

ATOMIC STRUCTURE

Lecture 3



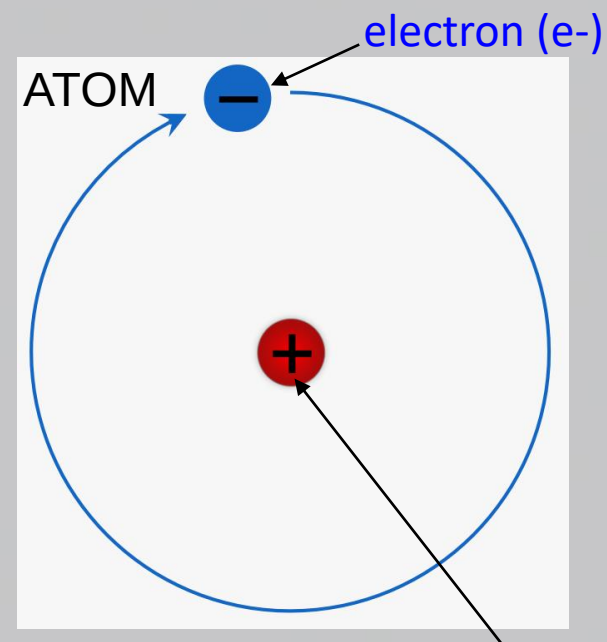
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WHAT IS IN THE ATOM?

Subatomic particles:

proton	mass = 1	charge = +1
neutron	mass = 1	charge = 0
electron	mass = 0	charge = -1



nucleus
(p+n)

Atomic Number **Z** **DEFINES ATOM TYPE**

17
Cl
chlorine
35.453

Symbol
Name
Average Atomic Mass

Number of protons = atomic number (**Z**) = number of electrons

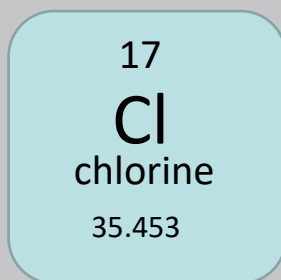
Mass of atom = mass number = number of protons + number of neutrons

$$A = Z + n$$



ISOTOPES

- two or more types of atoms that have the **same atomic number** (number of protons) and **same number of electrons (Z)** but **different numbers of neutrons** in their nuclei
- all isotopes of a given element have almost the same chemical properties but they have different atomic masses and physical properties



Two stable isotopes :

one with 18 neutrons

one with 20 neutrons

Z = 17

17 protons in every chlorine atom

n = 18

A = Z + n = 17 + 18 = 35

Cl-35 or ^{35}Cl

n = 20

A = Z + n = 17 + 20 = 37

Cl-37 or ^{37}Cl



(AVERAGE) ATOMIC MASS

In a sample of element, all isotopes are present. **So, need average mass**

$$\text{weighted average mass} = \sum (\text{mass of isotope}) \times \text{fraction of atoms of this isotope}$$

~~average mass = total mass $\div$ number of atoms~~

NOT simple average of isotopes

Chlorine: $\frac{3}{4}$ are Cl-35 and $\frac{1}{4}$ are Cl-37

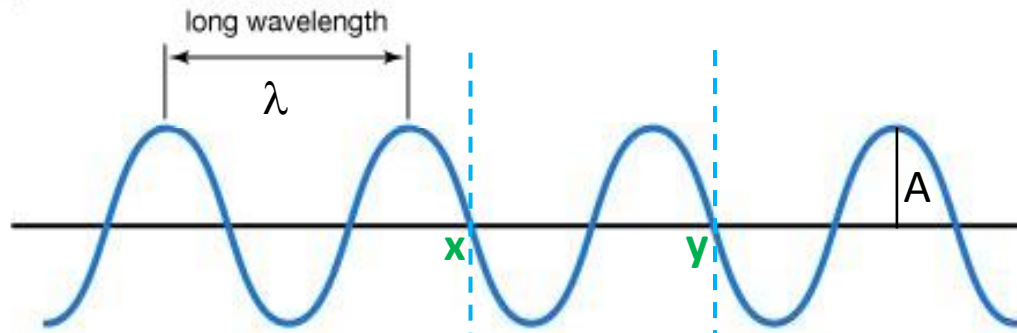
$$\begin{aligned} \text{Average atomic mass} &= \\ &= (35)(0.75) + (37)(0.25) = 35.5 \end{aligned}$$



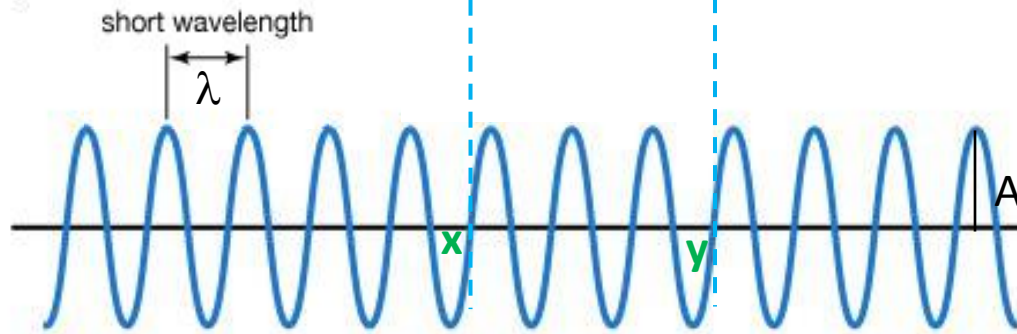
LIGHT: FREQUENCY and SPEED

Electromagnetic radiation travels in waves

Low frequency



High frequency



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λ - wavelength
[m, nm]

A – amplitude
[for light related to
intensity]

ν = frequency
[cycles/sec, 1/sec or
 sec^{-1} , Hertz (Hz)]

λ is related to speed
of wave (m/s) $x-y$

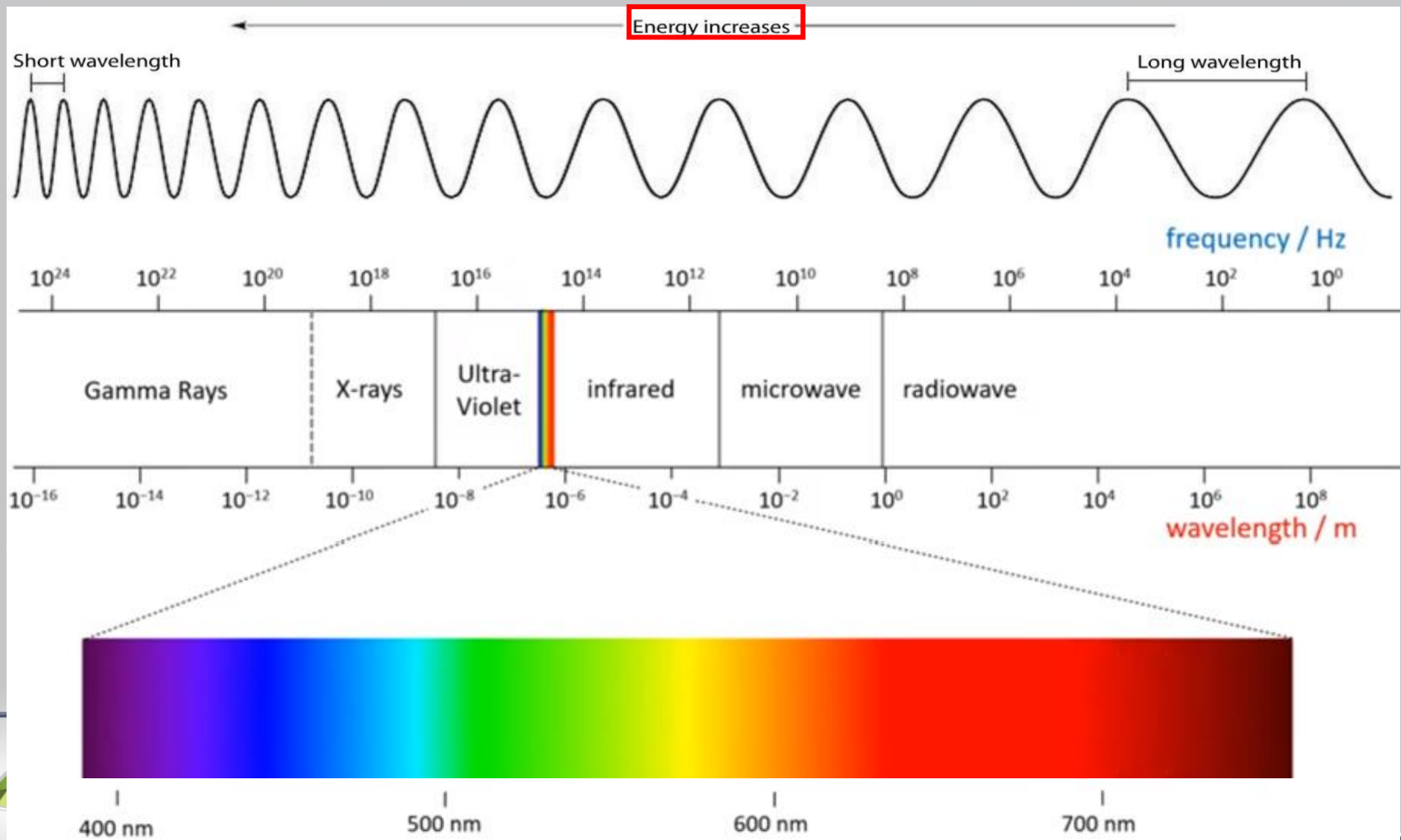
Speed of light = $c = 3 \times 10^8 \text{ m/s}$

$$c = \lambda \times \nu$$



ELECTROMAGNETIC SPECTRUM

$$c = \lambda \times \nu$$



ENERGY OF LIGHT

Anomaly associated with light waves and energy puzzled scientists for centuries

Energy of waves is related to the amplitude

BUT

Energy of light is related to the frequency

Max Planck:

- relationship between energy and frequency of light

$$E = h \times \nu$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

Planck constant

- came out with idea that light travels in packets of energy called **PHOTONS**

Albert Einstein

photoelectric effect (Nobel Prize)

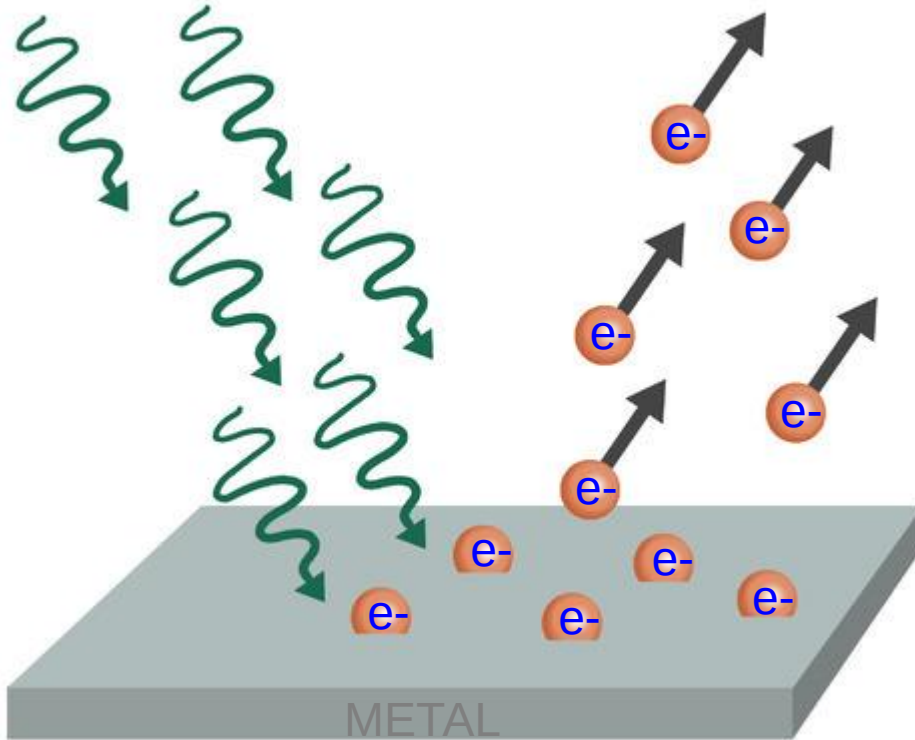
PHOTON - the smallest possible, quantized packets of electromagnetic energy



PHOTOELECTRIC EFFECT

Experimental evidence for the existence of photons and the dependence of their energy on frequency

photons of right frequency



- photons of right frequency (energy) eject electrons from the metal surface
- light energy ($E = h \times \nu$) equals the binding energy required to make electron leave the metal and its kinetic energy



ABSORPTION and EMISSION SPECTRA

light passing through the prism



visible spectrum

light passing through the flask filled with hydrogen



some wavelengths missing

ABSORPTION SPECTRUM

electricity passing through the flask filled with hydrogen



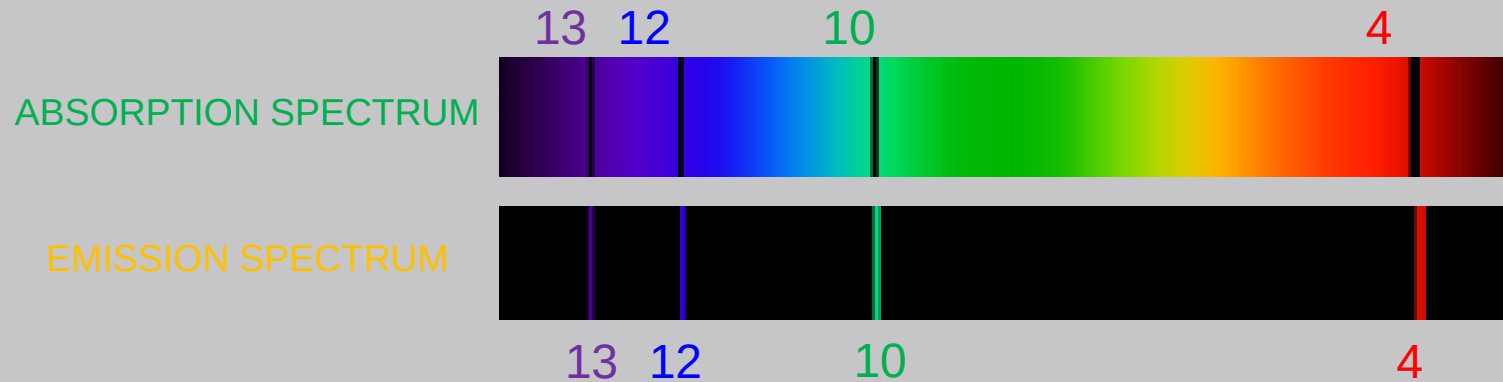
only a few bands of light

EMISSION SPECTRUM

energies absorbed = energies emitted



ABSORPTION and EMISSION SPECTRA

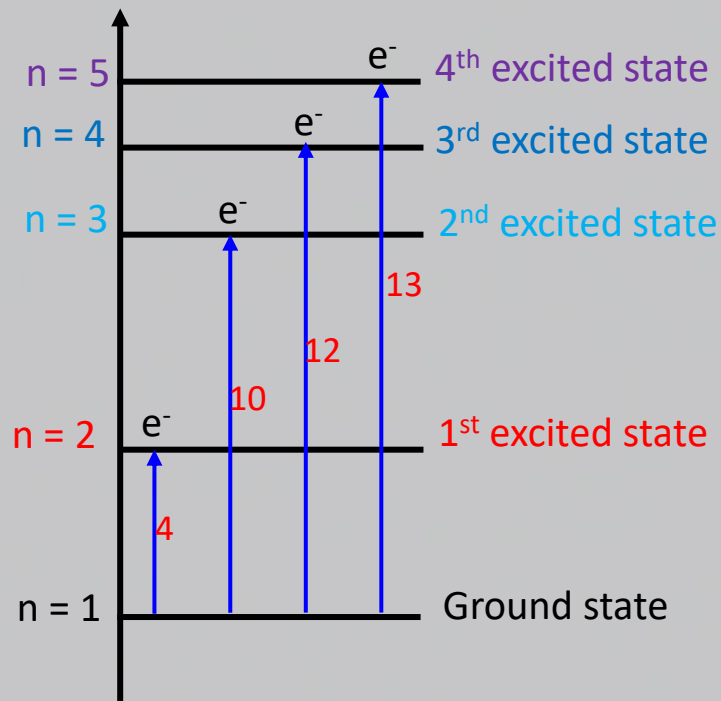


using fake numbers for simplicity

1. Has to do with hydrogen atom
2. Has to do with hydrogen electrons
3. Limited in energy absorbed
Limited in energy allowed – energy levels
4. Mechanism opposite but otherwise identical for emission

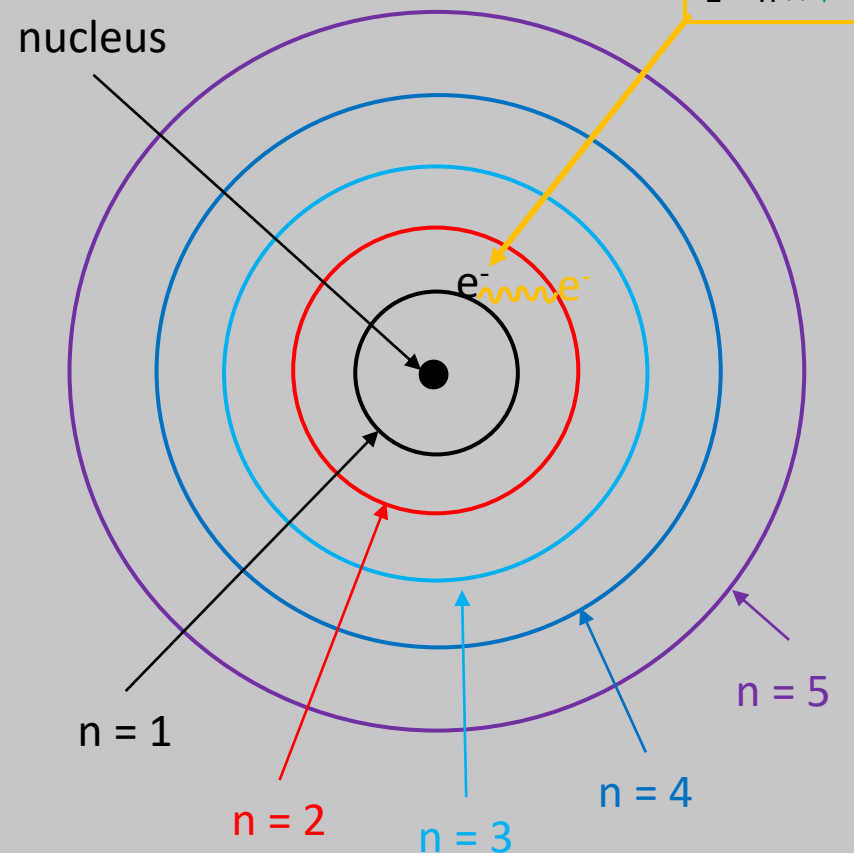


ENERGY LEVELS



in H atom electrons have only certain allowed energies

ORBIT MODEL (solar system)



- absorption spectrum – e^- move up levels and orbits
- emission spectrum – excited e^- move down levels and orbits



REAL NUMBERS

Wavelength λ , (nm)	Frequency ν , (Hz, s ⁻¹)	n_1	n_2
94	3.20×10^{15}	1	6
95	3.16×10^{15}	1	5
97	3.08×10^{15}	1	4
103	2.92×10^{15}	1	3
122	2.47×10^{15}	1	2
410	7.31×10^{14}	2	6
434	6.91×10^{14}	2	5
486	6.17×10^{14}	2	4
657	4.57×10^{14}	2	3
1094	2.74×10^{14}	3	6
1282	2.34×10^{14}	3	5
1876	1.60×10^{14}	3	4
2626	1.14×10^{14}	4	6
4053	7.40×10^{13}	4	5

$$c = \lambda \times \nu = 3 \times 10^8 \text{ m/s}$$

$$\nu = R_h \times \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$R_h = 3.29 \times 10^{15} \text{ s}^{-1}$$

Rydberg constant



REAL NUMBERS

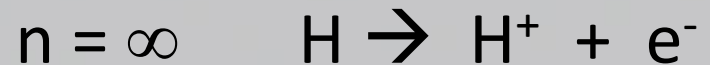
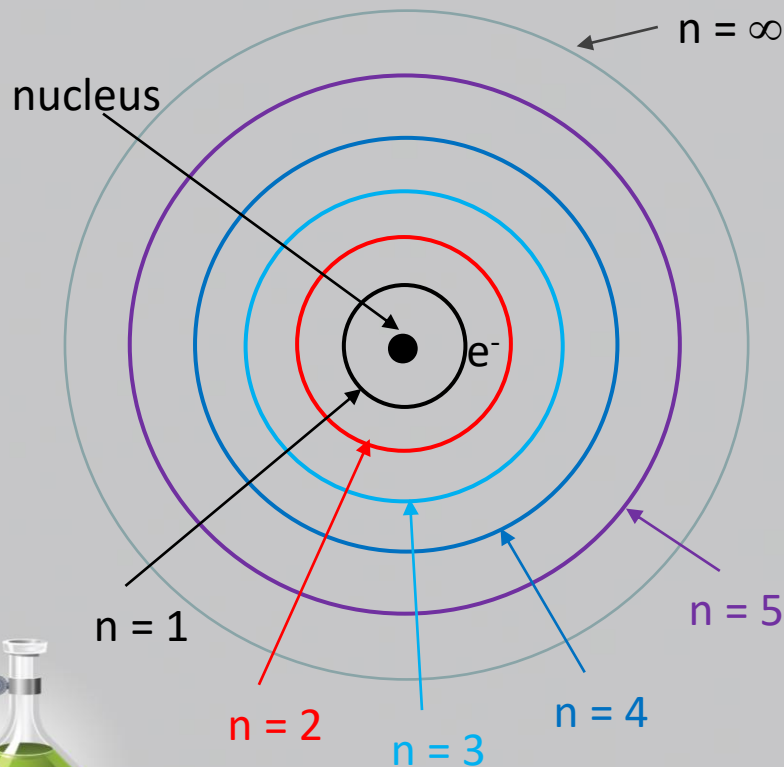
$$E = h \times \nu$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$\nu = R_h \times \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$

$$R_h = 3.29 \times 10^{15} \text{ s}^{-1}$$

$$E = h \times R_h \times \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right)$$



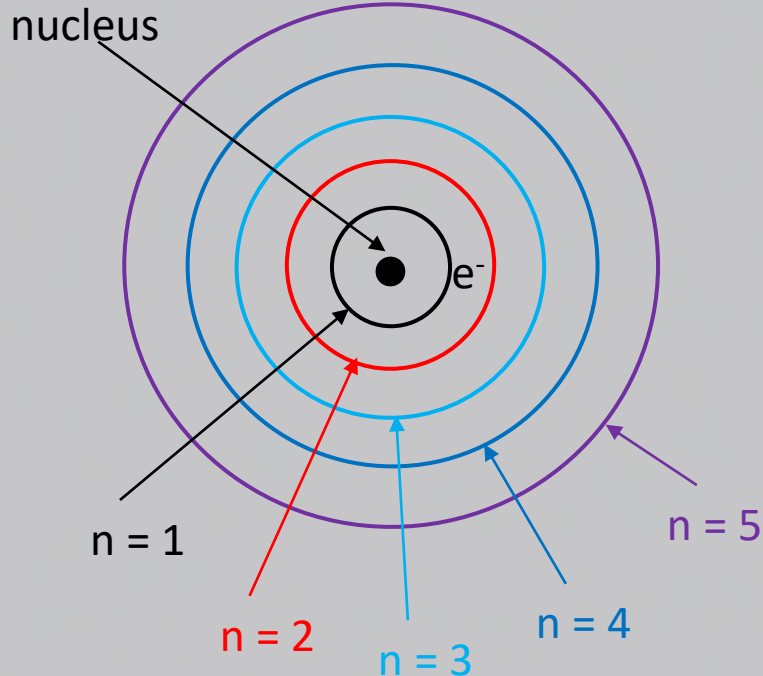
$$E = 2.18 \times 10^{-18} \text{ J} \times \left(\frac{1}{1^2} - \frac{1}{\infty^2} \right)$$

$$E = 2.18 \times 10^{-18} \text{ J}$$

IONISATION ENERGY



nucleus



H:	1e ⁻	(n=1) ¹
He:	2e ⁻	(n=1) ²
Li:	3e ⁻	(n=1) ² (n=2) ¹
Be:	4e ⁻	(n=1) ² (n=2) ²
B:	5e ⁻	(n=1) ² (n=2) ³
Ne:	10e ⁻	(n=1) ² (n=2) ⁶



H 1																	He 2				
Li 3	Be 4															B 5	C 6	N 7	O 8	F 9	Ne 10
Na 11	Mg 12															Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36				
Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54				
Cs 55	Ba 56	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86				
Fr 87	Ra 88	Ac 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112	Nh 113	Fl 114	Mc 115	Lv 116	Ts 117	Og 118				
Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71								
Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103								

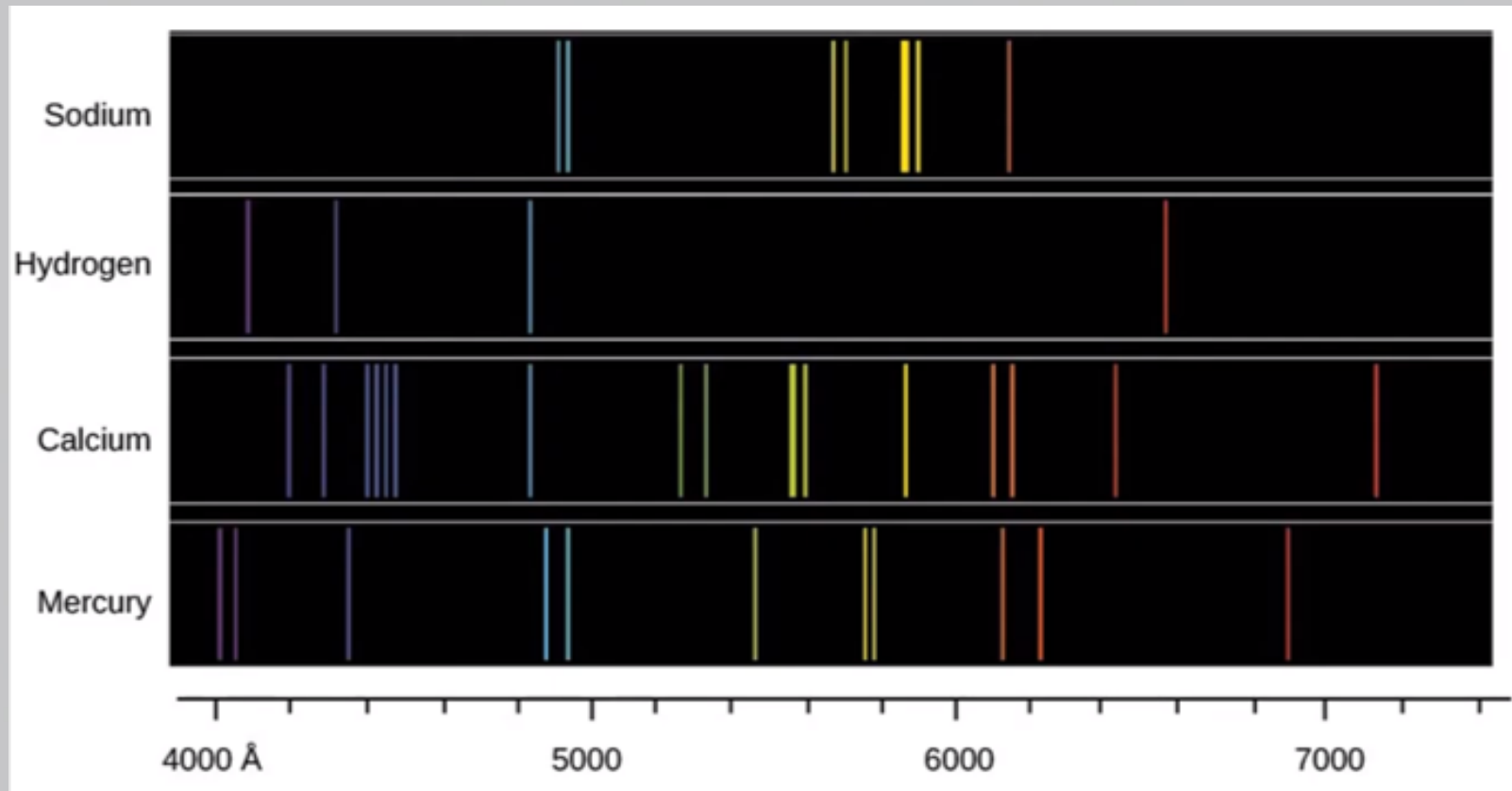
Shell	Max number e ⁻
1	2
2	8
3	18
4	32
5	50
∞	2n ²

'Shell atom configuration'

Cl 17e $(n=1)^2 (n=2)^8 (n=3)^7$

Ge 32e $(n=1)^2 (n=2)^8 (n=3)^{18} (n=4)^4$

MORE COMPLEX SPECTRA



More lines mean more transitions

Shells split into subshells

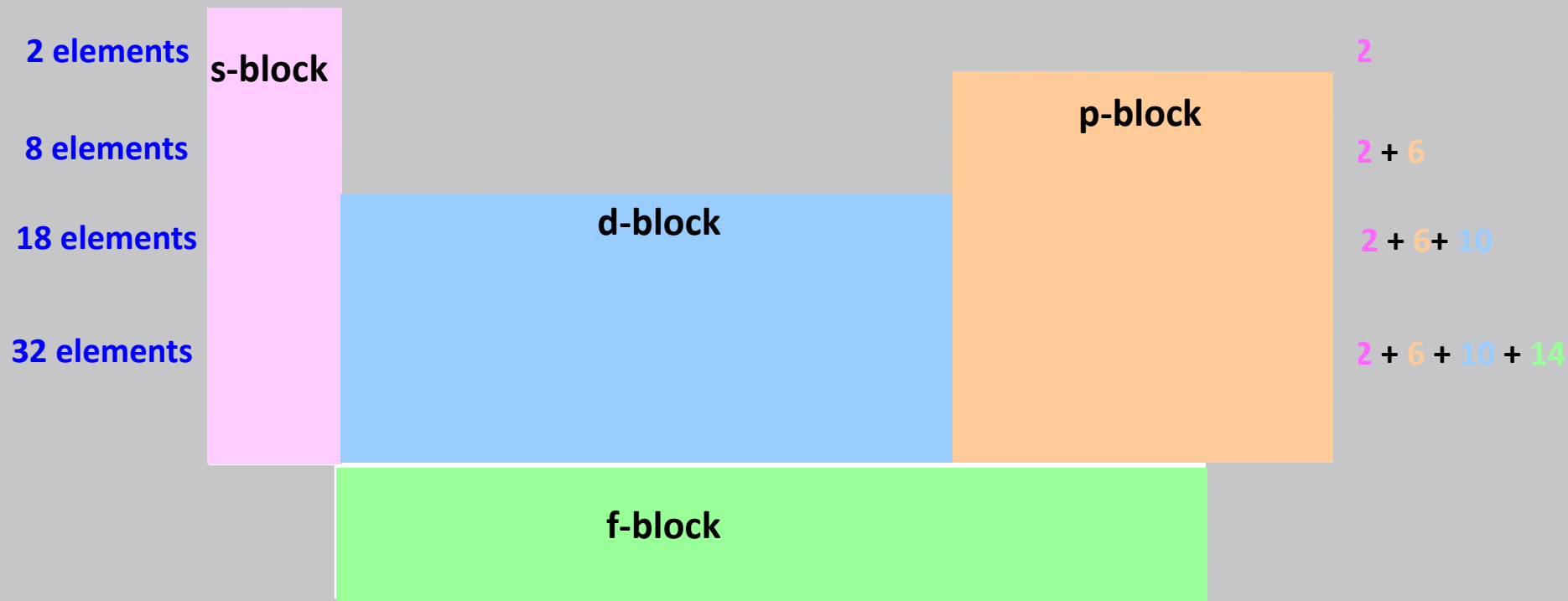


$$2n^2$$

numbers of **elements** in each row corresponds to the number of **electrons** that can be fitted in this row



PERIODIC TABLE BLOCKS



The **rows** correspond to the number of **shells** or energy levels in the atom

The **blocks** correspond to the type and number of **subshells** that electrons can be put on



Shell

n=1

n=2

n=3

n=4

Subshell

s

s + p

s + p + d

s + p + d + f

ELECTRON CONFIGURATION

s-block

1s	H 1	He 2
2s	Li 3	Be 4
3s	Na 11	Mg 12
4s	K 19	Ca 20
5s	Rb 37	Sr 38
6s	Cs 55	Ba 56
7s	Fr 87	Ra 88

2s¹

d-block

3d	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30
4d	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48
5d	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80
6d	Ac 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112

4d⁵

p-block

2p	B 5	C 6	N 7	O 8	F 9	Ne 10
3p	Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
4p	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
5p	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
6p	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
7p	Nh 113	Fl 114	Mc 115	Lv 116	Ts 117	Og 118

3p³

f-block

4f	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
5f	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103

5f¹⁰

s-block starts in period 1
p-block starts in period 2

d-block starts in period 3
f-block starts in period 4



<https://www.rsc.org/periodic-table>

ELECTRON CONFIGURATION

s-block

1s	H 1	He 2
2s	Li 3	Be 4
3s	Na 11	Mg 12
4s	K 19	Ca 20
5s	Rb 37	Sr 38
6s	Cs 55	Ba 56
7s	Fr 87	Ra 88

H $1s^1$
He $1s^2$
Li $1s^2 2s^1$
Be $1s^2 2s^2$

d-block

3d	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30
4d	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48
5d	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80
6d	Ac 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112

p-block

2p	B 5	C 6	N 7	O 8	F 9	Ne 10
3p	Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
4p	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
5p	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
6p	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
7p	Nh 113	Fl 114	Mc 115	Lv 116	Ts 117	Og 118

B $1s^2 2s^2 2p^1$
C $1s^2 2s^2 2p^2$
N $1s^2 2s^2 2p^3$
O $1s^2 2s^2 2p^4$
F $1s^2 2s^2 2p^5$
Ne $1s^2 2s^2 2p^6$

f-block

4f	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
5f	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103



<https://www.rsc.org/periodic-table>

ORBITALS

orbital – volume of space in which an electron is probably found

s subshell

1 s orbital

p subshell

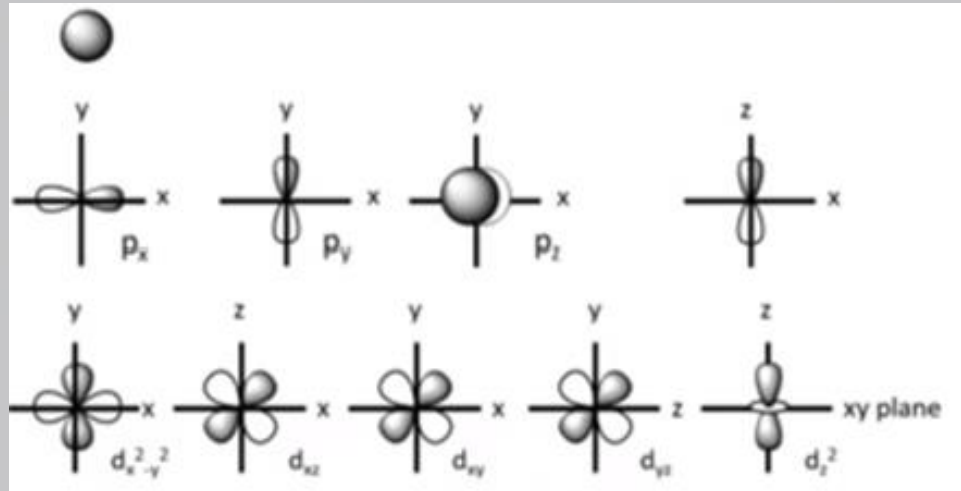
3 p orbitals

d subshell

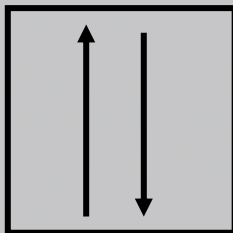
5 d orbitals

f subshell

7 f orbitals



<https://pixels.com/featured/4f-electron-orbitals-general-set-dr-mark-j-winter.html>



Pauli's exclusion principle – no more than two electrons may occupy any given orbital. If two electrons occupy the same orbital their spins must be paired.



ELECTRON CONFIGURATION – ROW 1 and 2

s-block

1s	H 1	He 2
2s	Li 3	Be 4
3s	Na 11	Mg 12
4s	K 19	Ca 20
5s	Rb 37	Sr 38
6s	Cs 55	Ba 56
7s	Fr 87	Ra 88

H $1s^1$

He $1s^2$

Li $1s^2 2s^1$

Be $1s^2 2s^2$

d-block

3d	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30
4d	Y 39	Zr 40	Nb 41	Mo 42	Tc 43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48
5d	La 57	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80
6d	Ac 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109	Ds 110	Rg 111	Cn 112

p-block

2p	B 5	C 6	N 7	O 8	F 9	Ne 10
3p	Al 13	Si 14	P 15	S 16	Cl 17	Ar 18
4p	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36
5p	In 49	Sn 50	Sb 51	Te 52	I 53	Xe 54
6p	Tl 81	Pb 82	Bi 83	Po 84	At 85	Rn 86
7p	Nh 113	Fl 114	Mc 115	Lv 116	Ts 117	Og 118

f-block

4f	Ce 58	Pr 59	Nd 60	Pm 61	Sm 62	Eu 63	Gd 64	Tb 65	Dy 66	Ho 67	Er 68	Tm 69	Yb 70	Lu 71
5f	Th 90	Pa 91	U 92	Np 93	Pu 94	Am 95	Cm 96	Bk 97	Cf 98	Es 99	Fm 100	Md 101	No 102	Lr 103

B $1s^2 2s^2 2p^1$

C $1s^2 2s^2 2p^2$

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

O $1s^2 2s^2 2p^4$

F $1s^2 2s^2 2p^5$

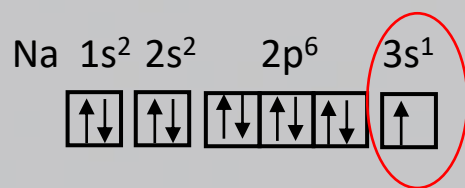
Ne $1s^2 2s^2 2p^6$

Hund's Rule – If more than one orbital in subshell is available, electrons will fill empty orbitals before pairing in one of them

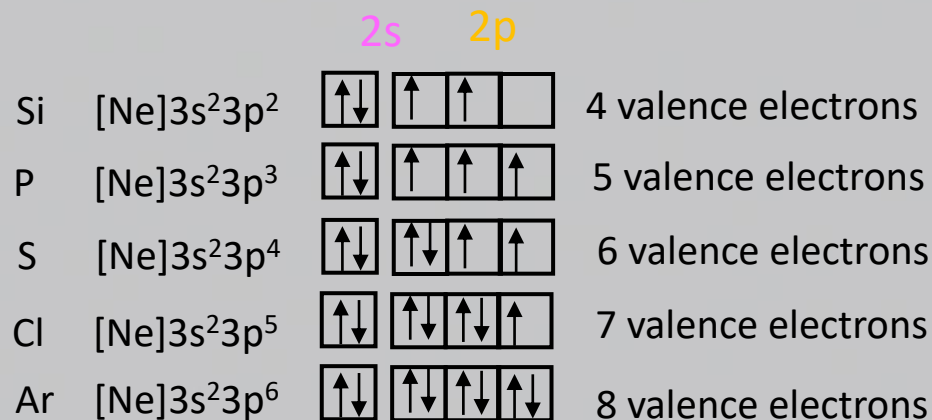
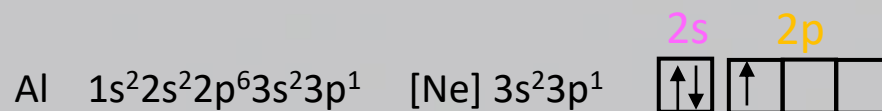


THIRD ROW AND SHORTHAND

s-block												p-block							
1s	H 1	He 2																	
2s	Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10	2p
3s	Na 11	Mg 12											Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	3p
4s	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	4p
		d-block																	



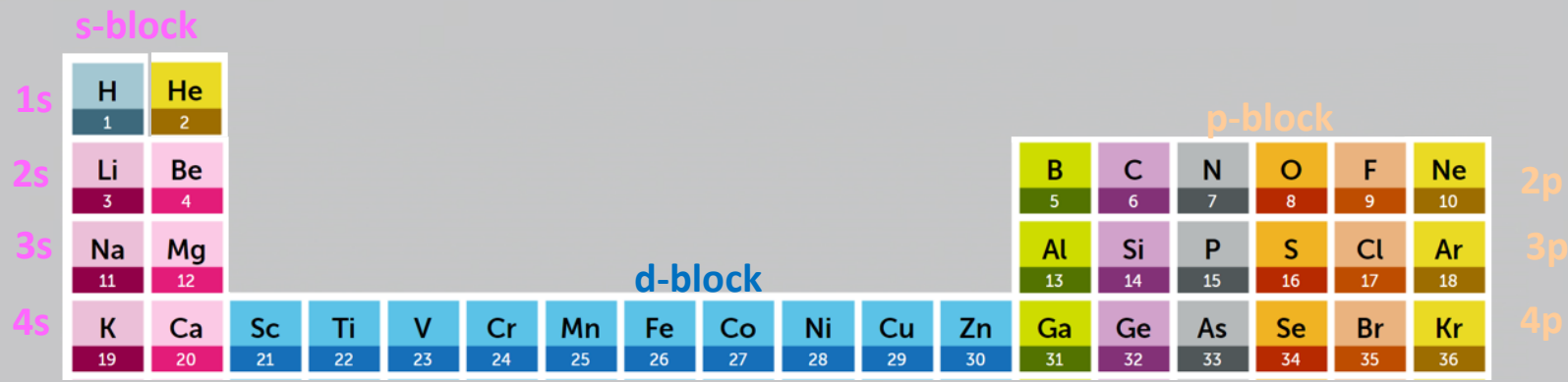
Valence electrons - electrons in the outermost shell



In shorthand method only **valence electrons** are shown



FOURTH ROW AND SHORTHAND



4s

K [Ar] 4s¹ ↑ 1 valence electron

Ca [Ar] 4s² ↑↓ 2 valence electron

3d

Sc [Ar] 4s² 3d¹ ↑↓ ↑ 1 unpaired e⁻

Ti [Ar] 4s² 3d² ↑↓ ↑ ↑ 2 unpaired e⁻

V [Ar] 4s² 3d³ ↑↓ ↑ ↑ ↑ 3 unpaired e⁻

Cr [Ar] 4s² 3d⁴ ↑↓ ↑ ↑ ↑ ↑ 4 unpaired e⁻
[Ar] 4s¹ 3d⁵ ↑ ↑ ↑ ↑ ↑ ↑ 6 unpaired e⁻

Half filled d subshell

4s 3d

Mn [Ar] 4s² 3d⁵ ↑↓ ↑ ↑ ↑ ↑ ↑ 5 unpaired e⁻

Fe [Ar] 4s² 3d⁶ ↑↓ ↑↓ ↑ ↑ ↑ ↑ 4 unpaired e⁻

Co [Ar] 4s² 3d⁷ ↑↓ ↑↓ ↑↓ ↑ ↑ ↑ 3 unpaired e⁻

Ni [Ar] 4s² 3d⁸ ↑↓ ↑↓ ↑↓ ↑↓ ↑ ↑ 2 unpaired e⁻

Cu [Ar] 4s² 3d⁹ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑ 1 unpaired e⁻
[Ar] 4s¹ 3d¹⁰ ↑ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 1 unpaired e⁻

Full d subshell

Zn [Ar] 4s² 3d¹⁰ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ 0 unpaired e⁻



FOURTH ROW AND VARIATIONS

1s	H 1	He 2											p-block						
2s	Li 3	Be 4											B 5	C 6	N 7	O 8	F 9	Ne 10	2p
3s	Na 11	Mg 12	d-block										Al 13	Si 14	P 15	S 16	Cl 17	Ar 18	3p
4s	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35	Kr 36	4p

		4s	3d	4p	
Ga	[Ar] 4s ² 3d ¹⁰ 4p ¹	↑↓	↑↓↑↓↑↓↑↓↑↓	↑	3 valence electrons
Ge	[Ar] 4s ² 3d ¹⁰ 4p ²	↑↓	↑↓↑↓↑↓↑↓↑↓	↑↑	4 valence electrons
As	[Ar] 4s ² 3d ¹⁰ 4p ³	↑↓	↑↓↑↓↑↓↑↓↑↓	↑↑↑	5 valence electrons
Se	[Ar] 4s ² 3d ¹⁰ 4p ⁴	↑↓	↑↓↑↓↑↓↑↓↑↓	↑↓↑↑	6 valence electrons
Br	[Ar] 4s ² 3d ¹⁰ 4p ⁵	↑↓	↑↓↑↓↑↓↑↓↑↓	↑↓↑↓↑	7 valence electrons
Kr	[Ar] 4s ² 3d ¹⁰ 4p ⁶	↑↓	↑↓↑↓↑↓↑↓↑↓	↑↓↑↓↑↓	8 valence electrons

Valence electrons – only shell 4 (outermost)



Question 1

Calculate the energy of a photon released when an electron in a hydrogen atom moves from the $n = 6$ orbit to the $n = 3$. $R = 2.18 \times 10^{-18} \text{ J}$.

- A. $1.82 \times 10^{-19} \text{ J}$
- B. $7.57 \times 10^{-20} \text{ J}$
- C. $4.91 \times 10^{-20} \text{ J}$
- D. $1.55 \times 10^{-19} \text{ J}$

Question 2

An x-ray has a wavelength of $1.2 \text{ \AA}$. Calculate the energy, in J, of one photon of this radiation.

- A. 1.7×10^{-20}
- B. 1.2
- C. 1.7×10^{-5}
- D. 1.7×10^{-15}
- E. 1.2×10^{-10}

Question 3

How many unpaired electrons are present in the ground-state electron configuration of an iron atom?

- A. 4 B. 2 C. 3 D. 5 E. 1

Question 4

What is the electron configuration of Tc? Use full and shorthand notation.

Question 5

What is the electron configuration of chromium and copper? Use full and shorthand notation. Name the phenomena observed.

Question 6

An atom has 5 valence electrons – 2 are in an s-subshell and 3 in a p-subshell. Which group is the atom in?

- A. oxygen group
- B. boron group
- C. alkaline earth metals
- D. noble gases
- E. nitrogen group

Question 7

Carbon has two naturally occurring isotopes, ^{12}C (98%) and ^{13}C (2%). What is the average atomic mass?

