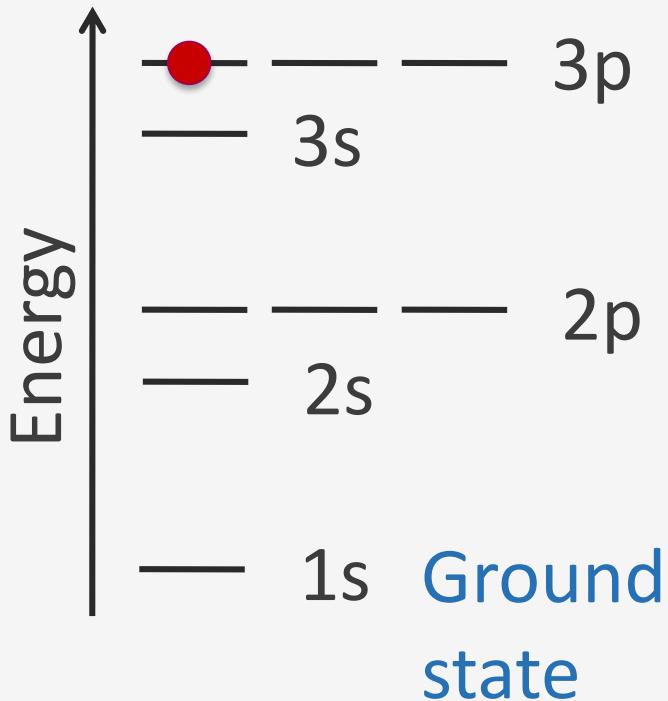
# How strong are electrons bonded: the H atom



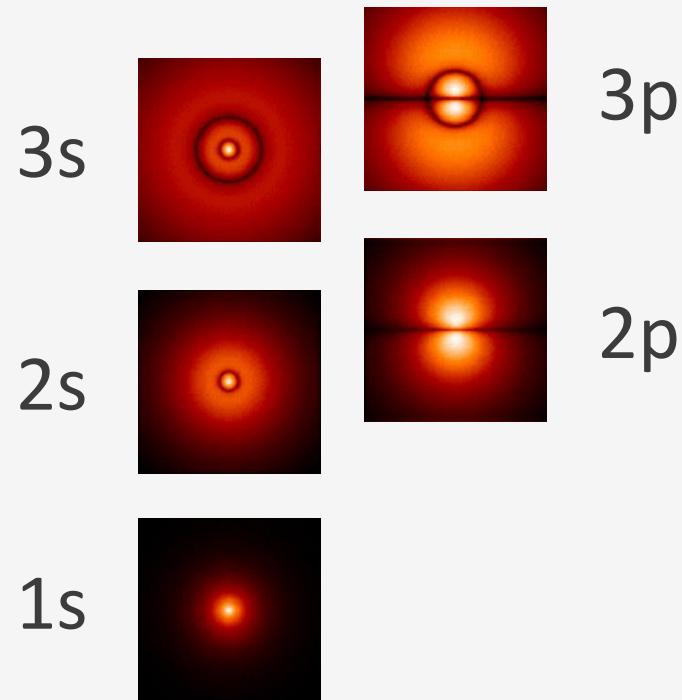
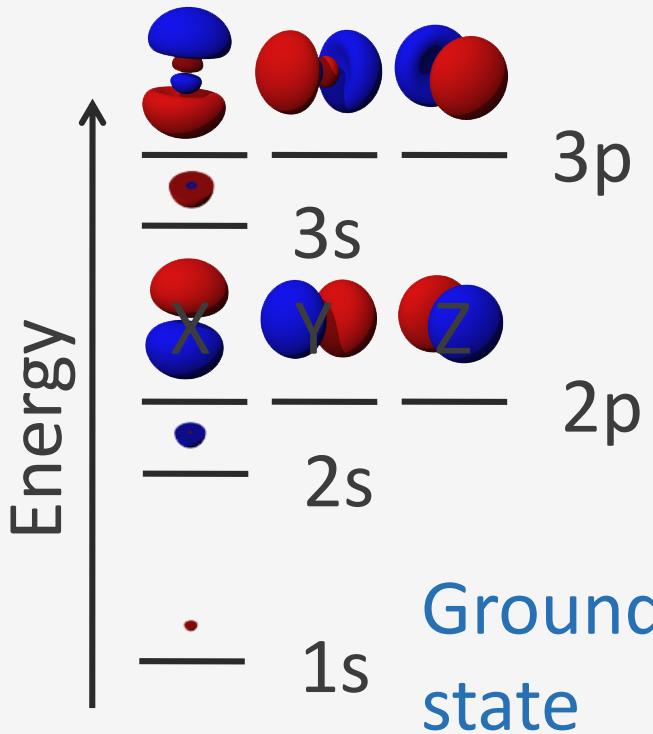
# How strong are electrons bonded: the H atom



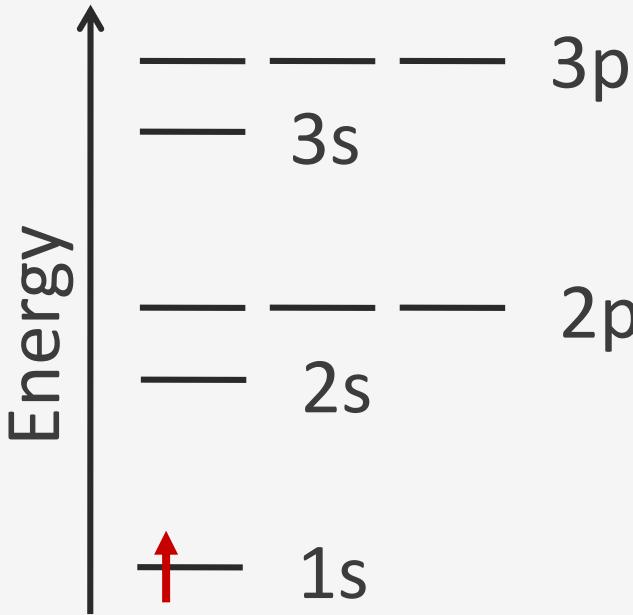
# How strong are electrons bonded: the H atom



# How strong are electrons bonded: the H atom



# How strong are electrons bonded



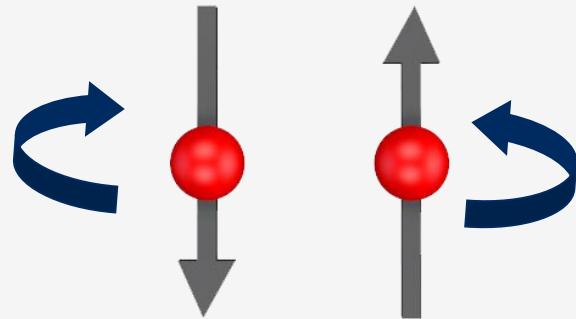
Periodic Table of the Elements

The Periodic Table of the Elements is displayed in a grid. The elements are color-coded according to their group:

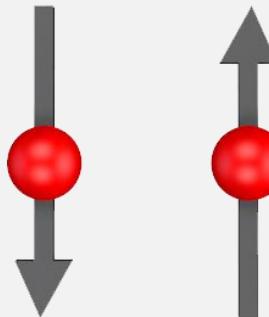
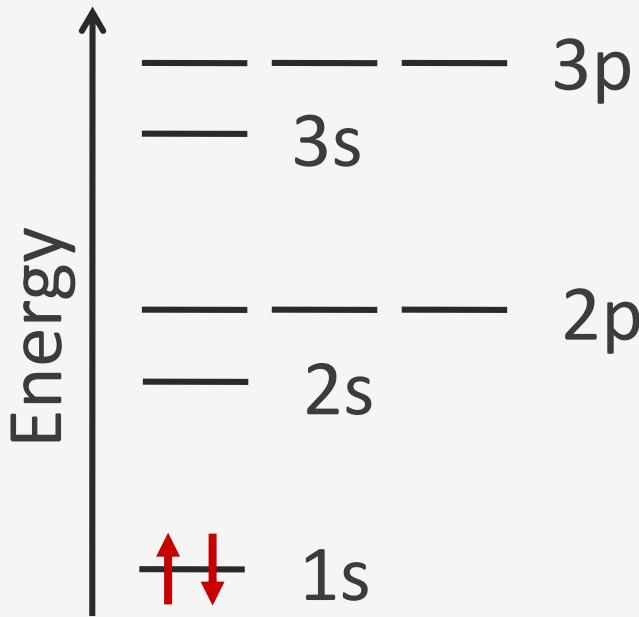
- Hydrogen (H) is green.
- Alkali metals (Li, Na, K, Rb, Cs, Fr) are yellow.
- Alkali earth metals (Be, Mg, Ca, Sr, Ba, Ra) are blue.
- Transition metals (Sc through Cd, Hf through Pt, Os through Au, Hg, Tl, Pb, Bi, Po, At, Ce through Lu) are orange.
- Other elements (C, N, O, F, Ne, Si, P, S, Cl, Ar, As, Se, Br, Kr, Ge, In, Sn, Sb, Te, I, Xe, Ti, Co, Ru, Rh, Ag, Cd, Ir, Pt, Au, Hg, Tl, Pb, Bi, Po, At, Ce through Lu) are grey.

1	H	2	He																								
3	Li	4	Be																								
11	Na	12	Mg																								
19	K	20	Ca																								
37	Rb	38	Sr																								
55	Cs	56	Ba																								
87	Fr	88	Ra																								
21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn								
39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd								
57	La	72	Ta	73	W	74	Re	75	Os	76	Ir	77	Pt	78	Au	79	Hg	80	Tl								
89	Ac	104	Rf	105	Db	106	Sg	107	Bh	108	Hs	109	Mt	110	Ds	111	Rg	58	Ce								
90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es								
101	No	102	Lr	103		61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu

# Electron spin

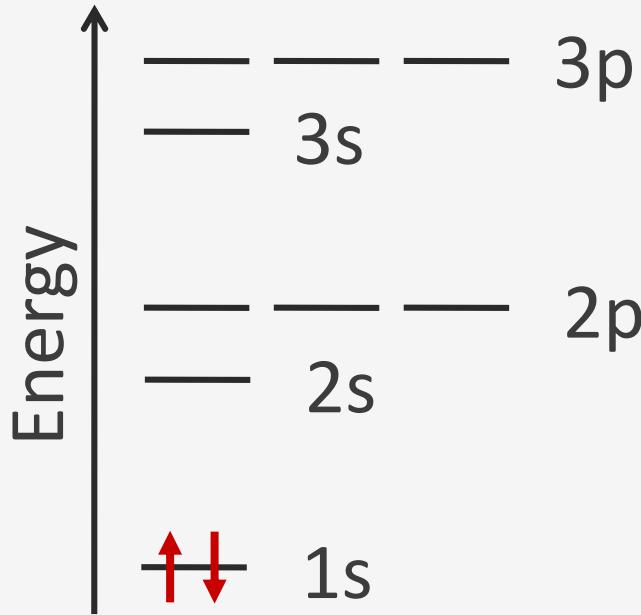


# How strong are electrons bonded:



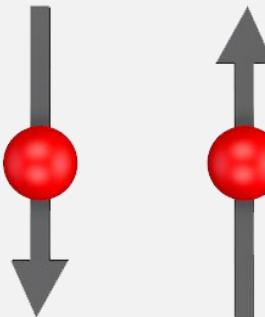
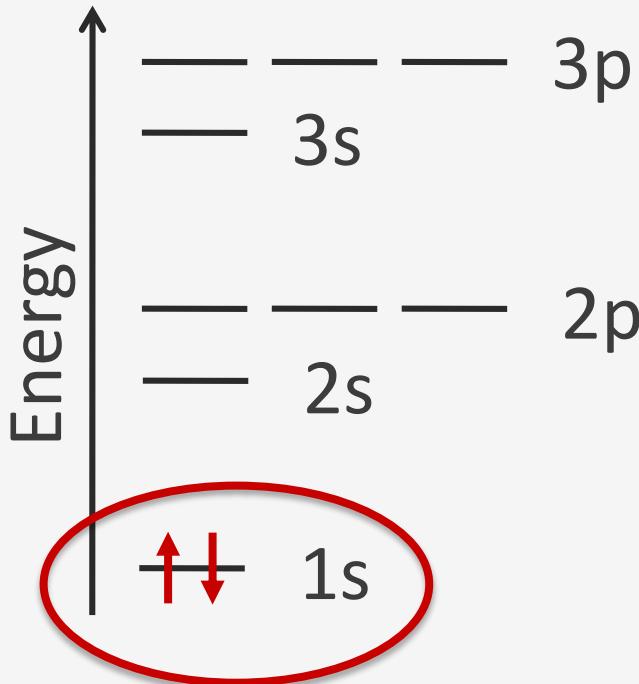
**Pauli principle:** two identical electrons can not occupy the same quantum state simultaneously.

# Pauli's Exclusion Principle:



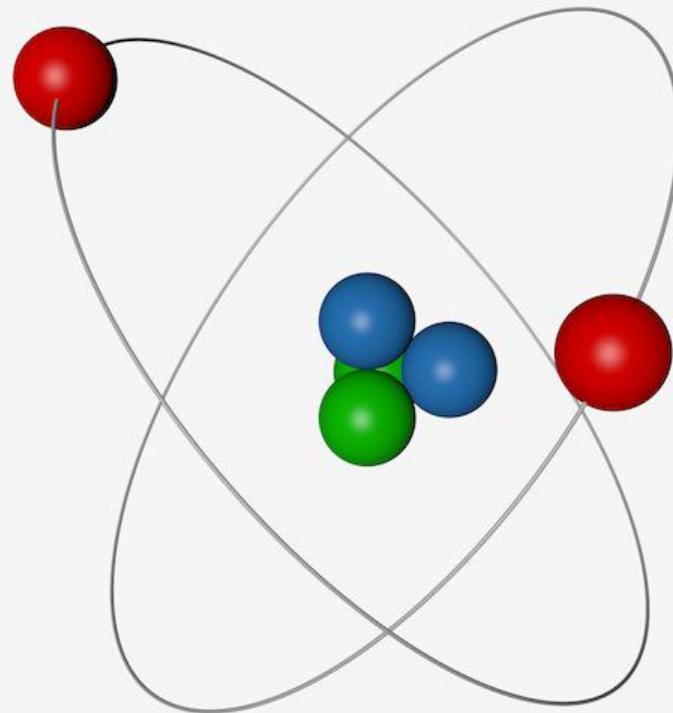
**Pauli principle:** two identical electrons can not occupy the same quantum state simultaneously.

# How strong are electrons bonded:

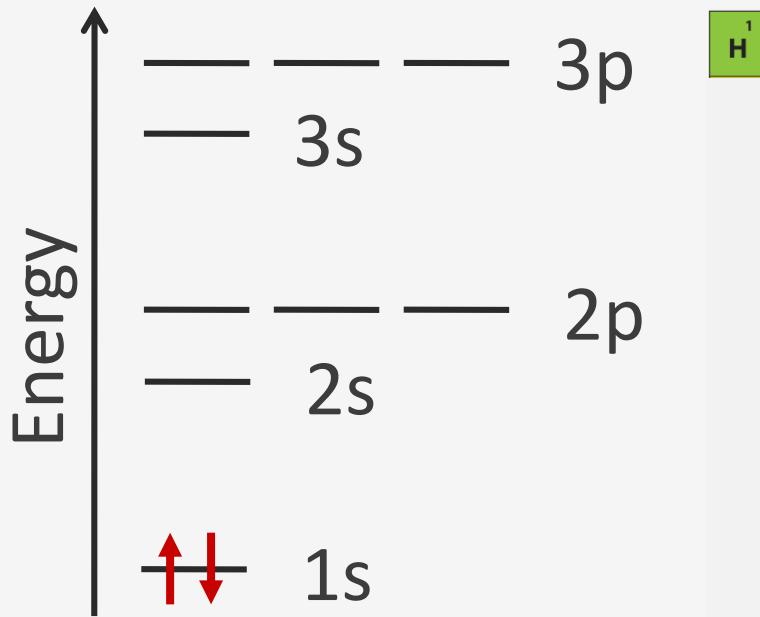


**Pauli principle:** two identical electrons can not occupy the same quantum state simultaneously.

# Helium



# How strong are electrons bonded

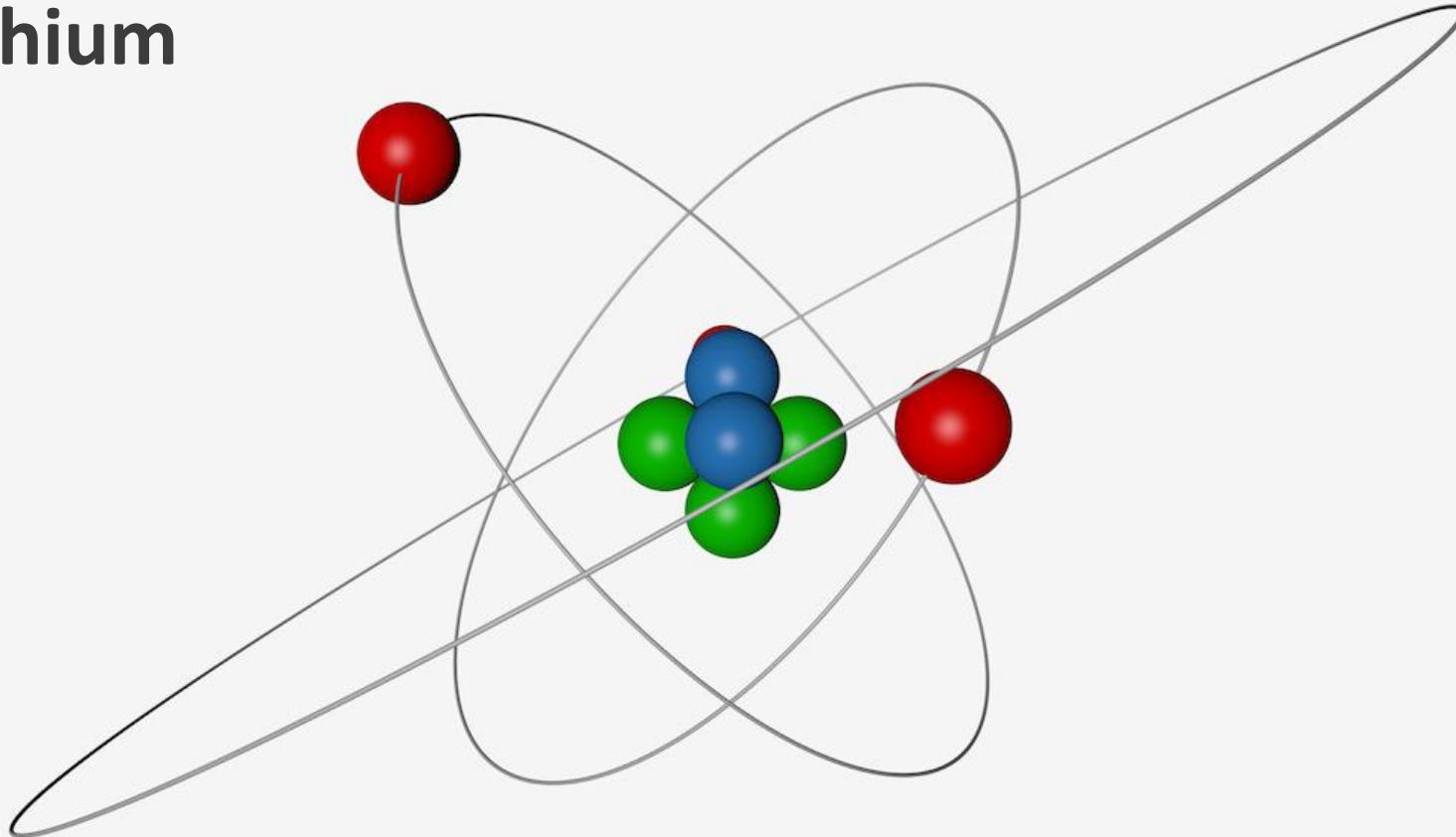


Periodic Table of the Elements

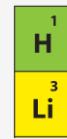
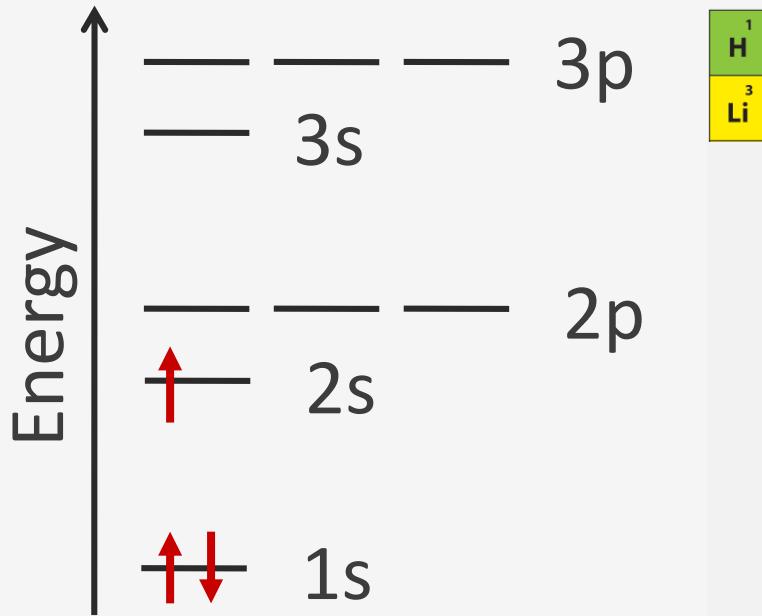
hydrogen	hydrogen
alkali metals	alkali metals
alkali earth metals	alkali earth metals
transition metals	transition metals



# Lithium



# How strong are electrons bonded

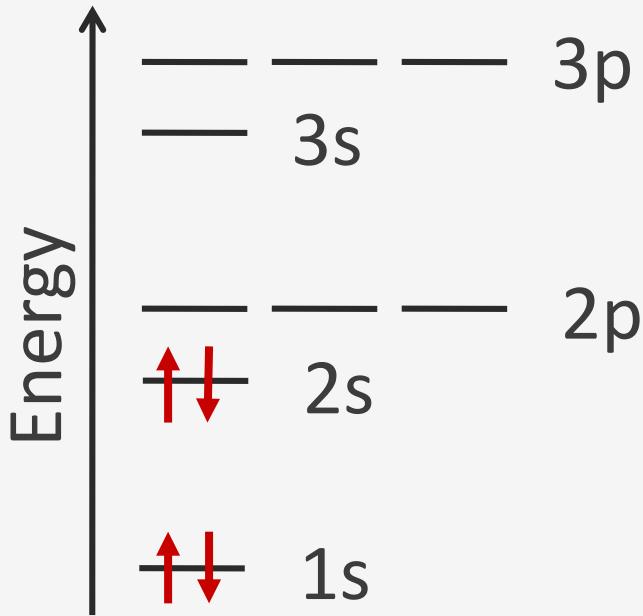


Periodic Table of the Elements

hydrogen	hydrogen
alkali metals	alkali metals
alkali earth metals	alkali earth metals
transition metals	transition metals



# How strong are electrons bonded



A small periodic table showing the first four elements: Hydrogen (H), Lithium (Li), Beryllium (Be), and Helium (He). Hydrogen is in green, Lithium and Beryllium are in yellow, and Helium is in red.

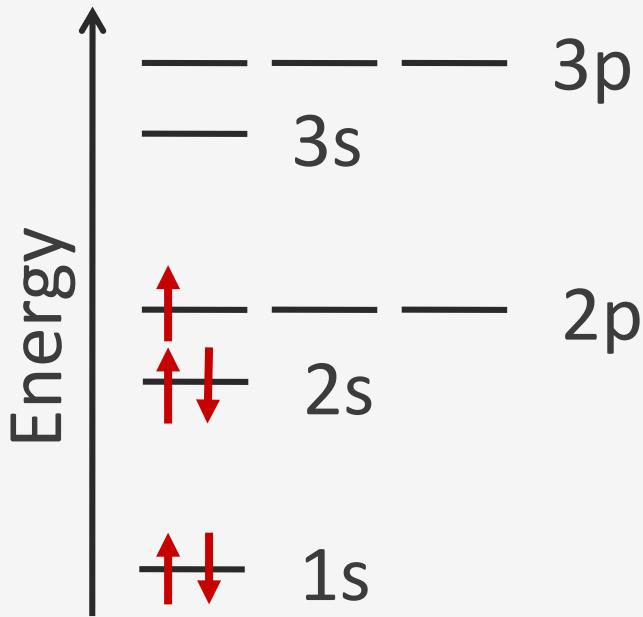
<sup>1</sup> H		
<sup>3</sup> Li	<sup>4</sup> Be	
		<sup>2</sup> He

Periodic Table of the Elements

- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |



# How strong are electrons bonded



<sup>1</sup> H
<sup>3</sup> Li
<sup>4</sup> Be

Periodic Table of the Elements

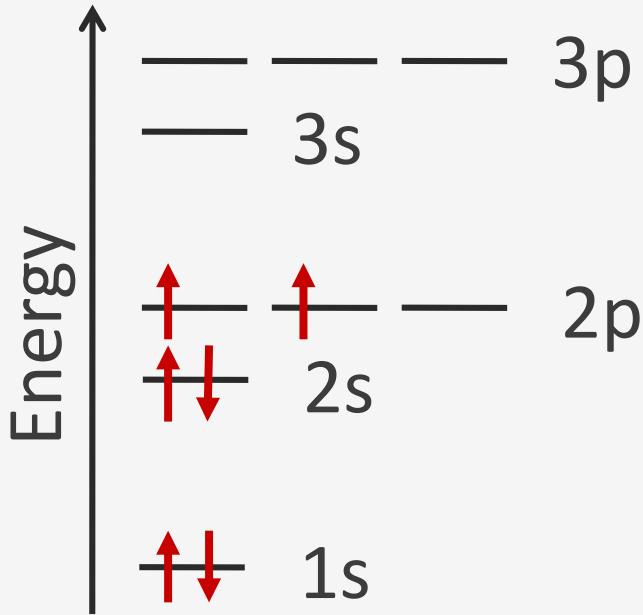
- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |

<sup>5</sup> B
----------------

<sup>2</sup> He
-----------------



# How strong are electrons bonded



1	H
3	Li
4	Be

Periodic Table of the Elements

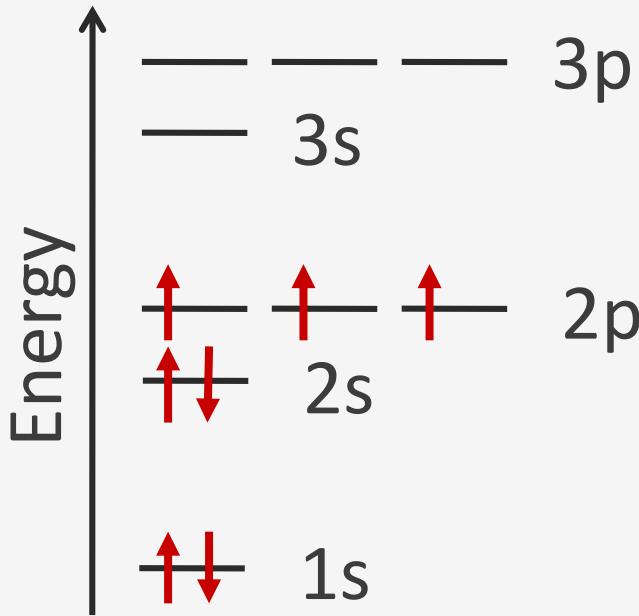
- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |

5	B
6	C

2	He
---	----

$C \rightarrow 1s^2 2s^2 2p^2$

# How strong are electrons bonded



<sup>1</sup> H
<sup>3</sup> Li
<sup>4</sup> Be

Periodic Table of the Elements

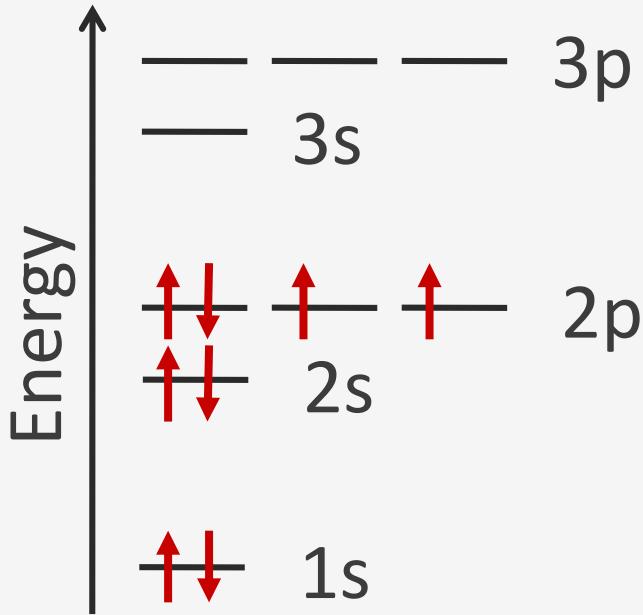
- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |

<sup>5</sup> B
<sup>6</sup> C
<sup>7</sup> N

<sup>2</sup> He
-----------------

$N \rightarrow 1s^2 2s^2 2p^3$

# How strong are electrons bonded



<sup>1</sup> H
<sup>3</sup> Li
<sup>4</sup> Be

Periodic Table of the Elements

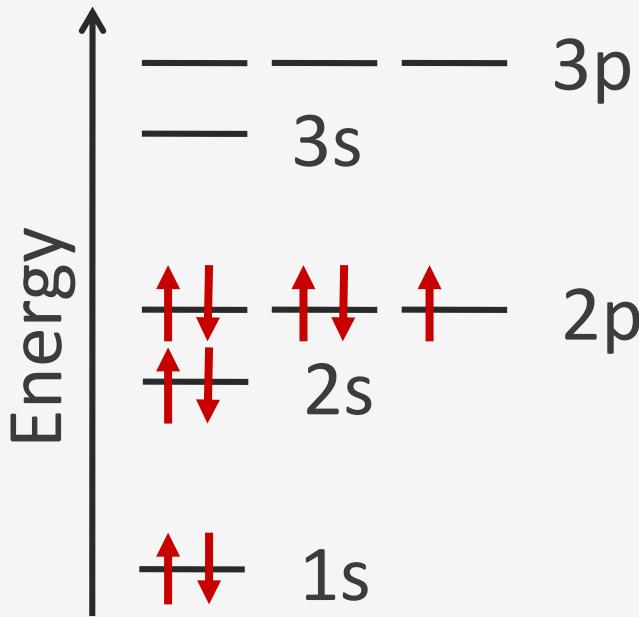
- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |

<sup>5</sup> B
<sup>6</sup> C
<sup>7</sup> N
<sup>8</sup> O

<sup>2</sup> He
-----------------



# How strong are electrons bonded



1	H
3	Li
4	Be

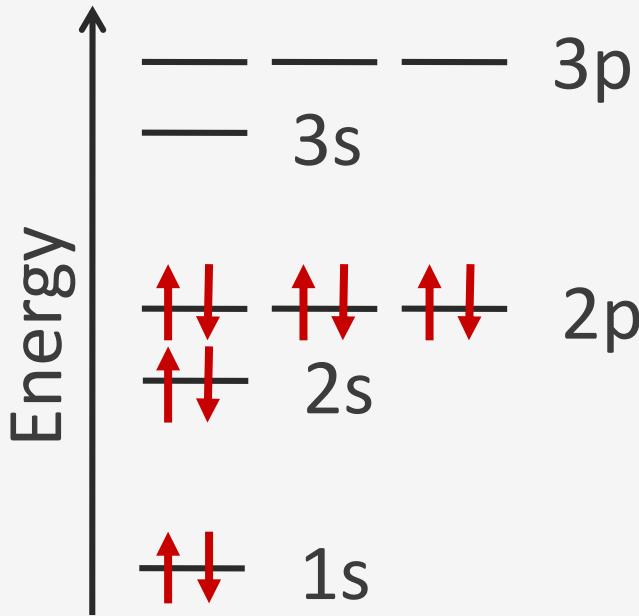
Periodic Table of the Elements

- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |

5	B	6	C	7	N	8	O	9	F	2	He
---	---	---	---	---	---	---	---	---	---	---	----



# How strong are electrons bonded



1	H
3	Li
4	Be

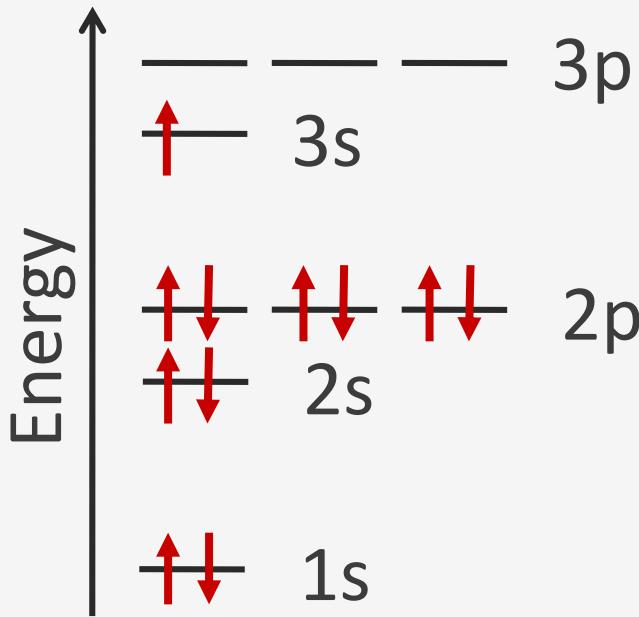
Periodic Table of the Elements

- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |

5	B	6	C	7	N	8	O	9	F	10	He
Li											



# How strong are electrons bonded



1	H
3	Li
11	Na

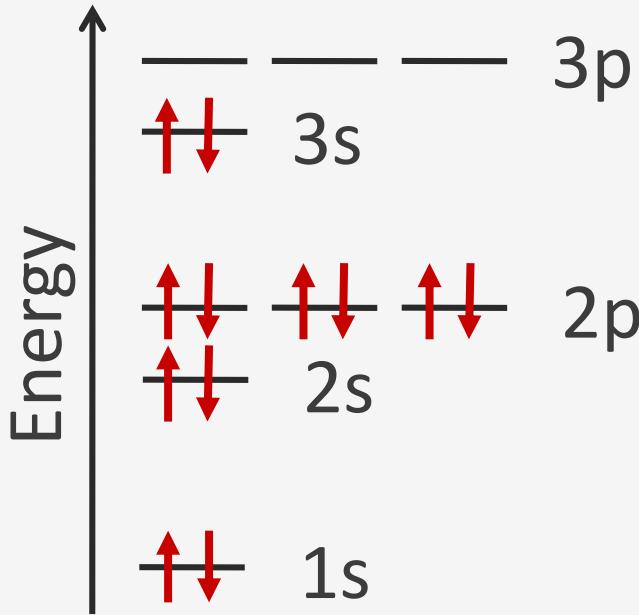
Periodic Table of the Elements

hydrogen	hydrogen
alkali metals	alkali metals
alkali earth metals	alkali earth metals
transition metals	transition metals

5	C	7	O	F	10
B	N				He Ne



# How strong are electrons bonded



1	H
3	Li
11	Na
4	Be
12	Mg

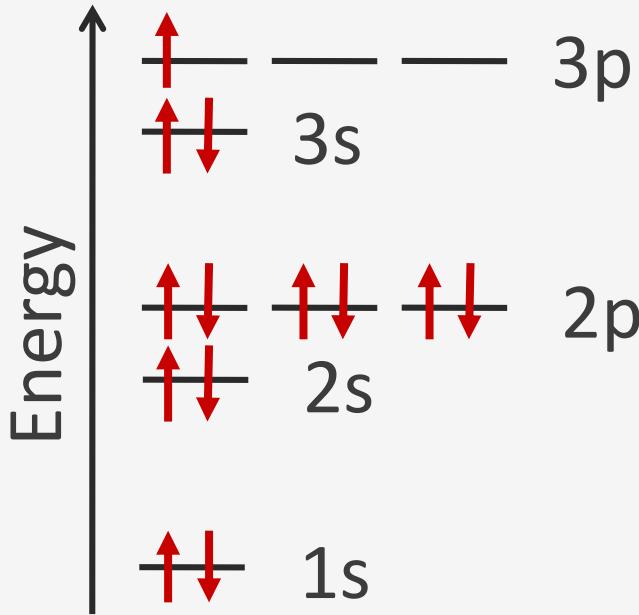
Periodic Table of the Elements

- |                     |                     |
|---------------------|---------------------|
| hydrogen            | hydrogen            |
| alkali metals       | alkali metals       |
| alkali earth metals | alkali earth metals |
| transition metals   | transition metals   |

5	B	6	C	7	N	8	O	9	F	10	Ne
---	---	---	---	---	---	---	---	---	---	----	----



# How strong are electrons bonded



<sup>1</sup> H	
<sup>3</sup> Li	
<sup>4</sup> Be	
<sup>11</sup> Na	<sup>12</sup> Mg

Periodic Table of the Elements

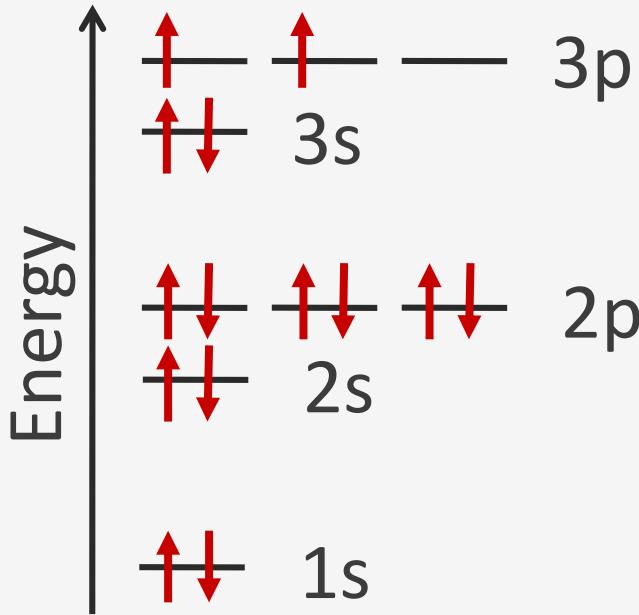
hydrogen  
alkali metals  
alkali earth metals  
transition metals

hydrogen  
alkali metals  
alkali earth metals  
transition metals

<sup>5</sup> B
<sup>6</sup> C
<sup>7</sup> N
<sup>8</sup> O
<sup>9</sup> F
<sup>10</sup> Ne



# How strong are electrons bonded: the Si atom



1	H
3	Li
11	Na
4	Be
12	Mg

Periodic Table of the Elements

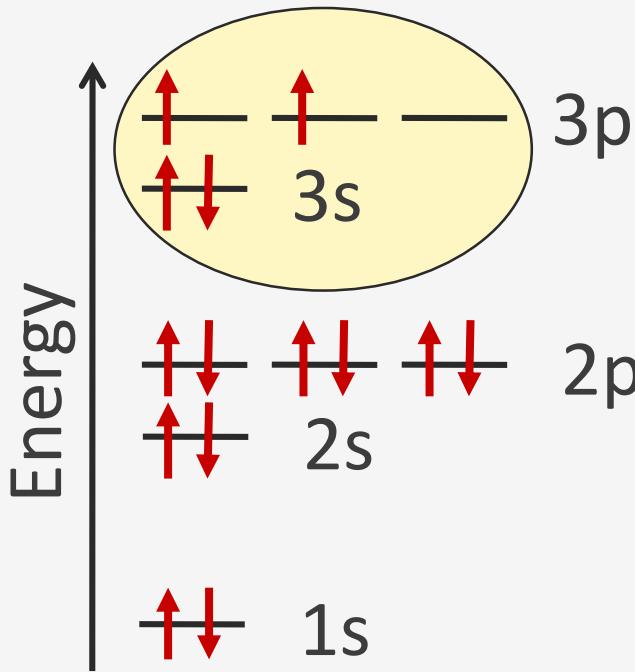
hydrogen  
alkali metals  
alkali earth metals  
transition metals

hydrogen  
alkali metals  
alkali earth metals  
transition metals

5	B	6	C	7	N	8	O	9	F	10	He
13	Al	14	Si								



# Bonding of electrons in Si network



A periodic table of elements. Silicon (Si) is highlighted with a red box and a red arrow points to its entry. The table includes element number, symbol, atomic mass, and group/period information.

VIIIA						
						2 He 4.0026
III A	IV A	V A	VIA	VIIA		
5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180	
IB	IIB	13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453
29 Cu 63.546	30 Zn 65.38	31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904
47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	54 Xe 131.29
79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po [209]	85 At [210]
						86 Rn [222]

Si atom: 14 electrons

# Bonding of electrons in Si network

