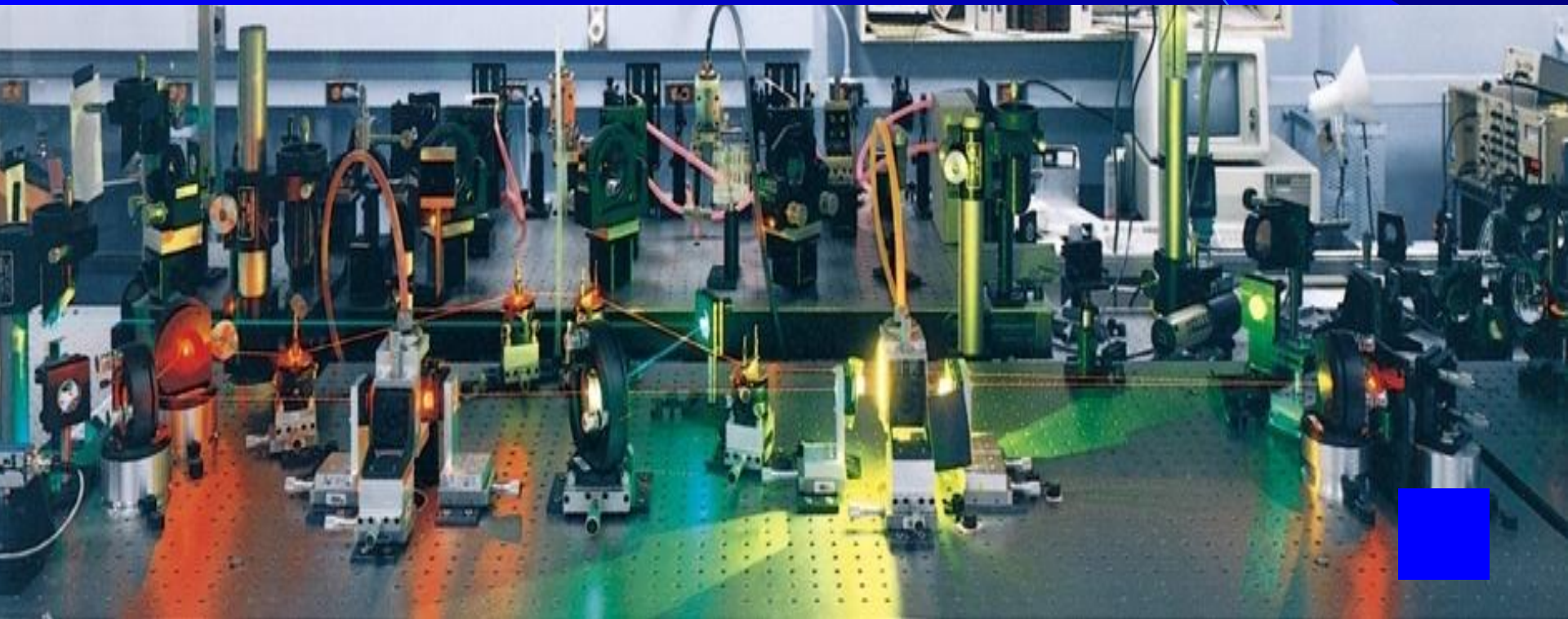
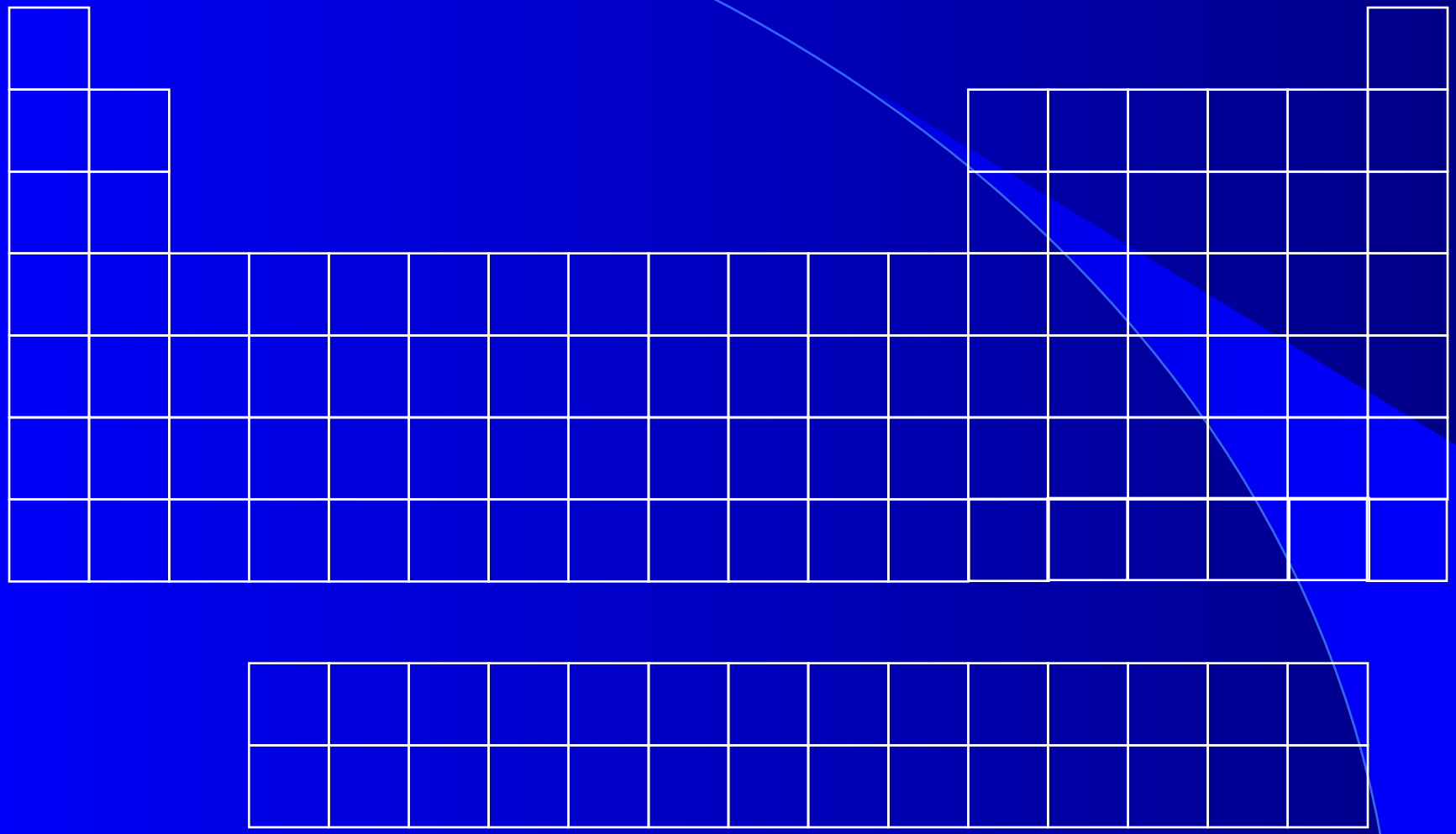
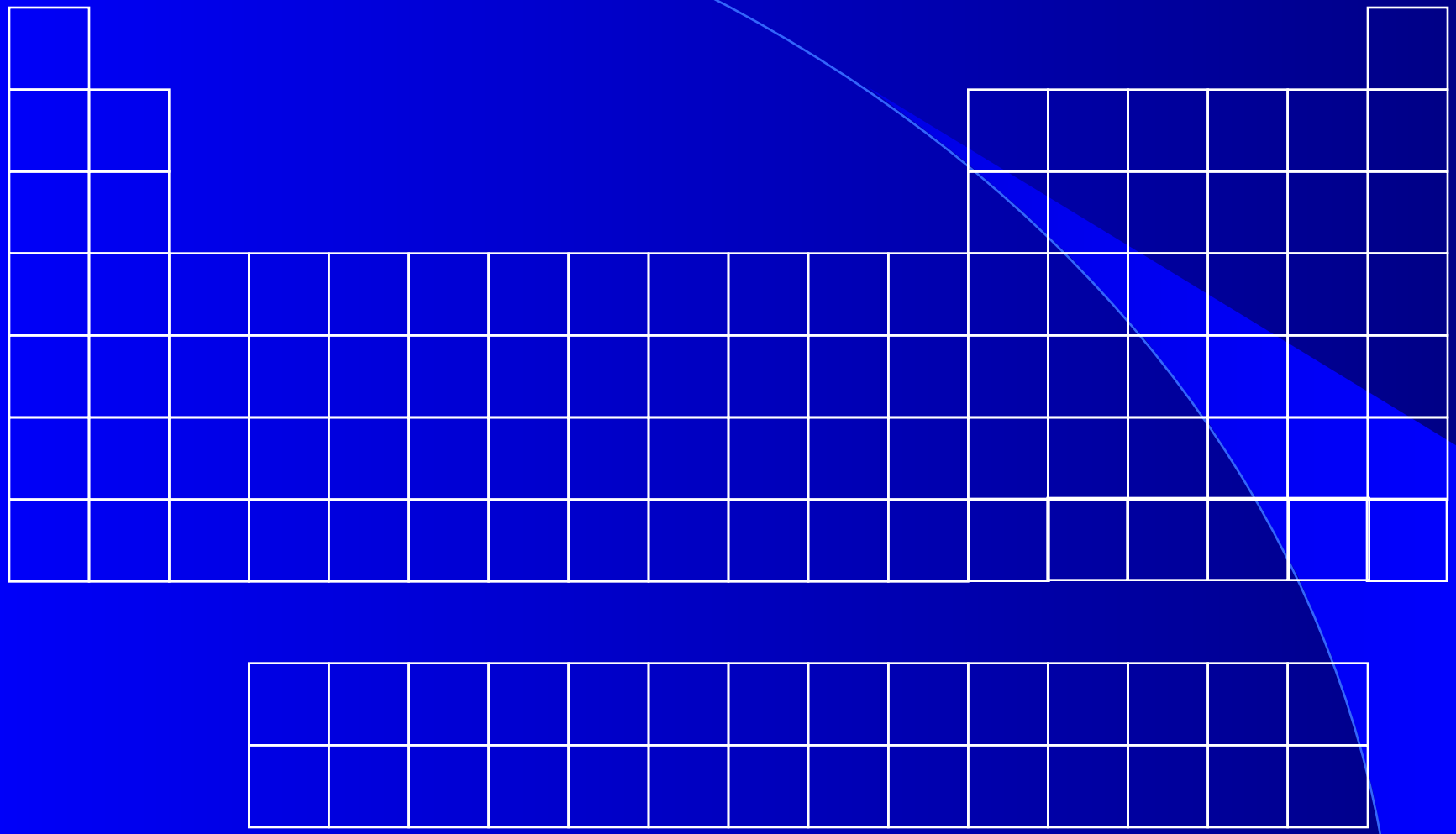
Quantum Theory and the Electronic Structure of Atoms (7)
&
Periodic Relationships Among the Elements (8)



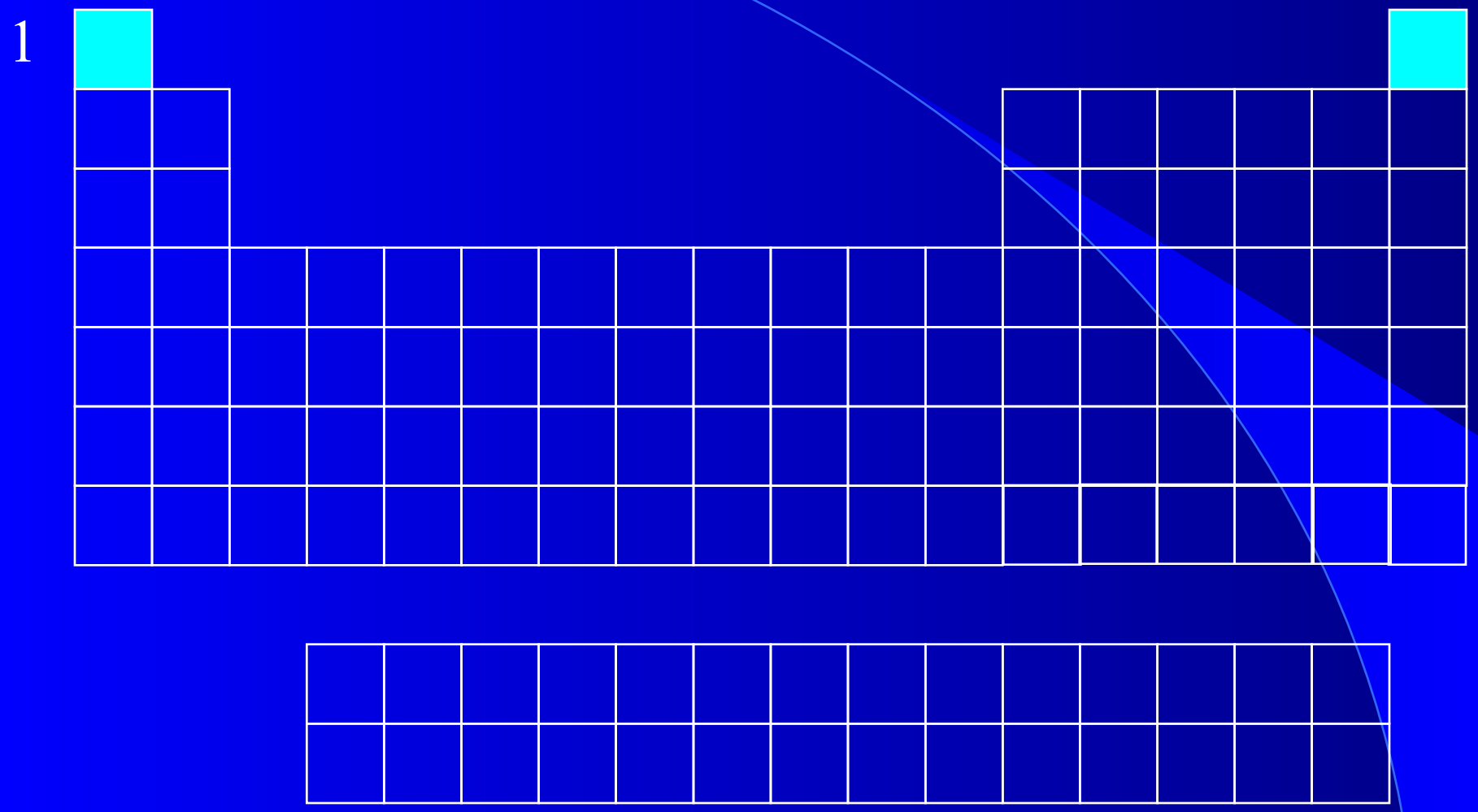
The Periodic Table



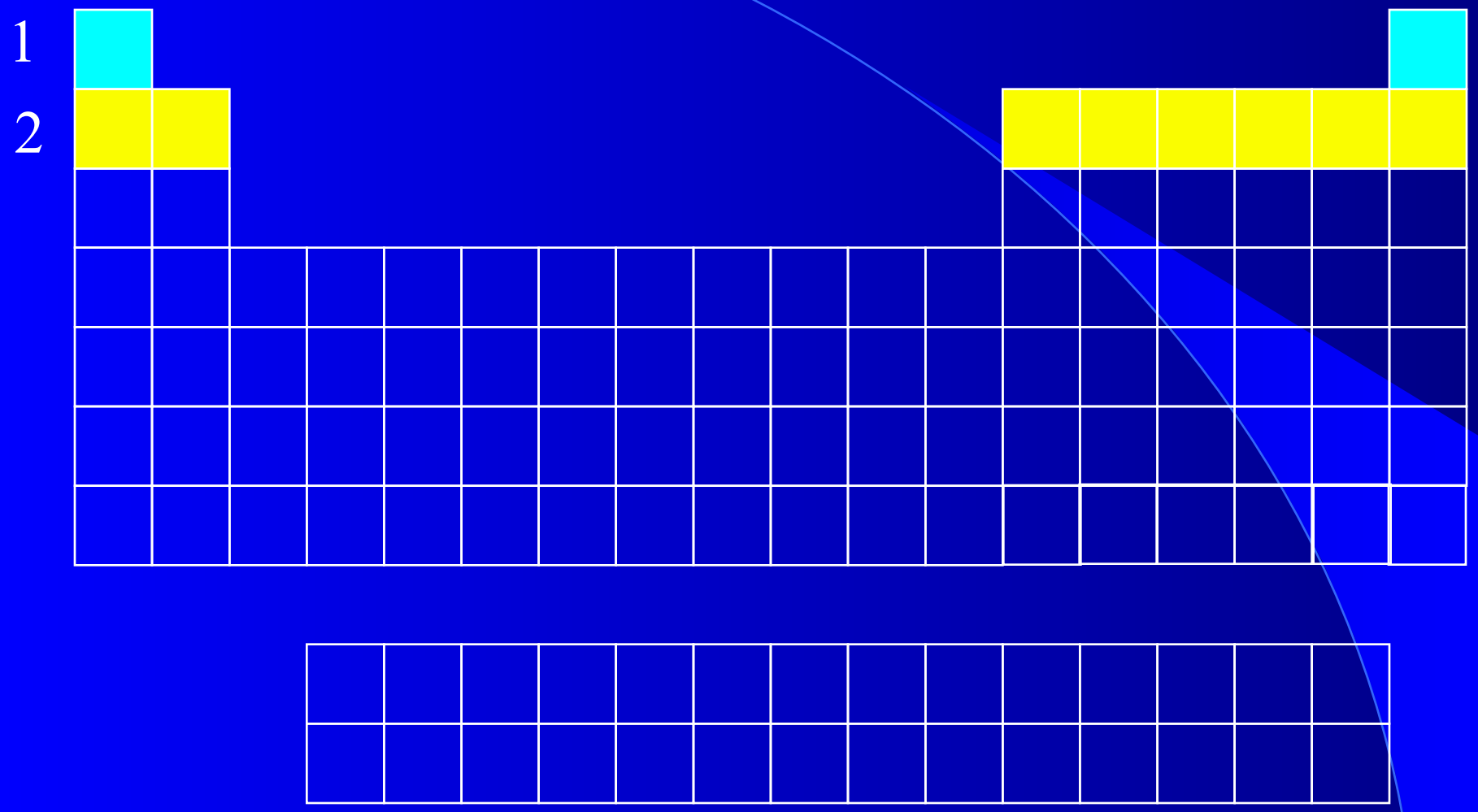
Each row is a period



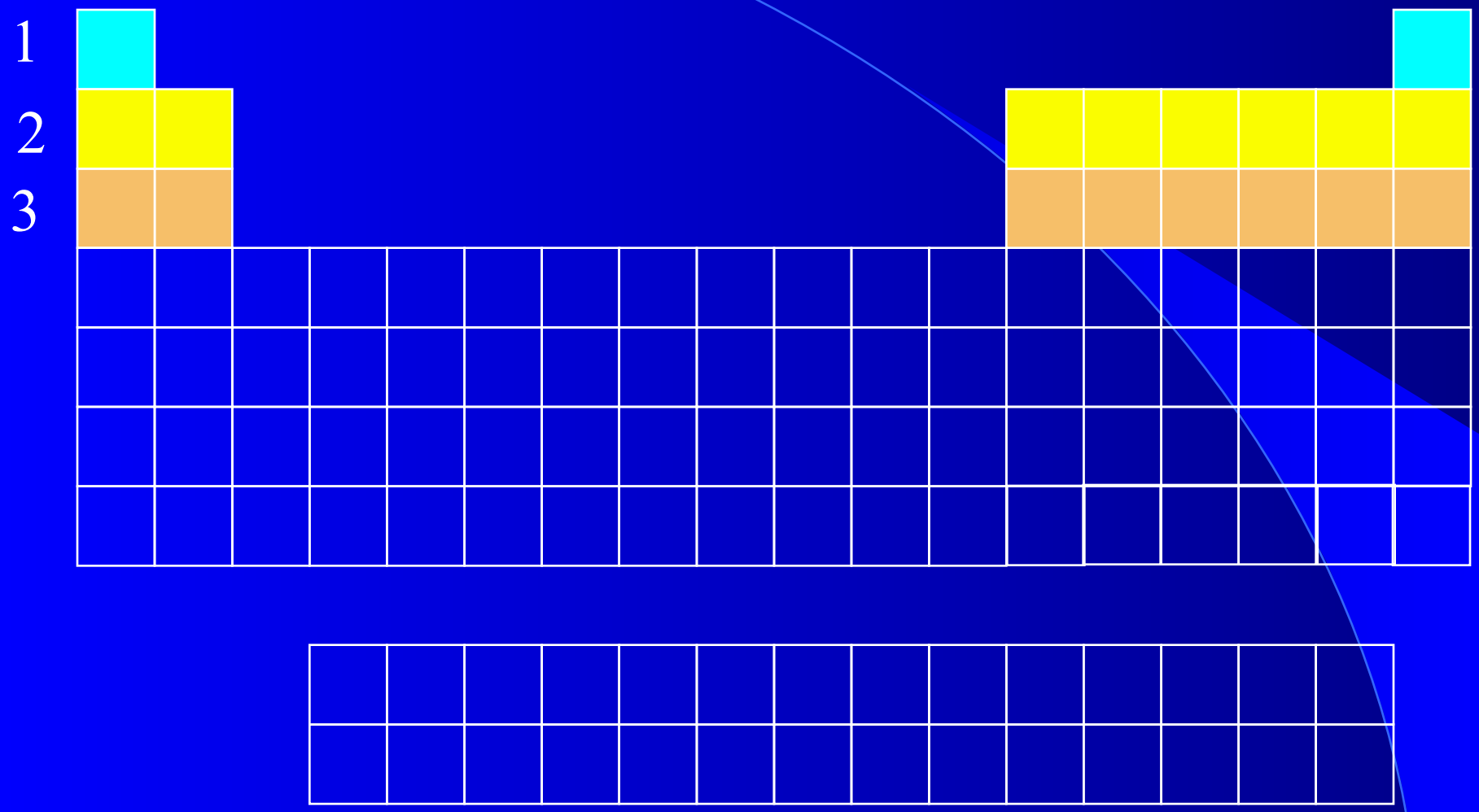
Each row is a period



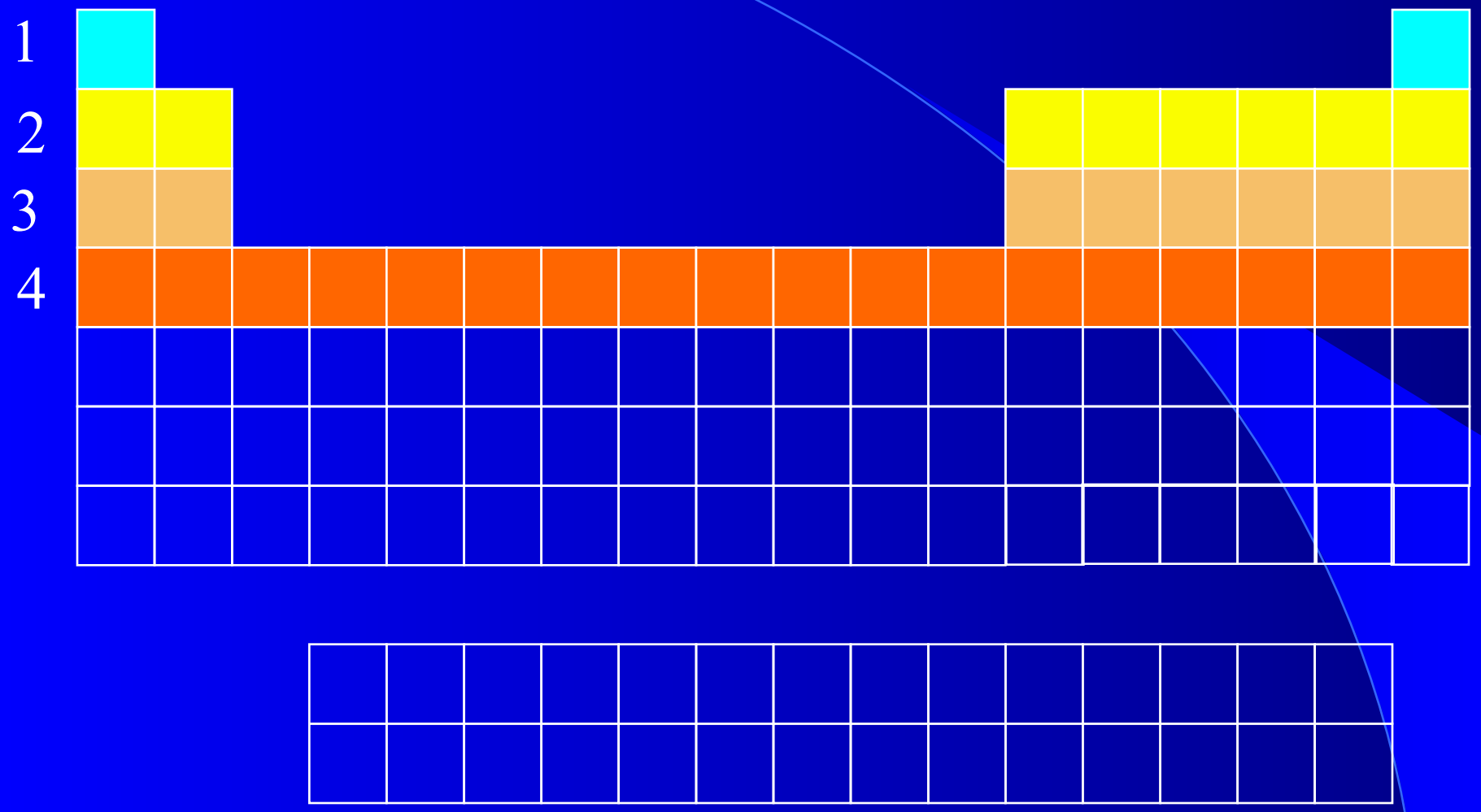
Each row is a period



Each row is a period



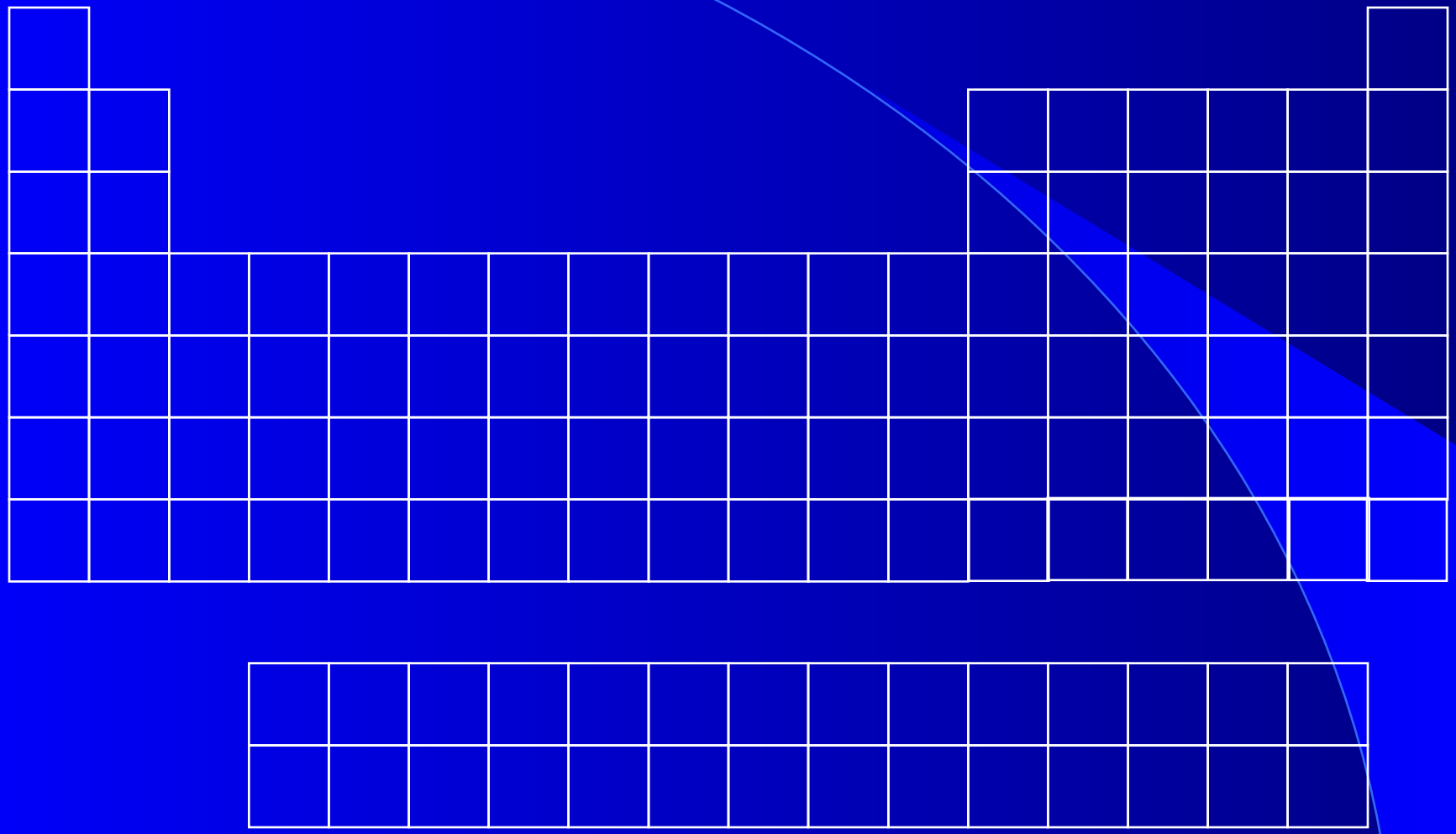
Each row is a period



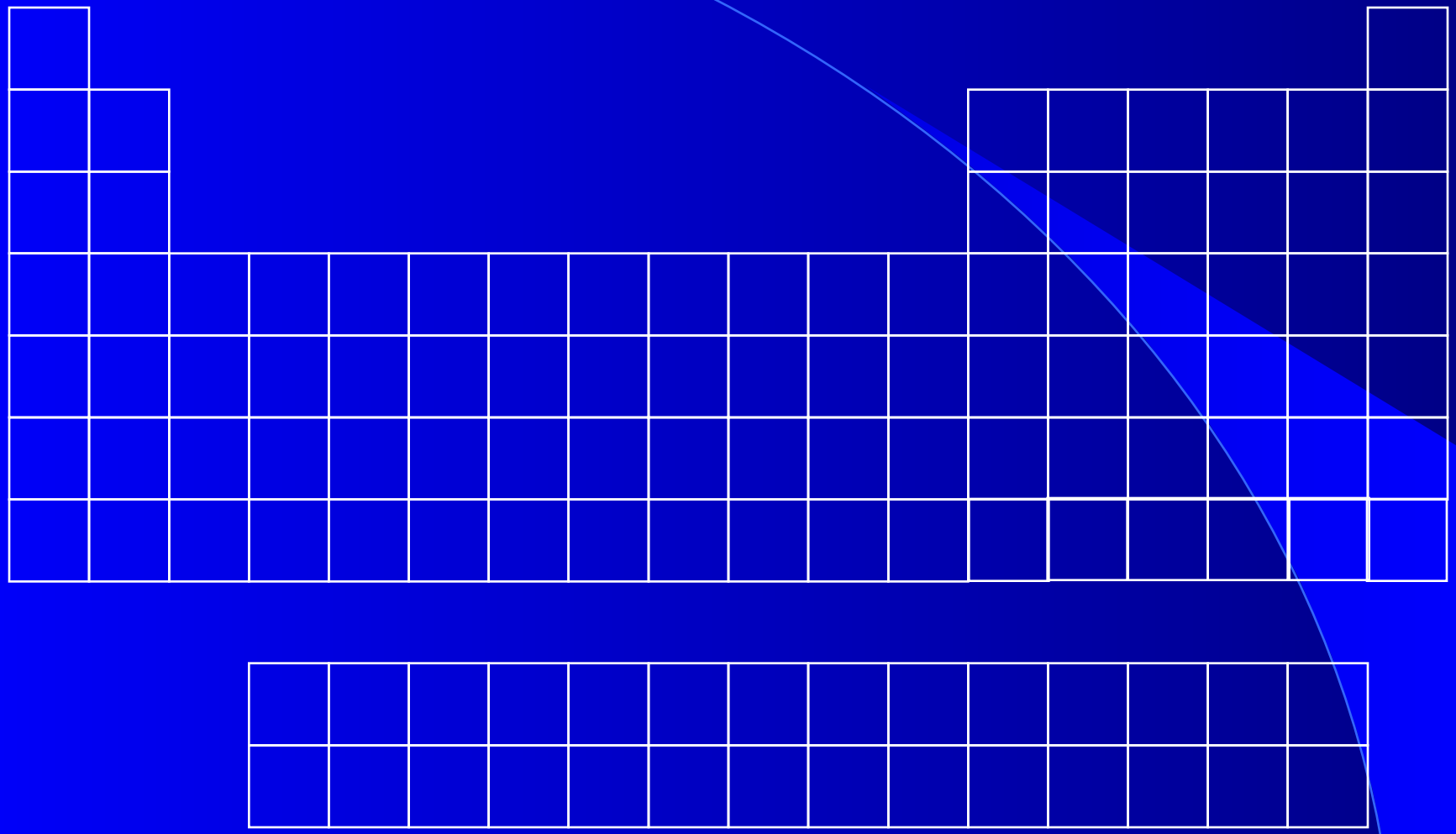
Each row is a period

Each row is a period

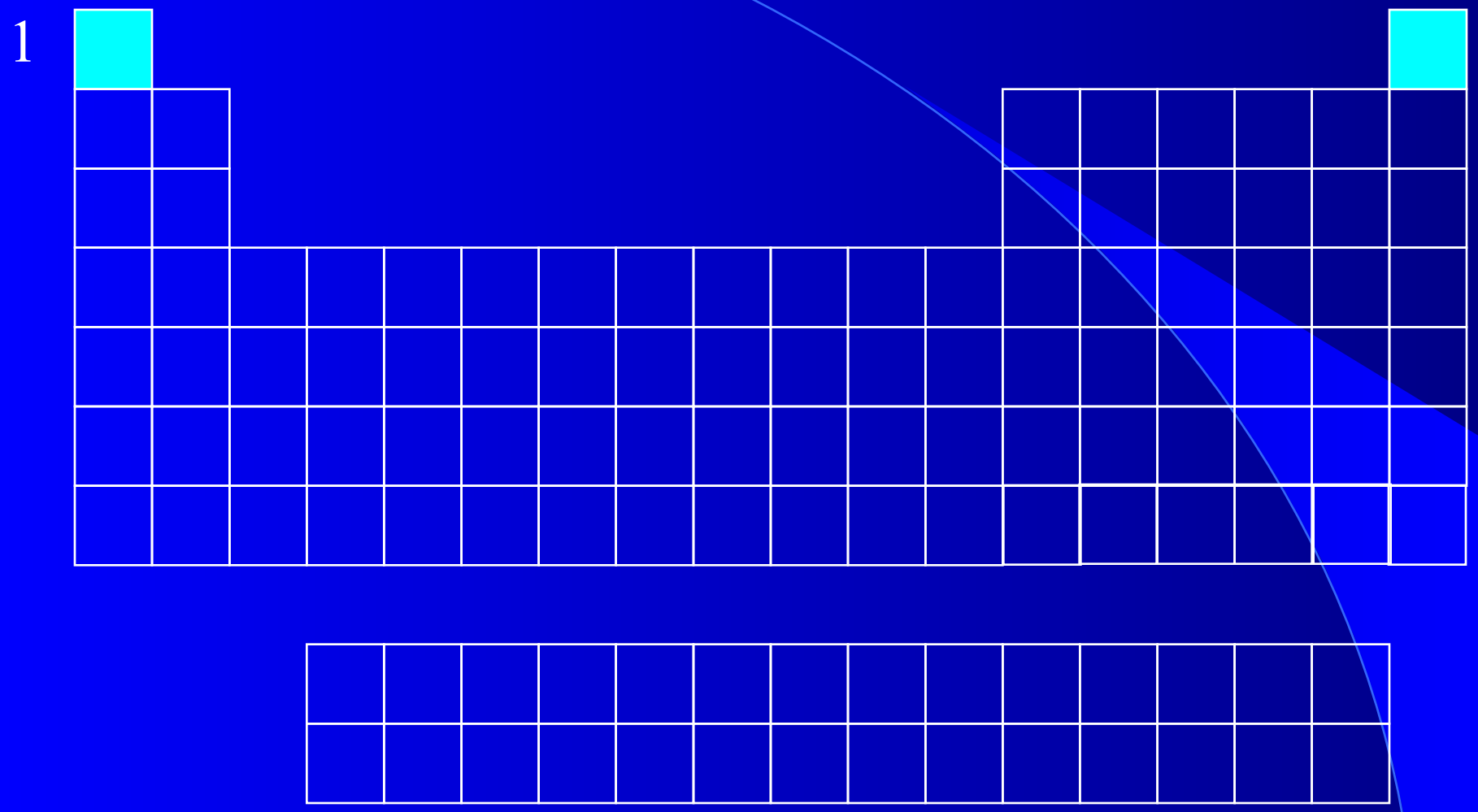
The Periodic Table



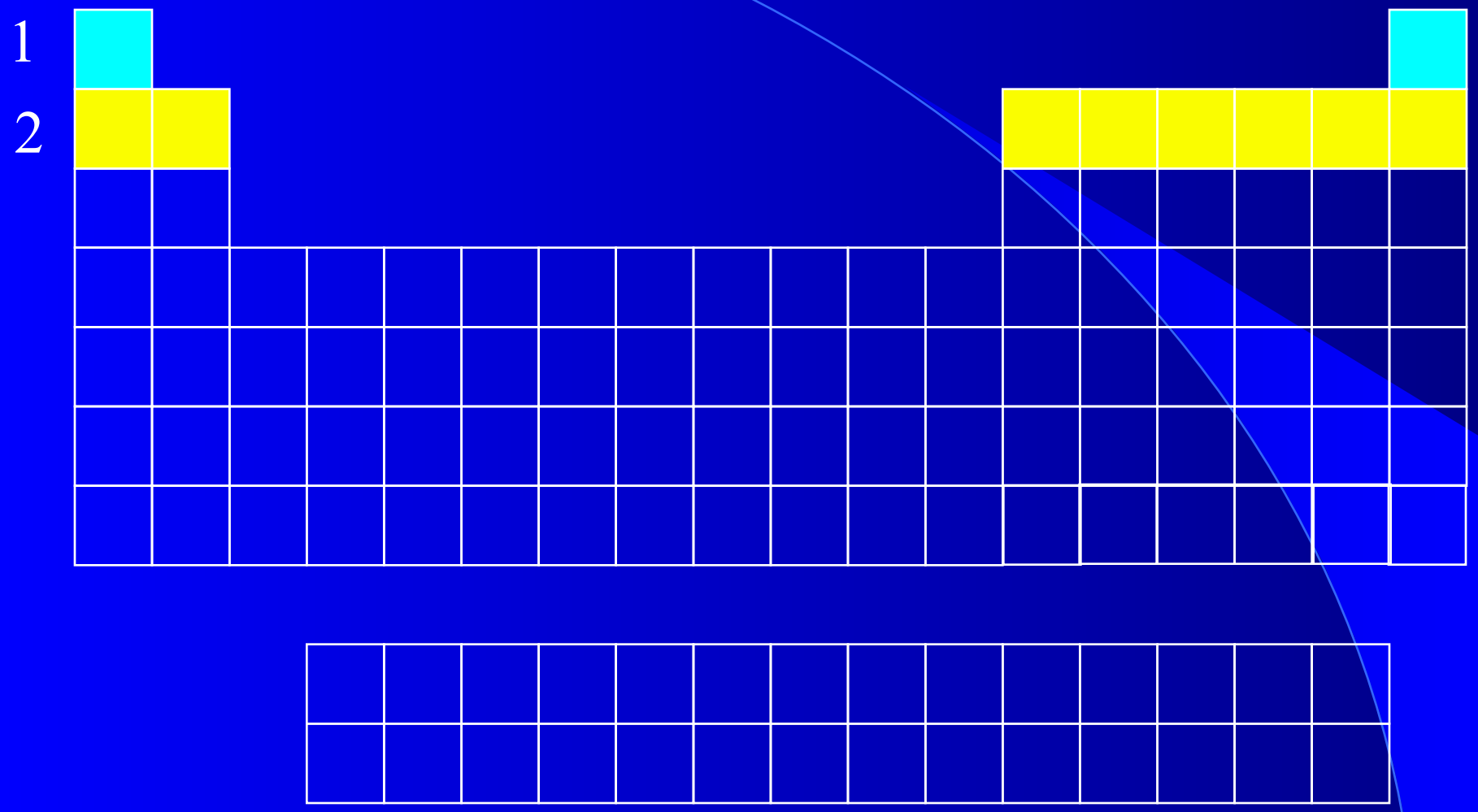
Each row is a period



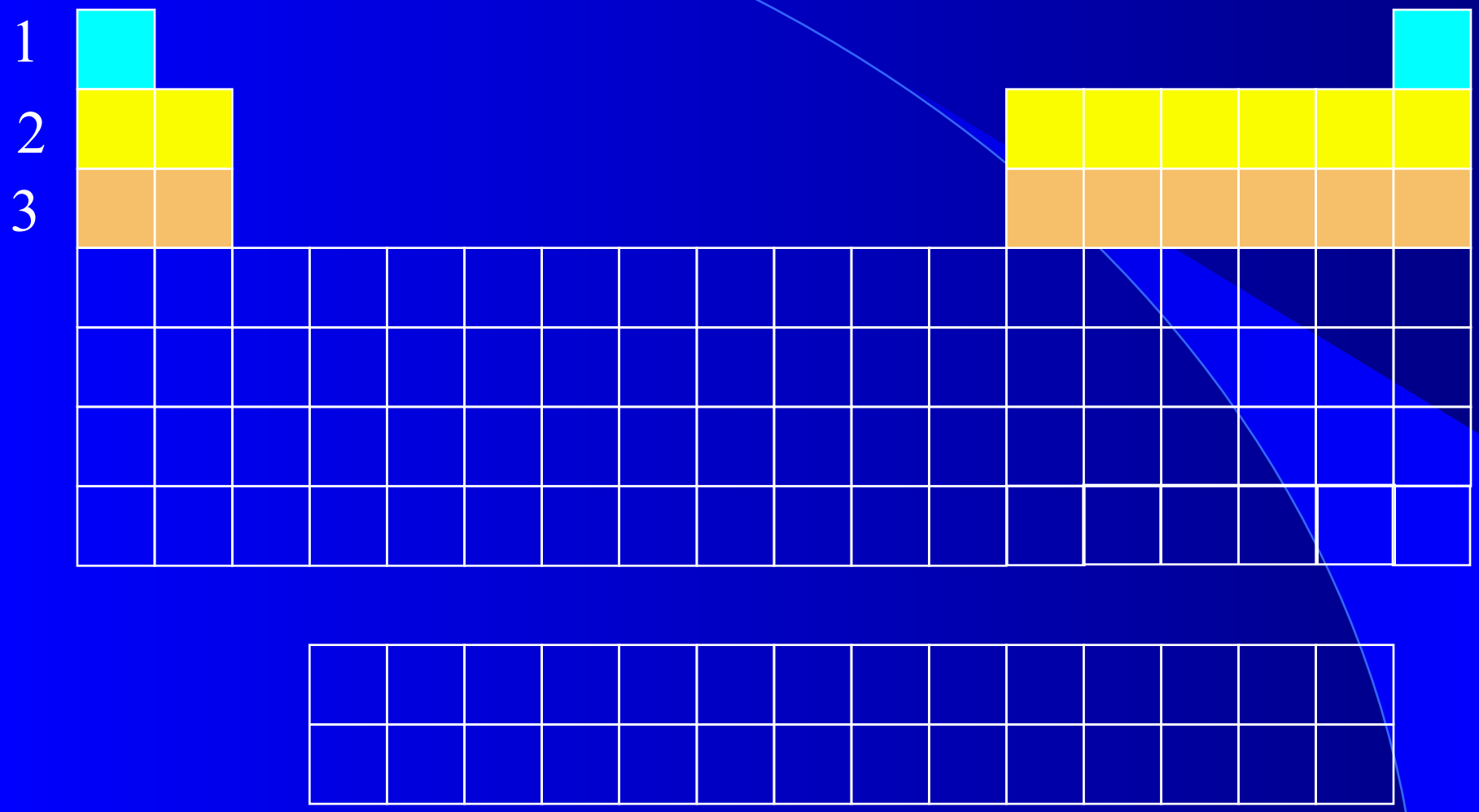
Each row is a period



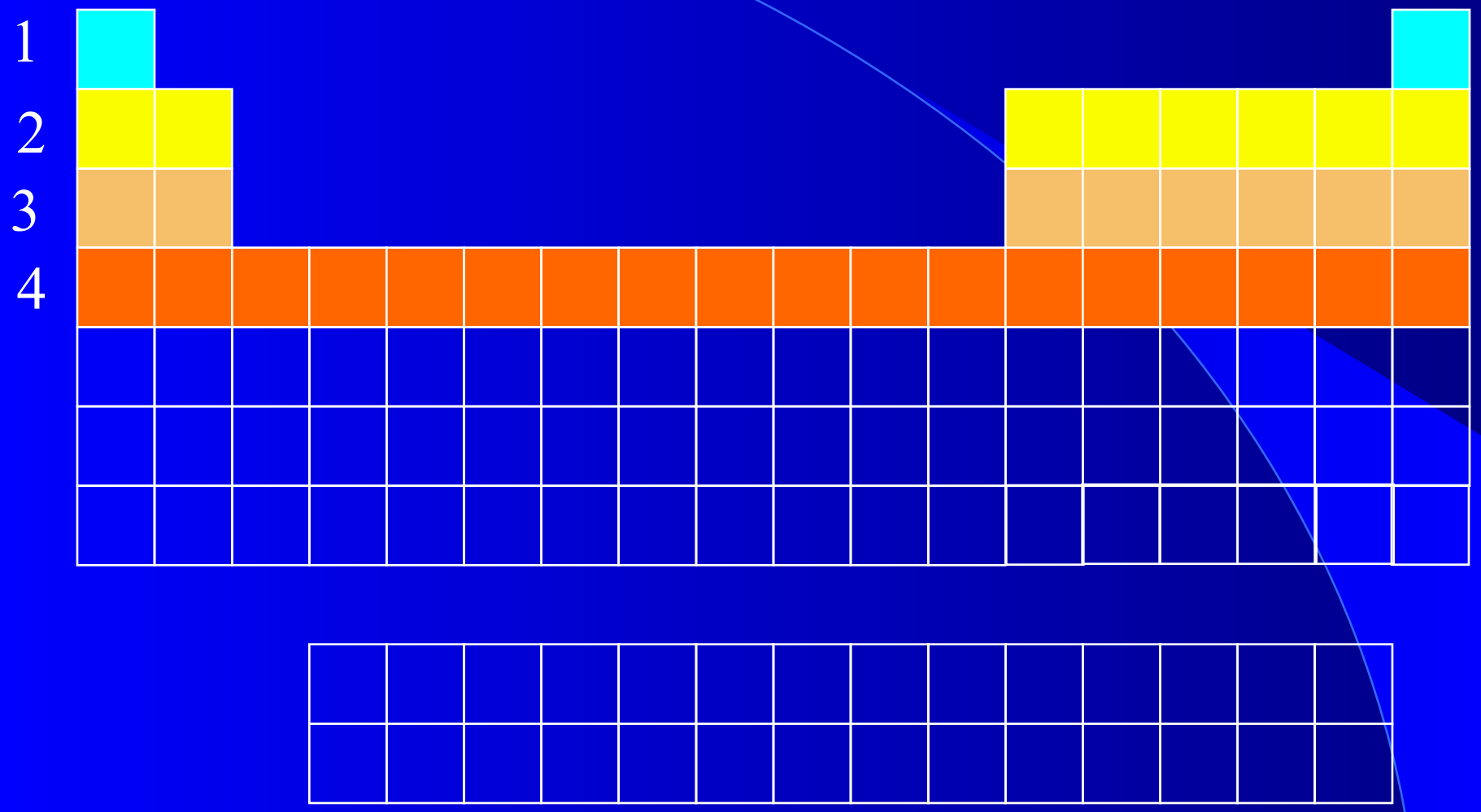
Each row is a period



Each row is a period



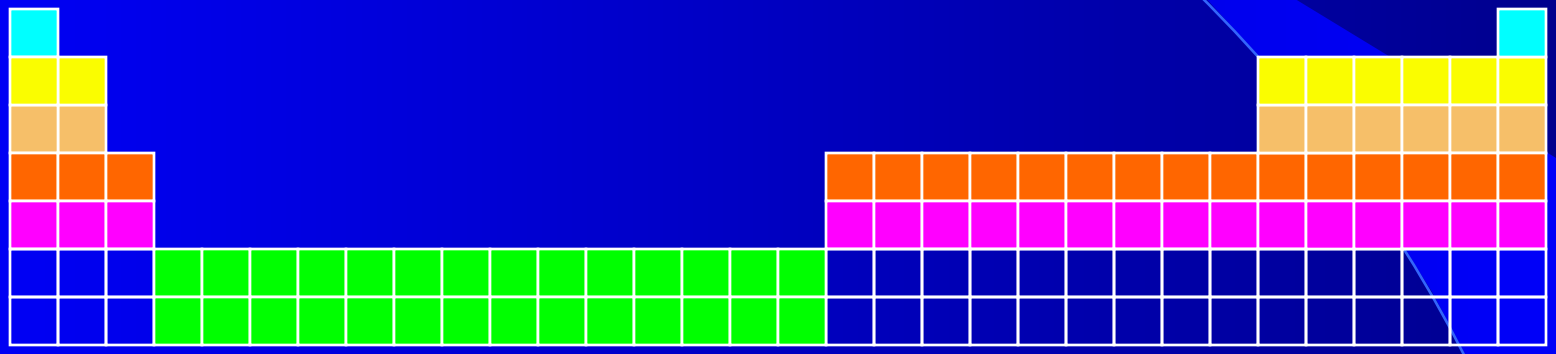
Each row is a period



Each row is a period

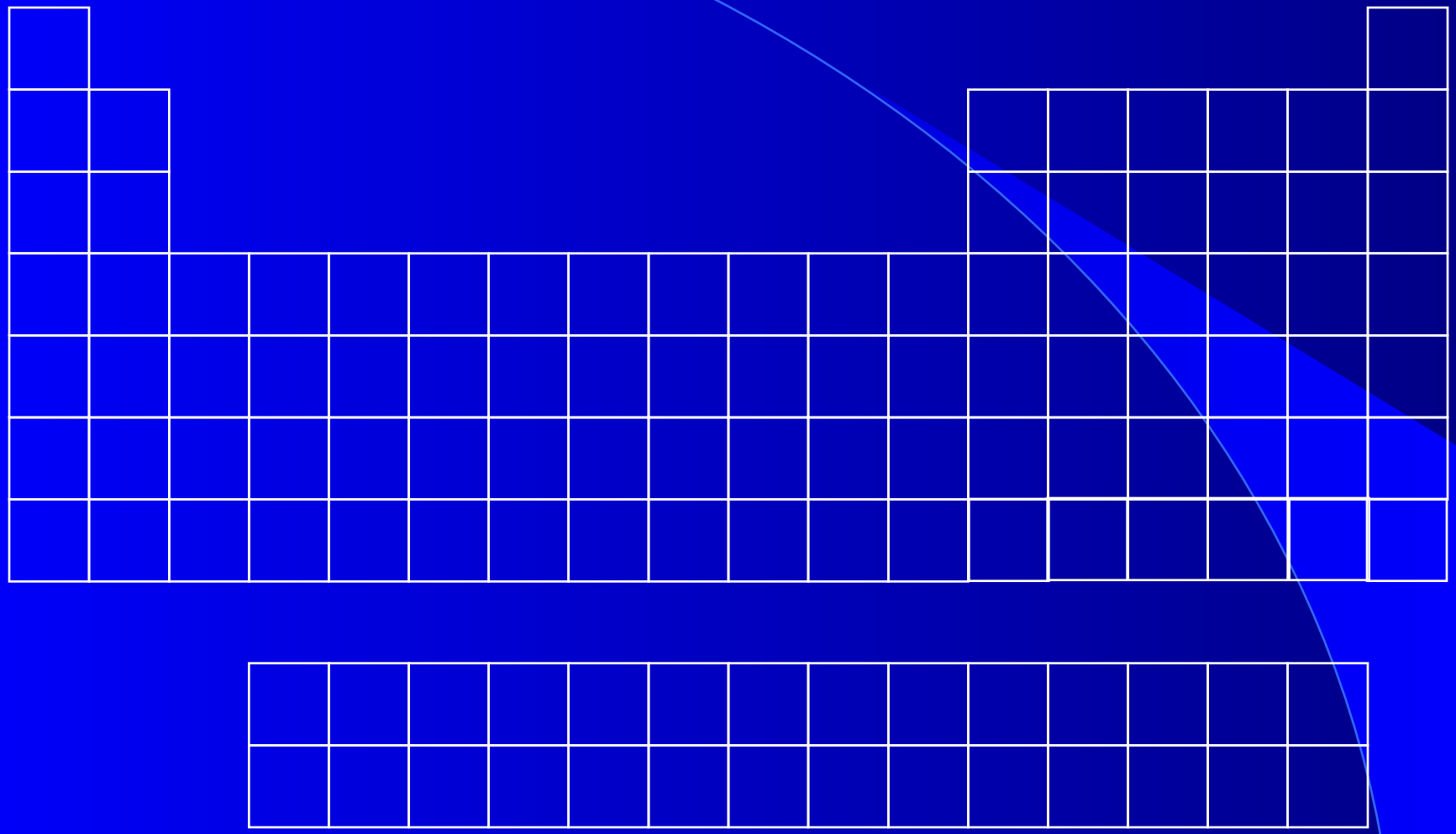
Each row is a period

The Periodic Table

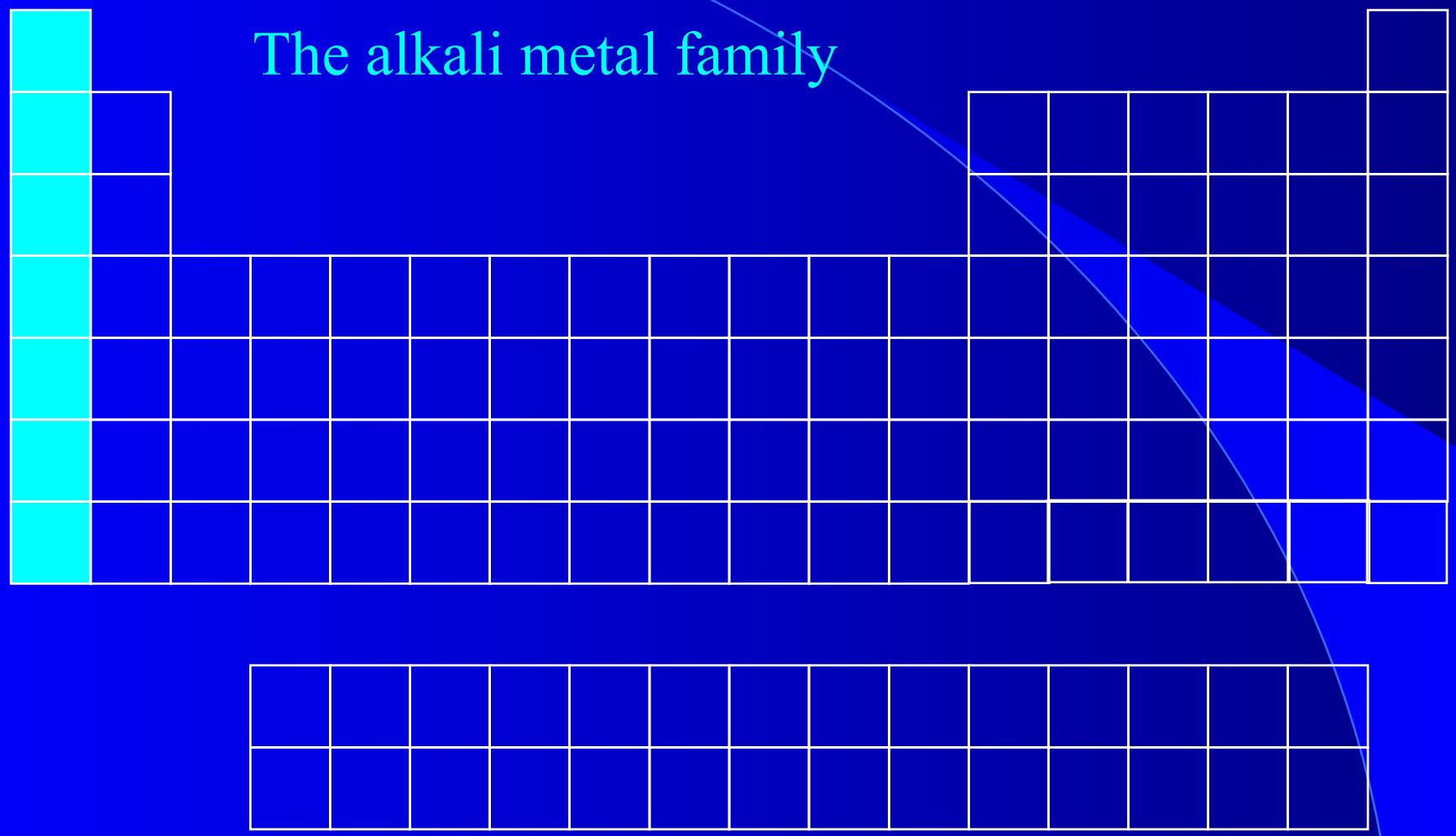


It’s not a convenient shape to print when inserted

Each column is a family



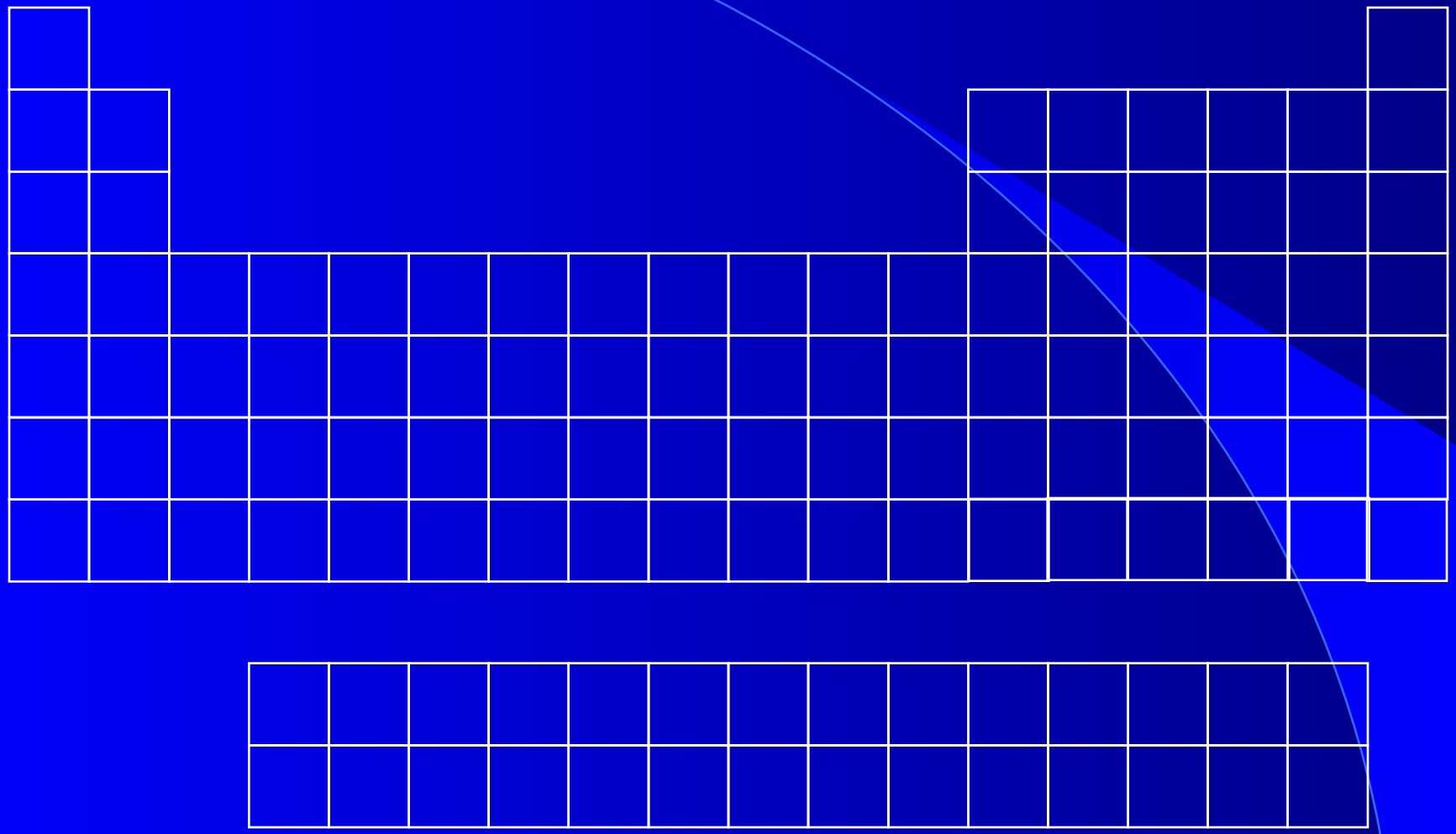
Each column is a family



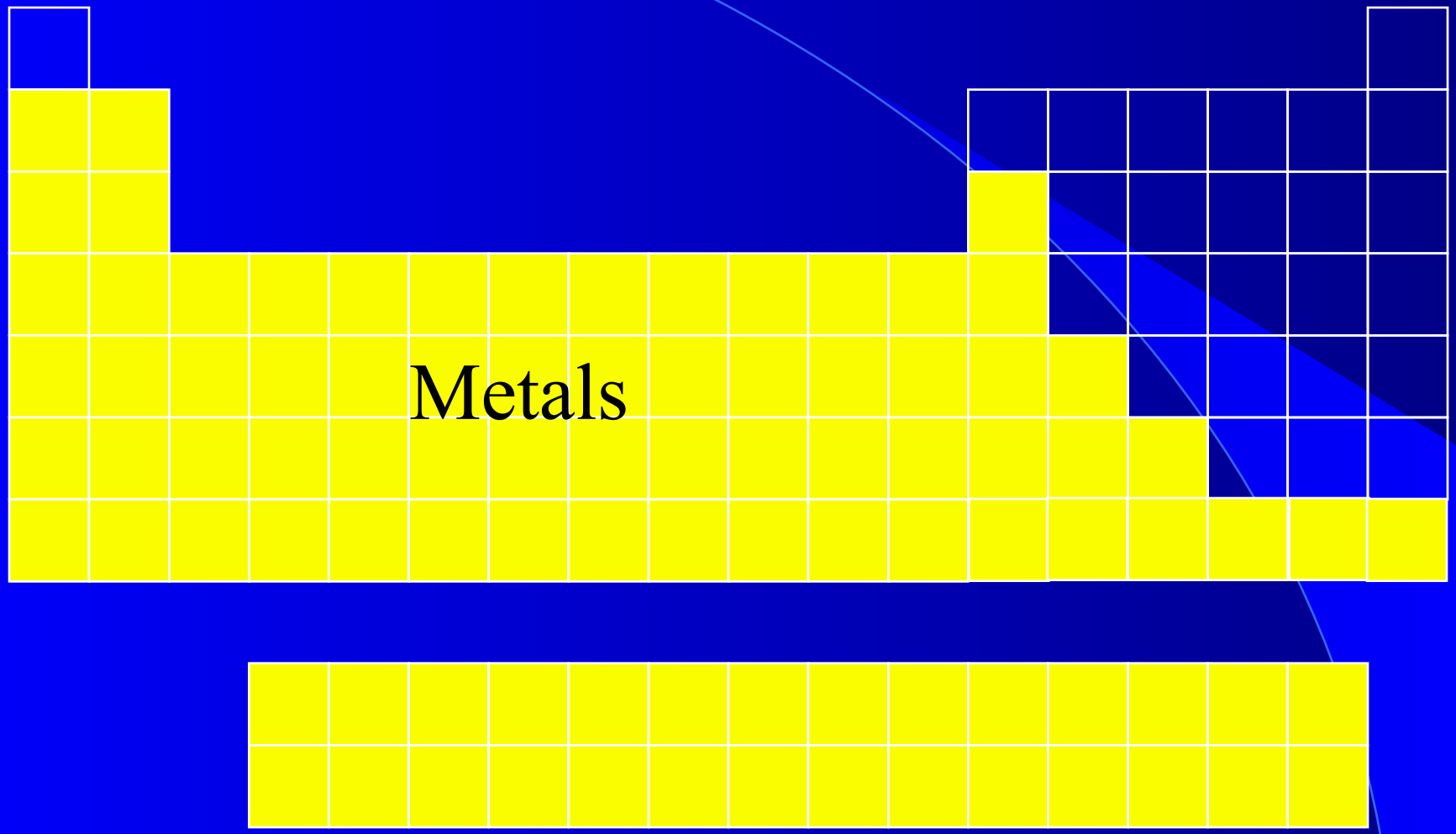
Element Families

- Elements in the same family exhibit similar properties
- Alkali metals are:
- soft shiny metals
- react violently with water to produce alkaline (basic) solutions
- http://www.youtube.com/watch?v=eCk0lYB_8c0
- never found in elemental form

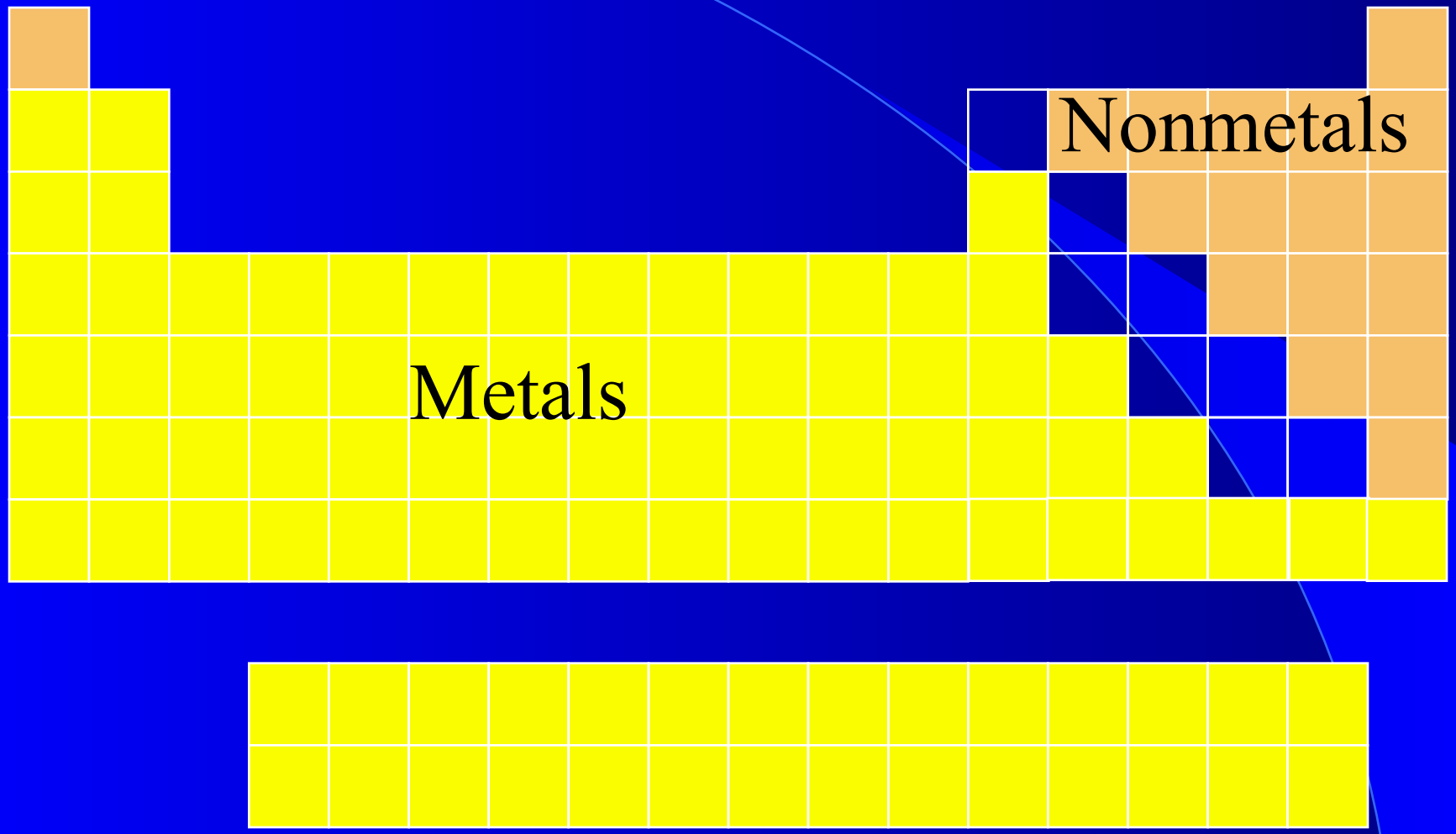
General categories



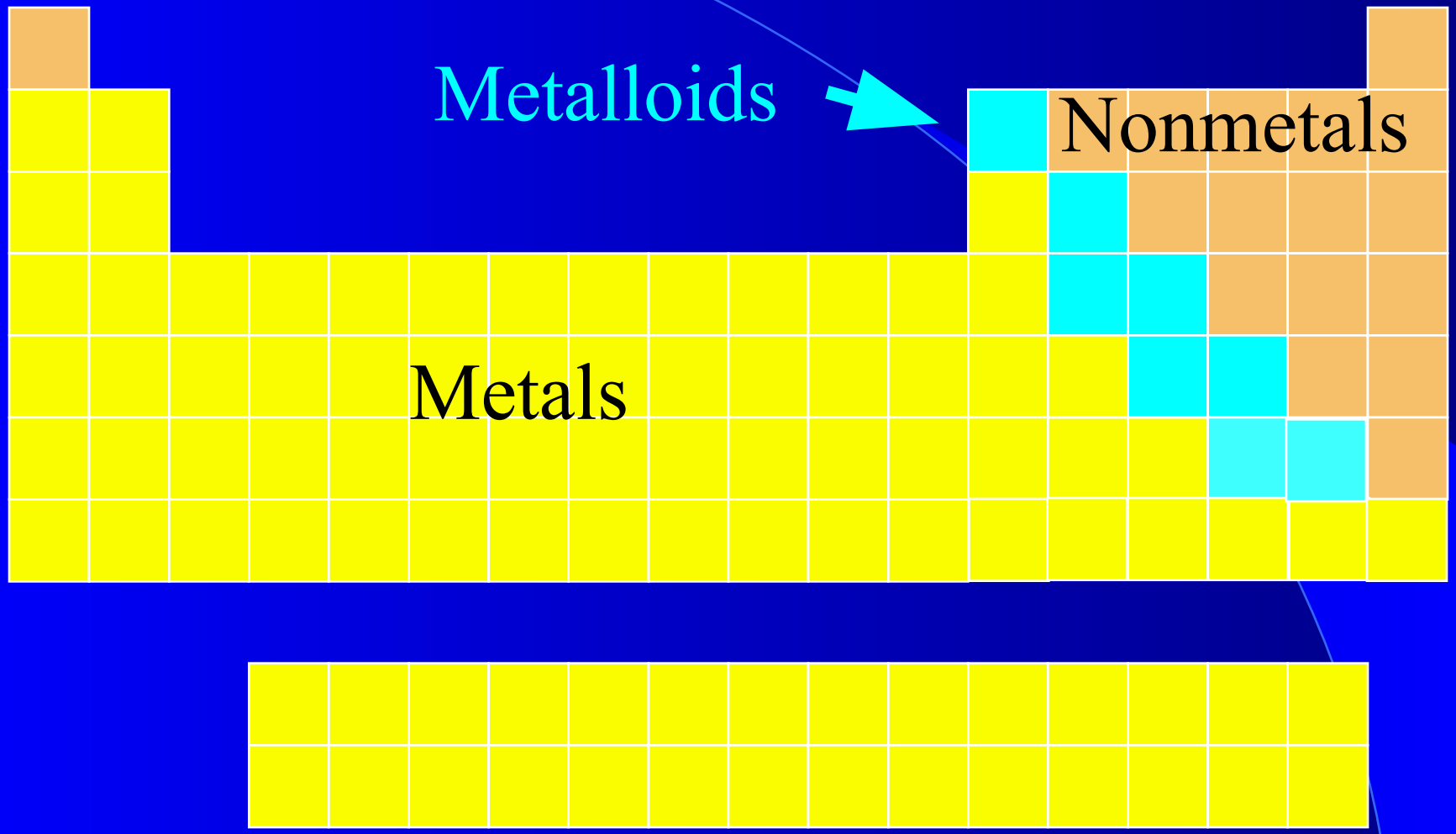
General categories



General categories



General categories



Metals

- Shiny substances whose atoms tend to give up electrons
- Good conductors of heat and electricity
- Malleable and ductile
- The majority of elements are metals

  94 of 118

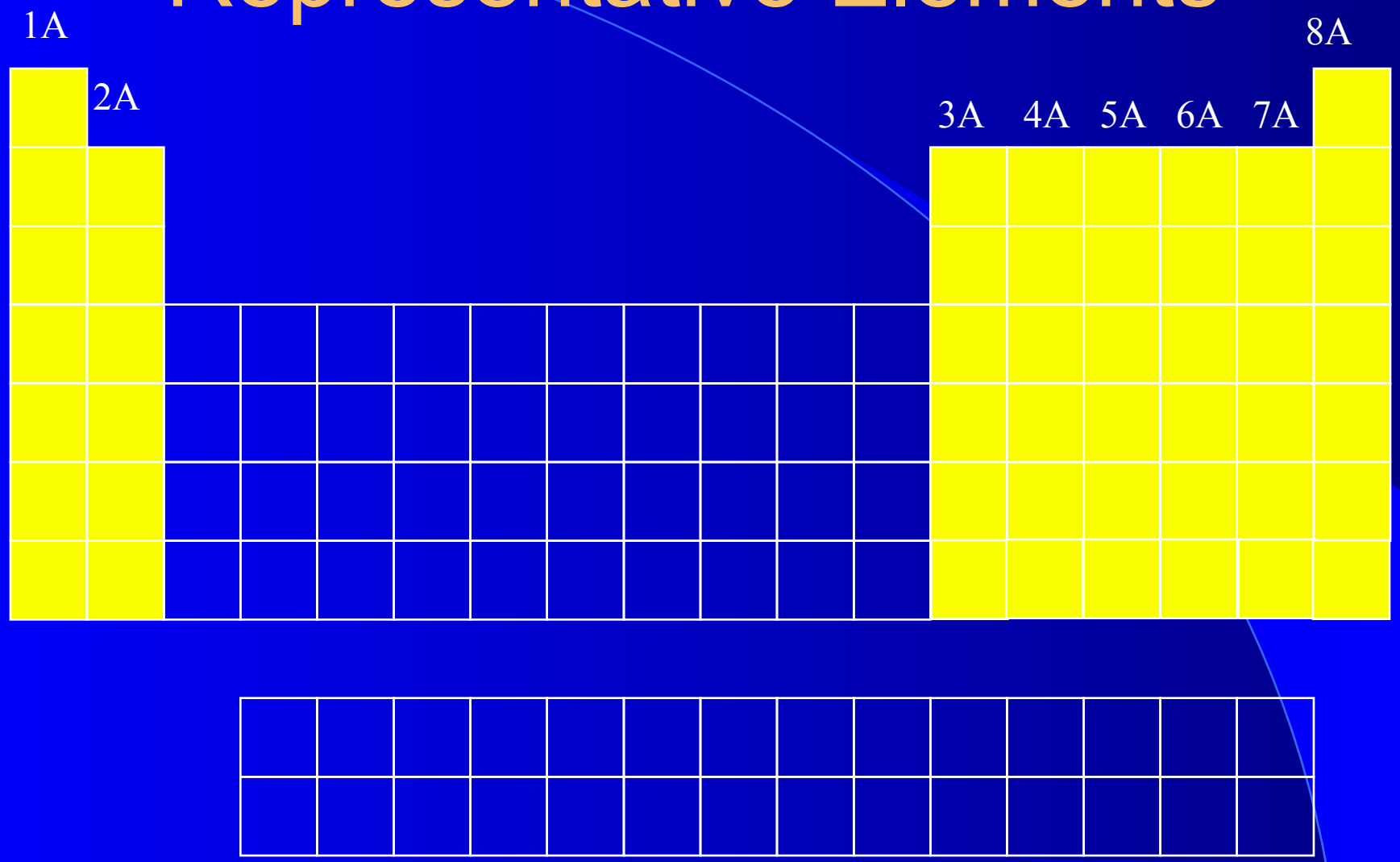
Nonmetals

- Do not generally conduct electricity
- Do not give up electrons, tend to pick them up instead
- Mostly gases, liquids and soft solids at room temperature (25ºC)

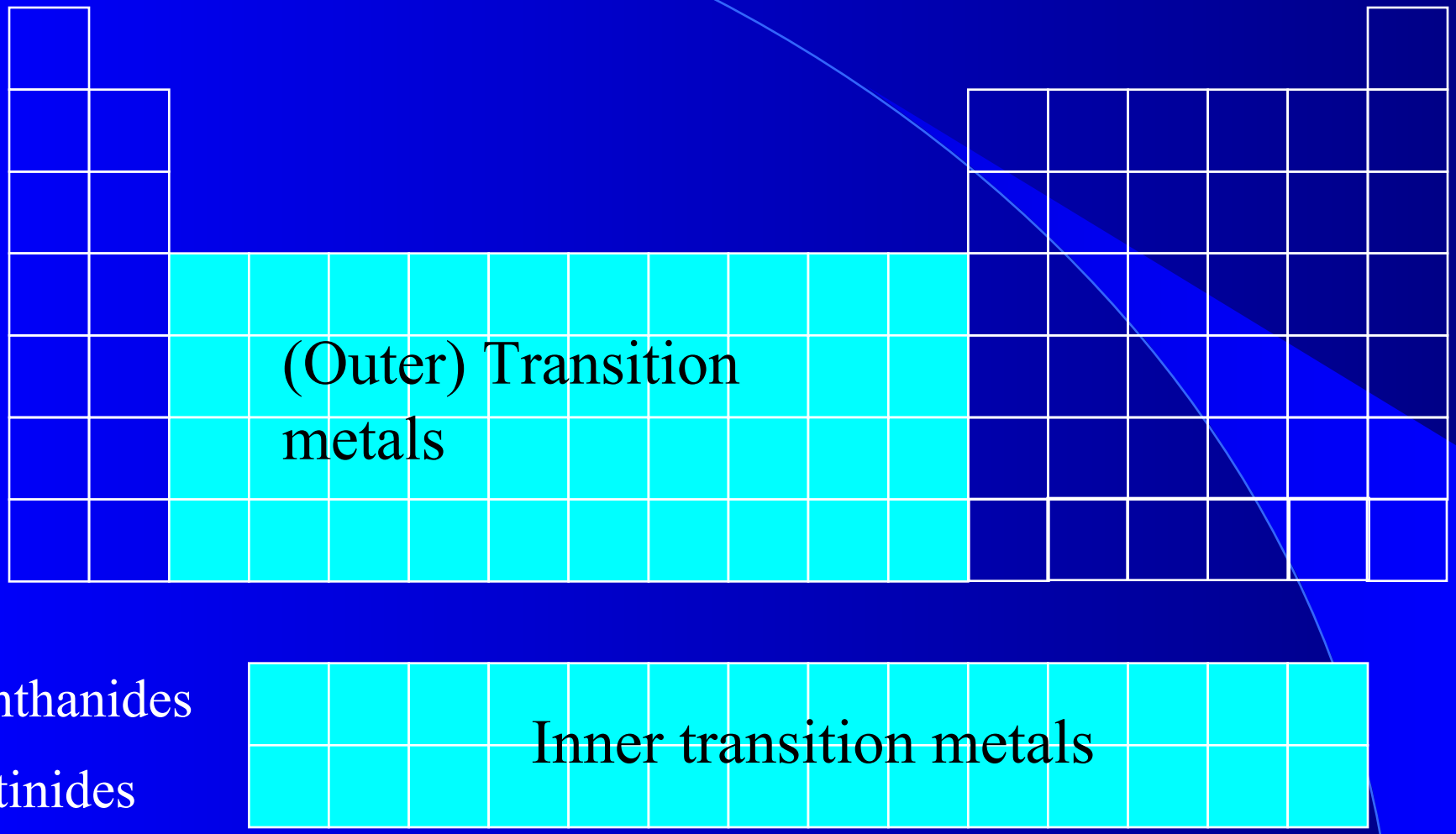
Metalloids

- Have intermediate properties
- Neither good conductors
- Nor bad conductors
- They're semiconductors!
- Silicon Valley is the center of germanium-doped, silicon wafers

Representative Elements



Transition Metals



Lanthanides

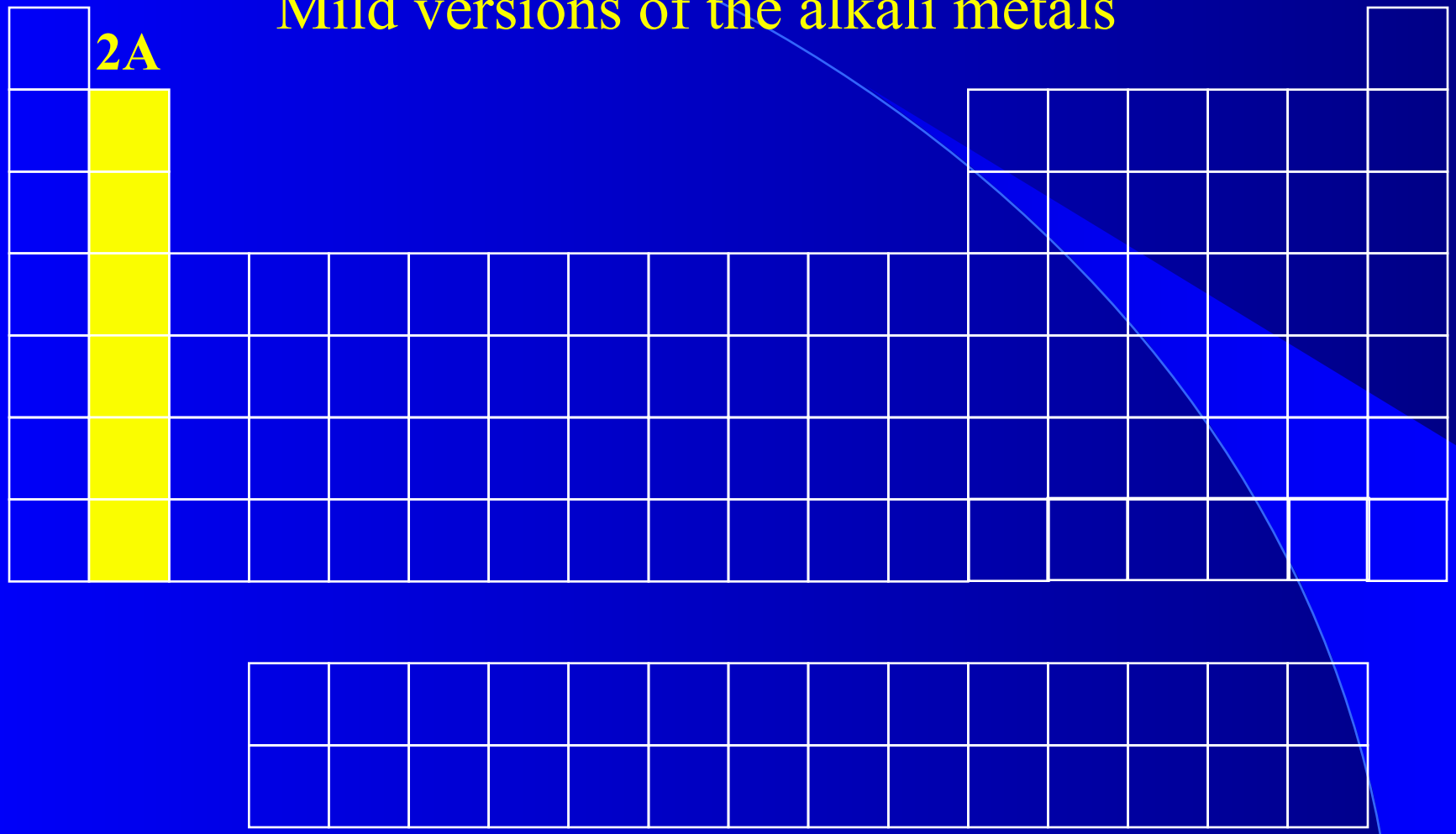
Actinides

Other families of elements...

- Elements within some groups show such striking chemical behavior that they are given special names
- We've already talked about the alkali metal family

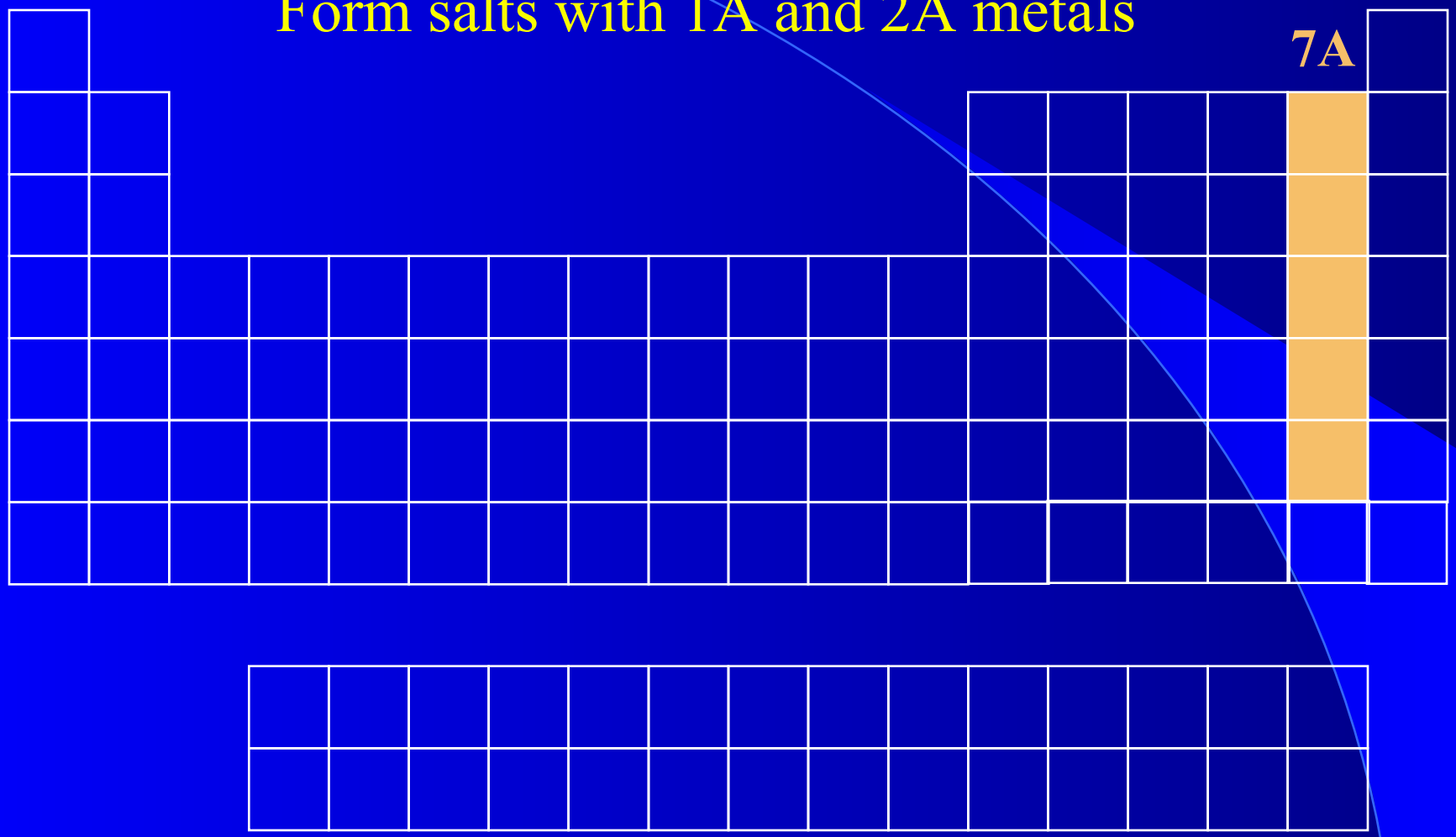
Alkaline earth metals

Mild versions of the alkali metals



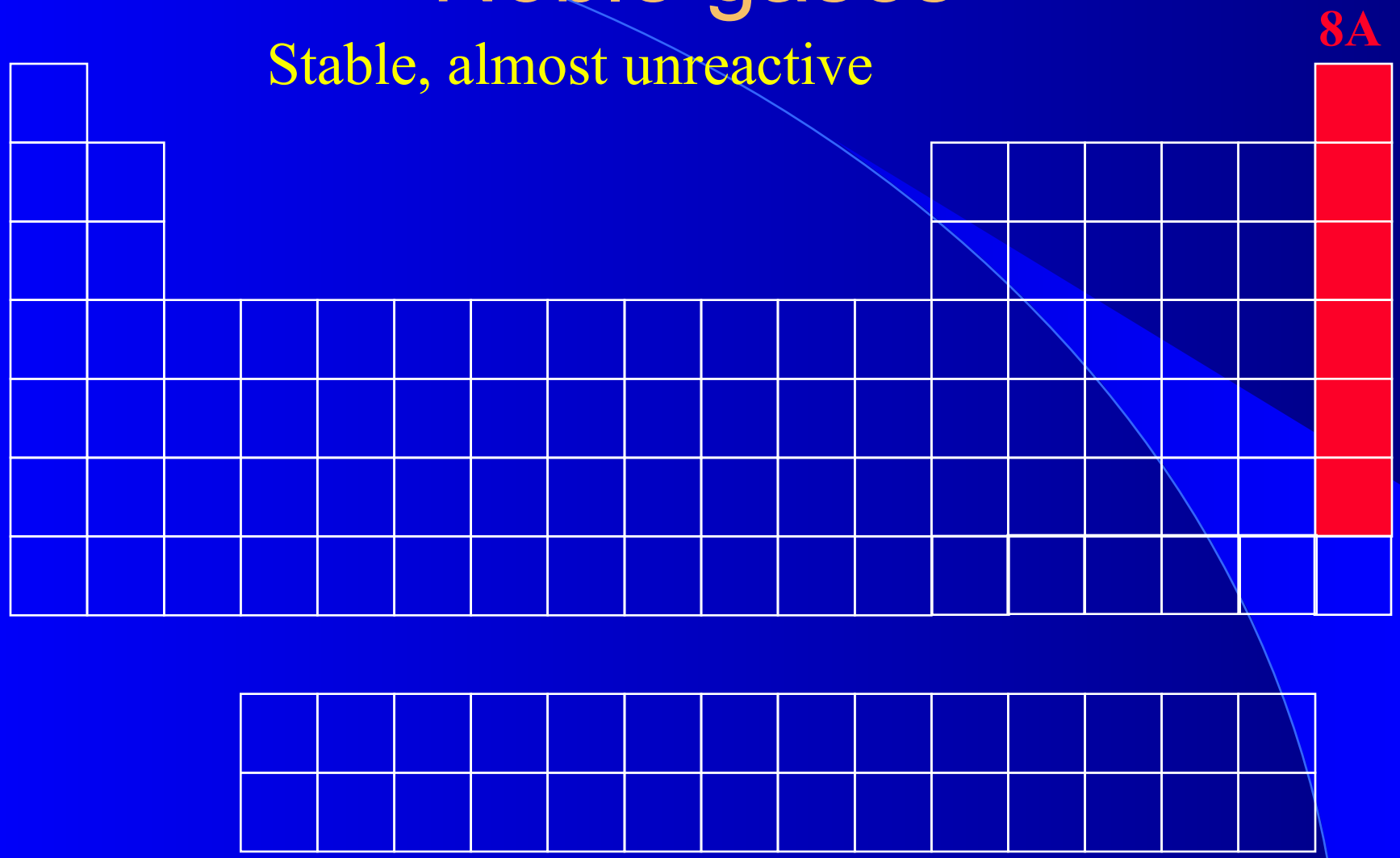
Halogens

Form salts with 1A and 2A metals



Noble gases

Stable, almost unreactive



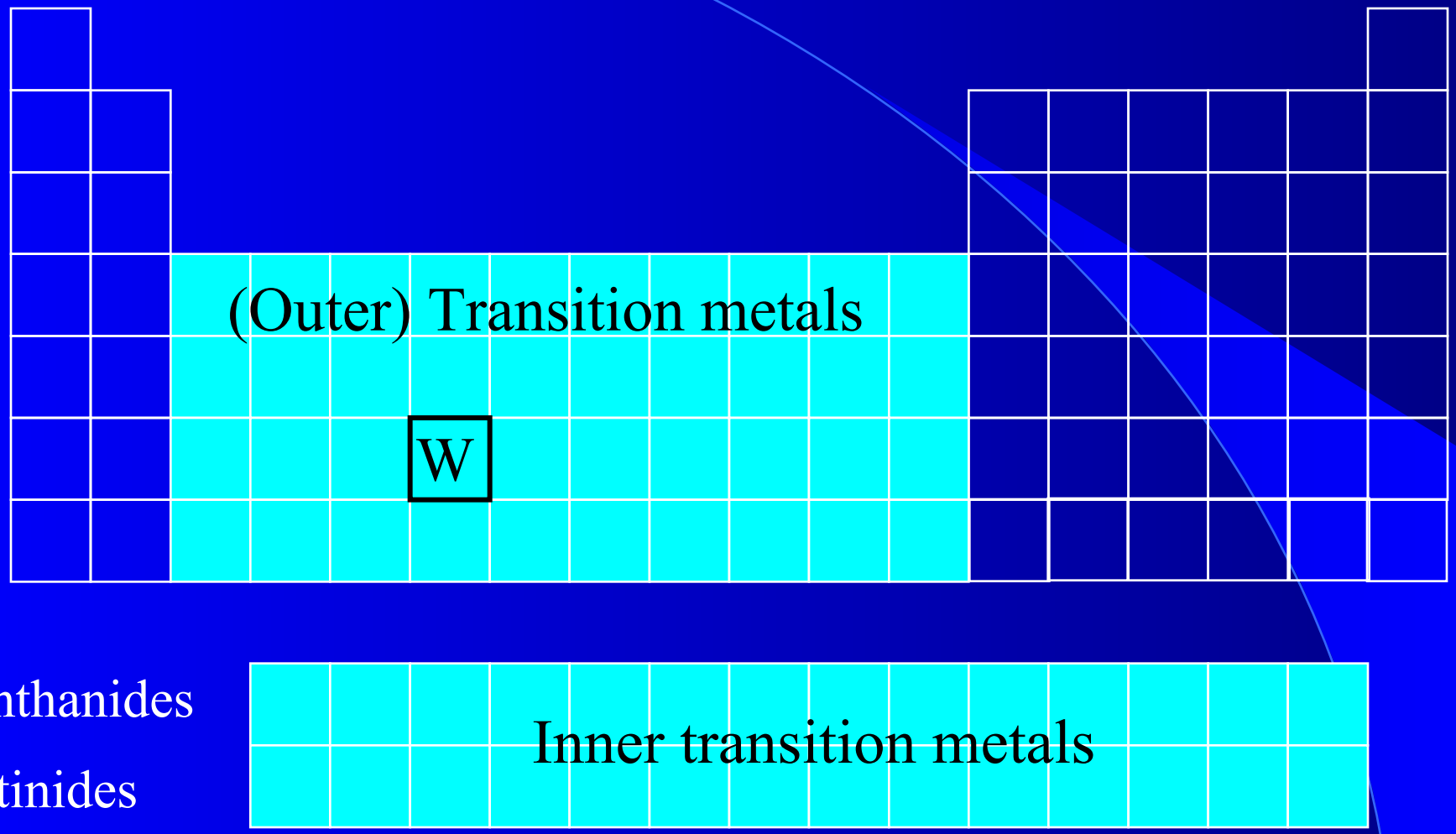
To which class of elements does tungsten (W) belong?

1. Alkaline earth metals
2. Inner transition metals
3. Outer transition metals
4. Halogens

To which class of elements does tungsten (W) belong?

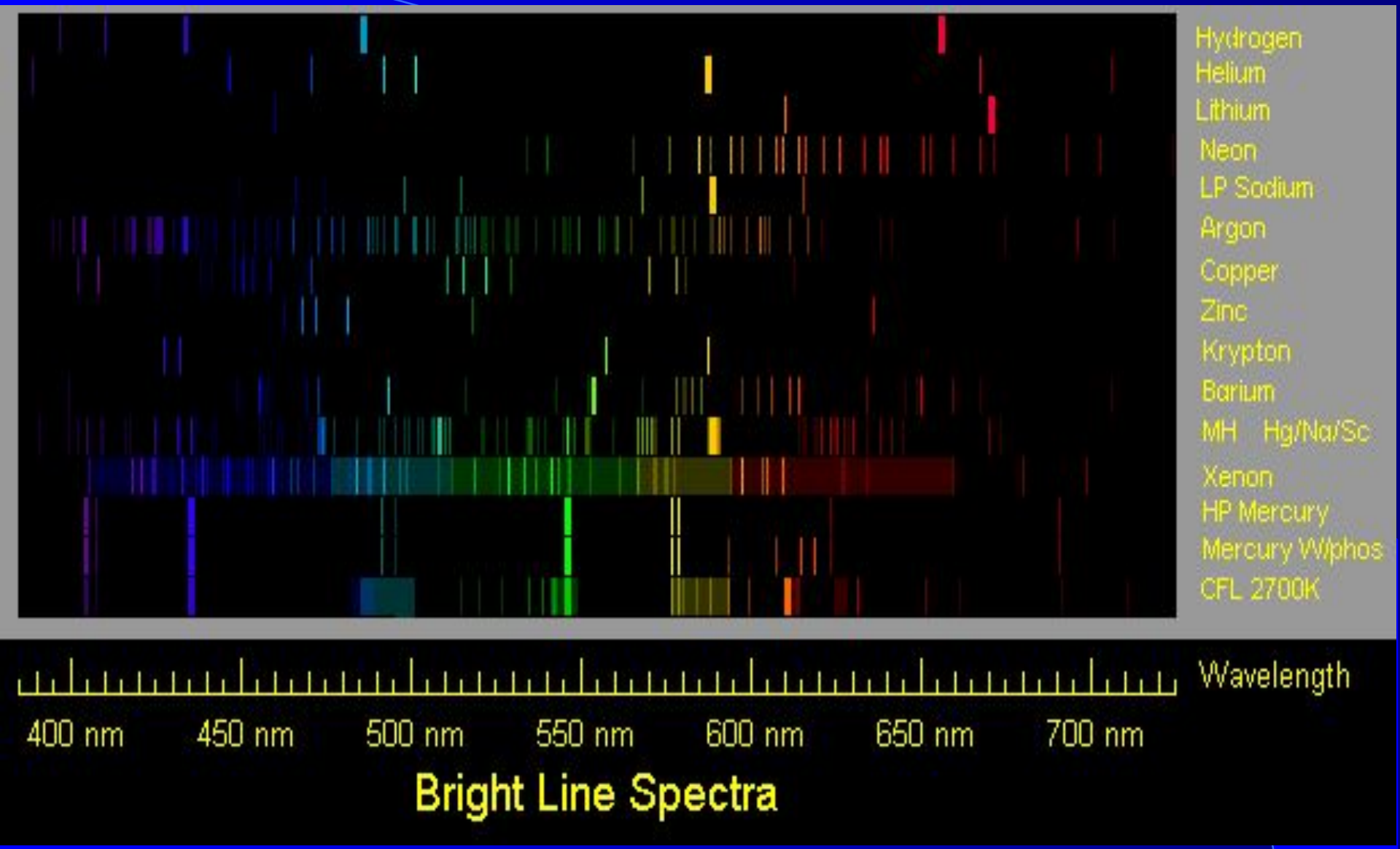
1. Alkaline earth metals
2. Inner transition metals
3. Outer transition metals
4. Halogens

Transition Metals



The Electronic Structure of Atoms

- When certain elements were strongly heated, they produced very narrow lines of pure color through a prism
- The explanation lay in the quantized energy model for the atom



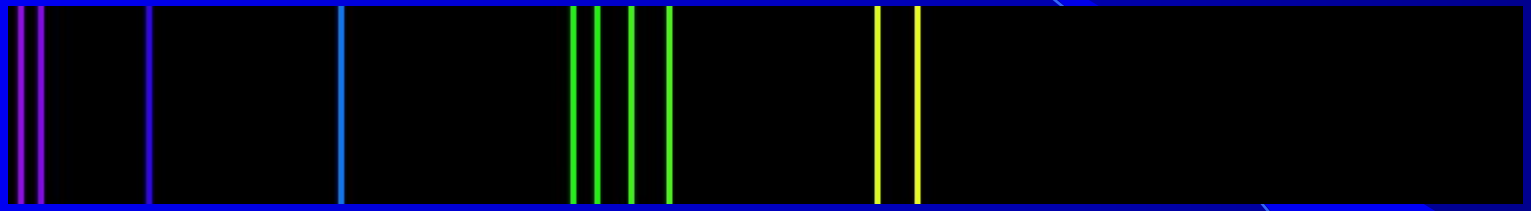
http://members.misty.com/don/spectra.html

Fireworks!

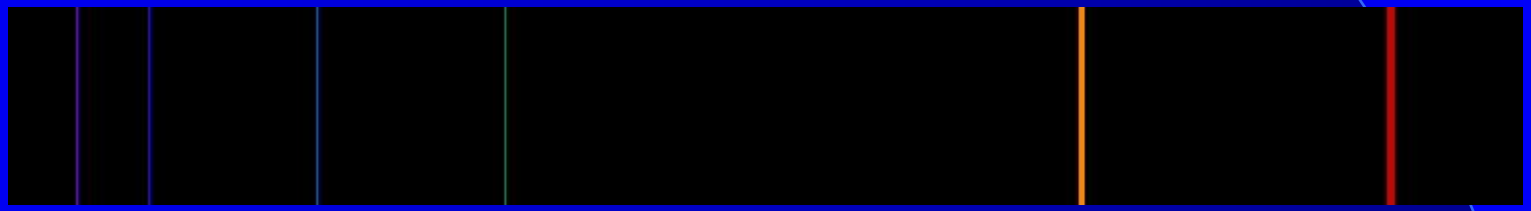
- Sodium - yellow-orange (NaCl)
- Copper – green ($CuCH_3COO$)
- Lithium – magenta ($Li_2C_2O_4$)
- Powdered iron - gold sparks (Fe)
- Powdered magnesium - silver sparks (Mg)

Sodium

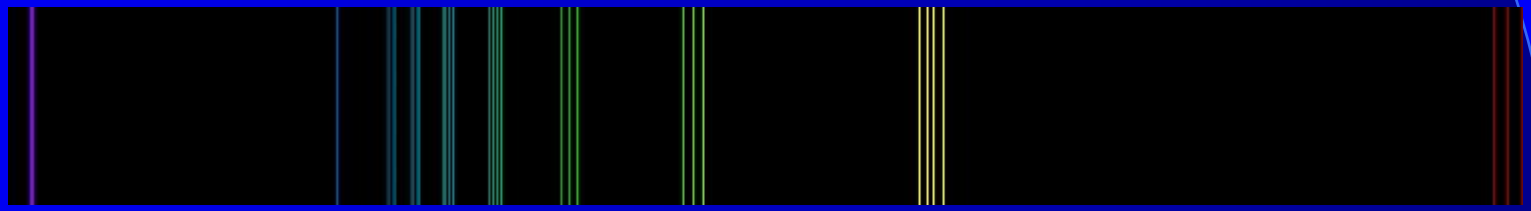
Copper



Lithium



Potassium



Classical Physics VS Quantum Theory

Studying atoms leads to the following questions:

- How many electrons are present in a particular atom?
- What energies do the individual electrons possess?
- Where in the atom can electrons be found?

Classical Physics VS Quantum Theory

- Molecules behave like rebounding balls as pressure exerted by gases
- Physics was able to predict and explain some these macroscopic phenomena but failed to explain the stability of molecules; that is, it could not explain the forces that hold atoms together
- Properties of atoms and molecules are ***not*** governed by the same physical laws as larger objects

Classical Physics VS Quantum Theory

- Physicists had always assumed that energy is continuous and that any amount of energy could be released in a radiation process
- Max Planck in 1900 started new era While studying the data on radiation emitted by solids heated to various temperatures
- He discovered atoms and molecules emit energy only in certain discrete quantities:

Quanta

- Planck's ***quantum theory*** turned physics upside down

Mystery # 1, “Heated Solids Problem” Solved by Max Planck in 1900

- When solids are heated, they emit electro- magnetic radiation over a wide range of wavelengths.

- Radiant energy emitted by an object at a certain temperature depends on its wavelength.

Mystery # 1, “Heated Solids Problem” Solved by Max Planck in 1900

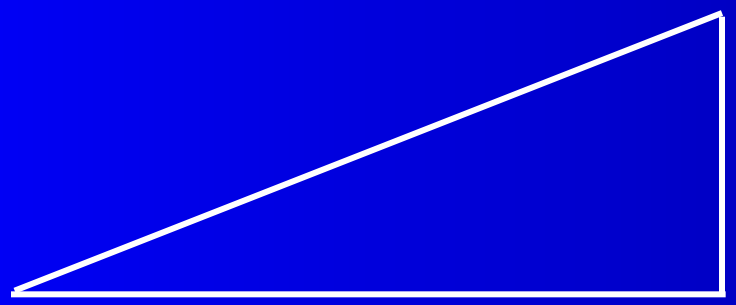
Energy (light) is emitted or absorbed only in discrete quantities, like small packages or bundles (*quantum*).

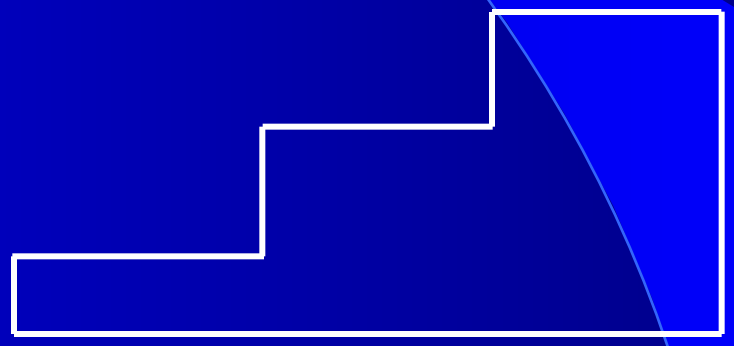
Quantum

The smallest quantities of energy that can be emitted (or absorbed) in the form of electromagnetic radiation

Quantum Theory

- Energy Continuum
- Quantized Energy





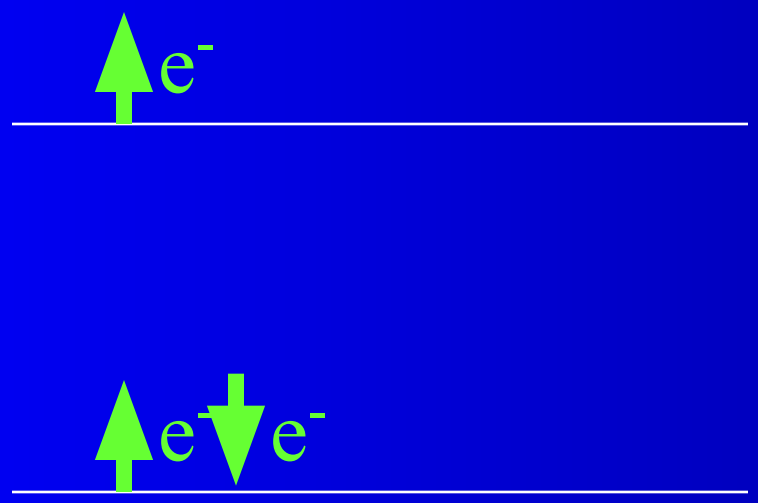
The Electronic Structure of Atoms

- When certain elements were strongly heated, they produced very narrow lines of pure color through a prism
- The explanation lay in the quantized energy model for the atom

Spectral Lines

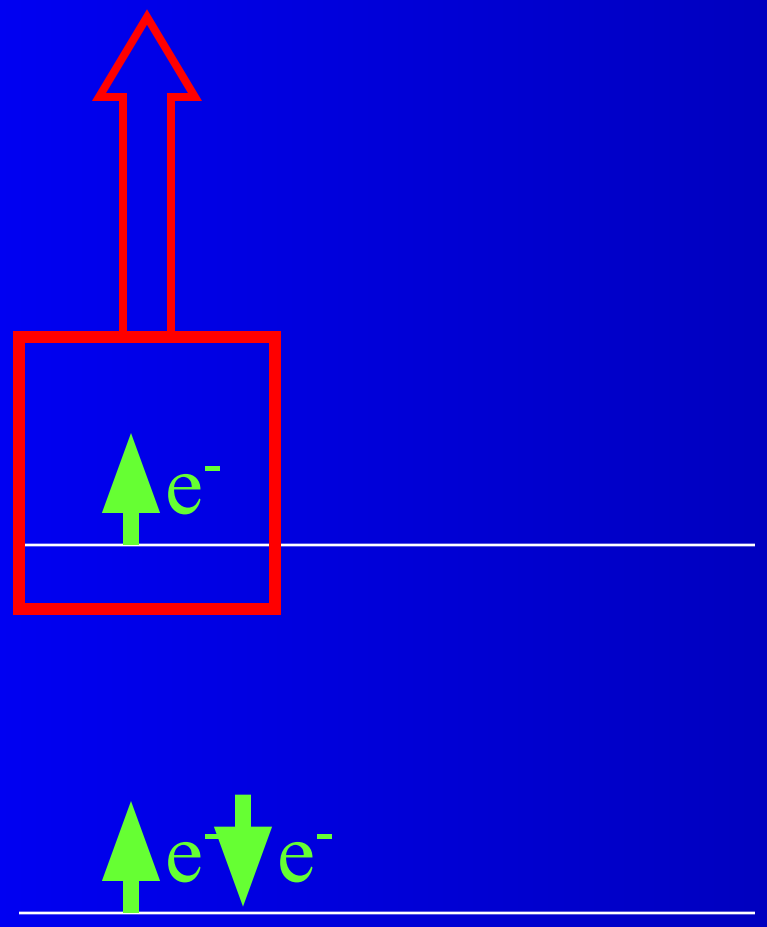
atom energy levels

Spectral Lines



atom energy levels

Spectral Lines



atom energy levels

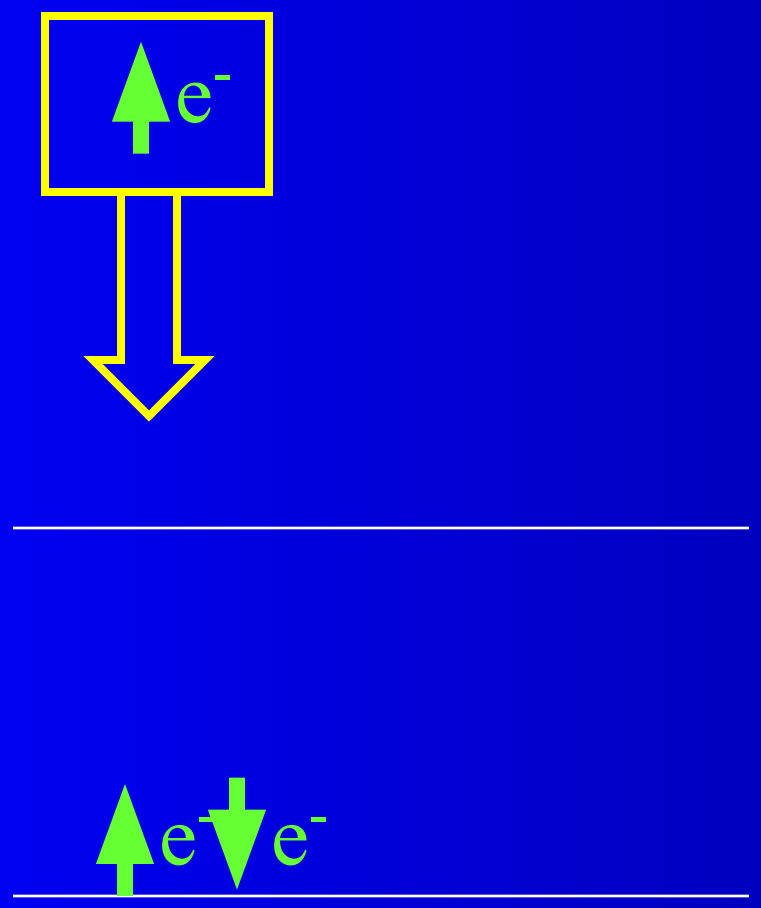
Heat from the flaming alcohol provides energy to move electrons to higher energy levels, or even to escape entirely (ionization)…

Spectral Lines

A vacancy now exists…

atom energy levels

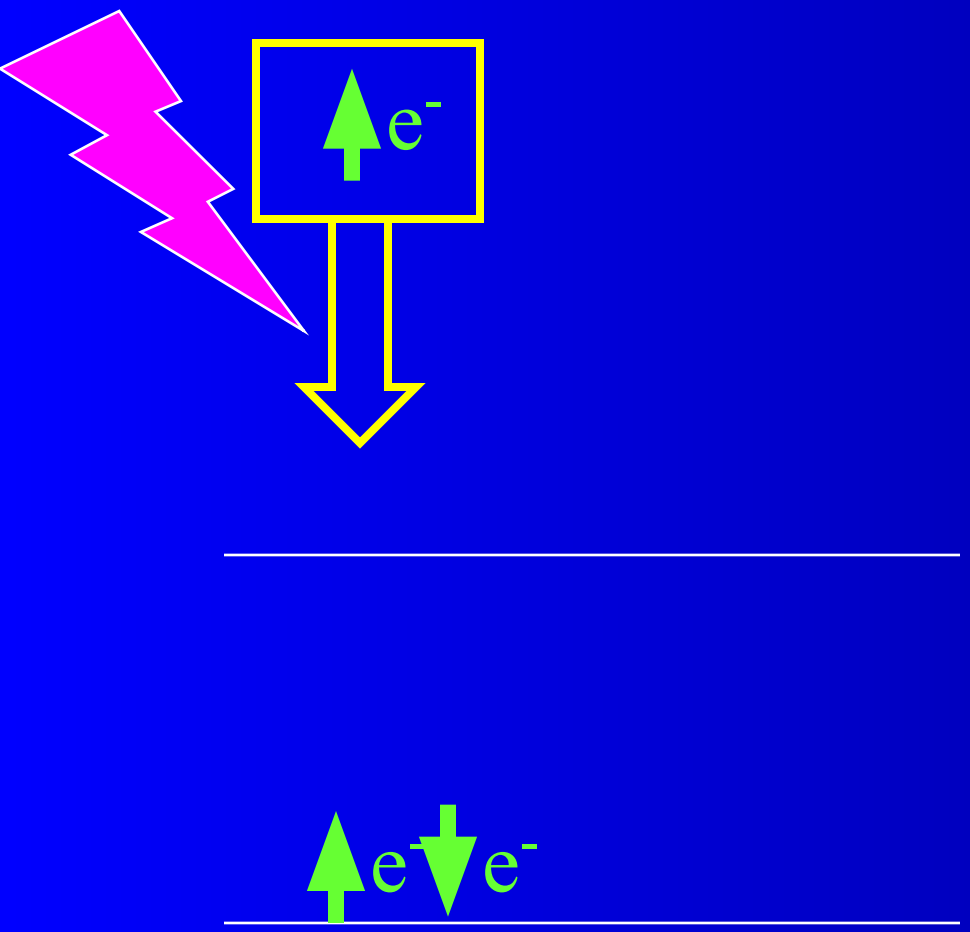
Spectral Lines



atom energy levels

As an electron drops into the vacancy in a cooler region, energy is released in the form of light

Spectral Lines

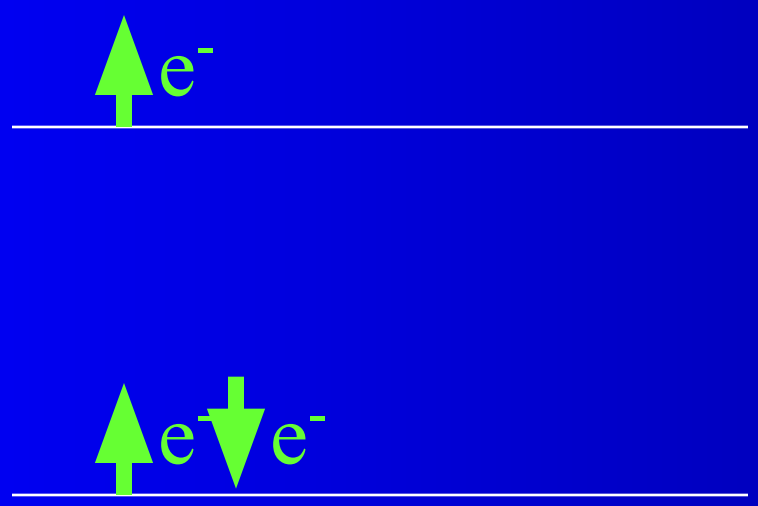


atom energy levels

As an electron drops into the vacancy in a cooler region, energy is released in the form of light

Spectral Lines

The atom is now back to its ground state



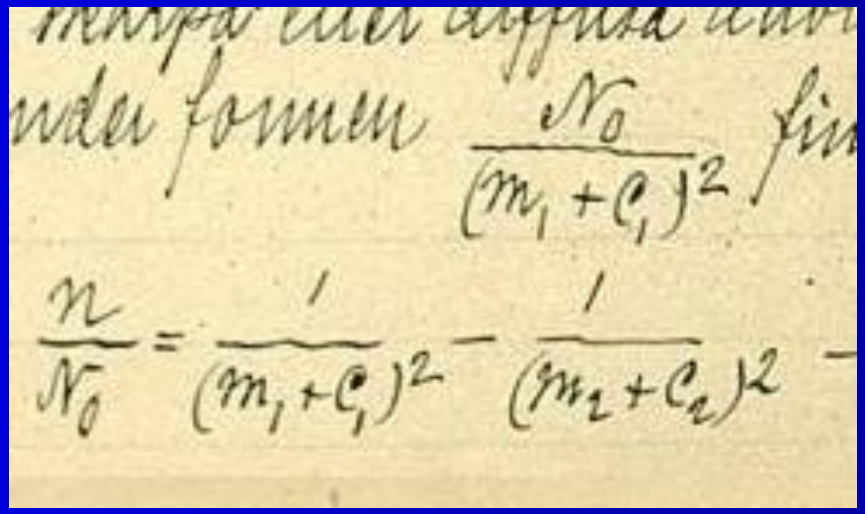
atom energy levels

Quantum Mechanics

- Electrons are restricted to certain regions of space dependent on how much energy they possess
- Only certain energy values are allowed for electrons

The Rydberg Formula

- The formula for the spacing of spectral lines in hydrogen-like atoms was derived by Swedish scientist Johannes Rydberg and presented on November 5, 1888

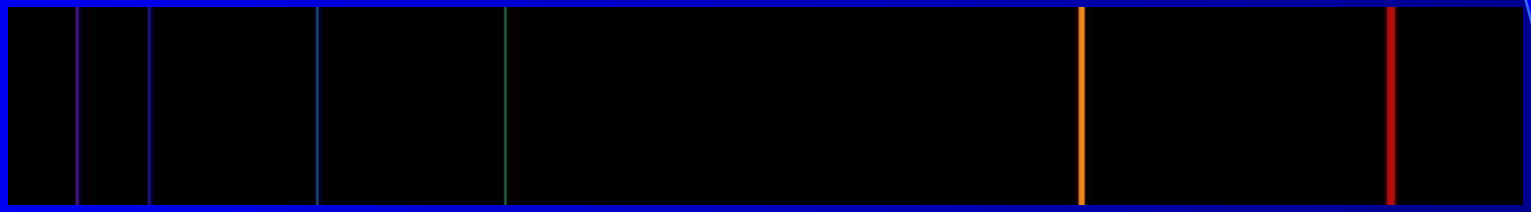


$$\frac{n}{N_0} = \frac{1}{(m_1+c_1)^2} - \frac{1}{(m_2+c_2)^2} -$$

Spectral Lines

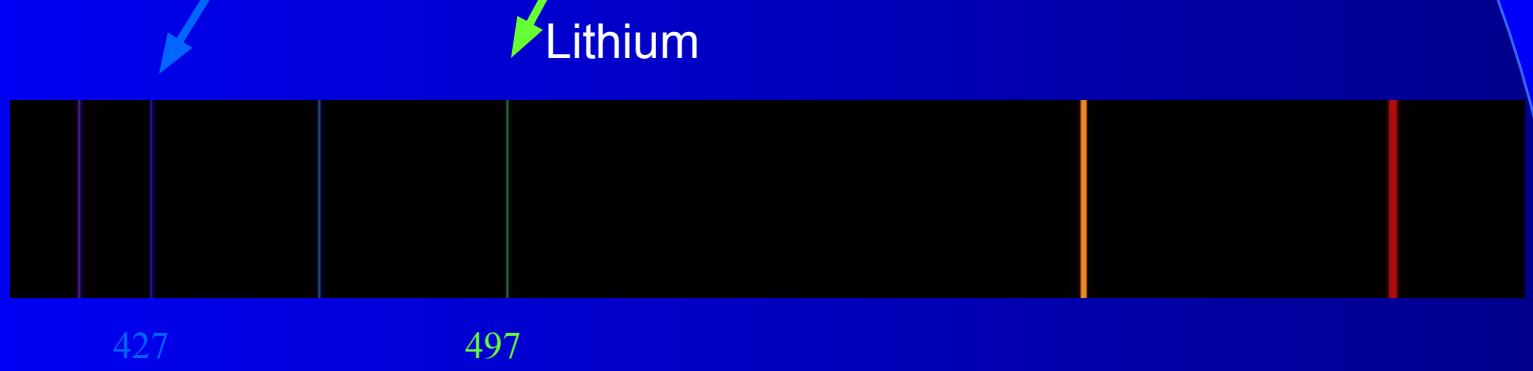
- Lithium's fuchsia flame emission is due to

Lithium



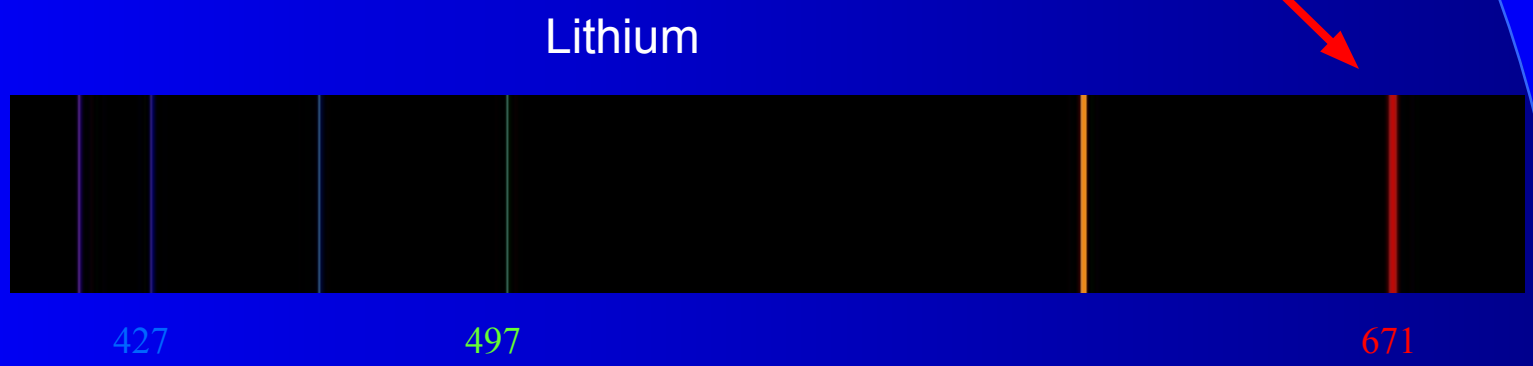
Spectral Lines

- Lithium's fuchsia flame emission is due to
- Sharp lines at 427 and 497 nm



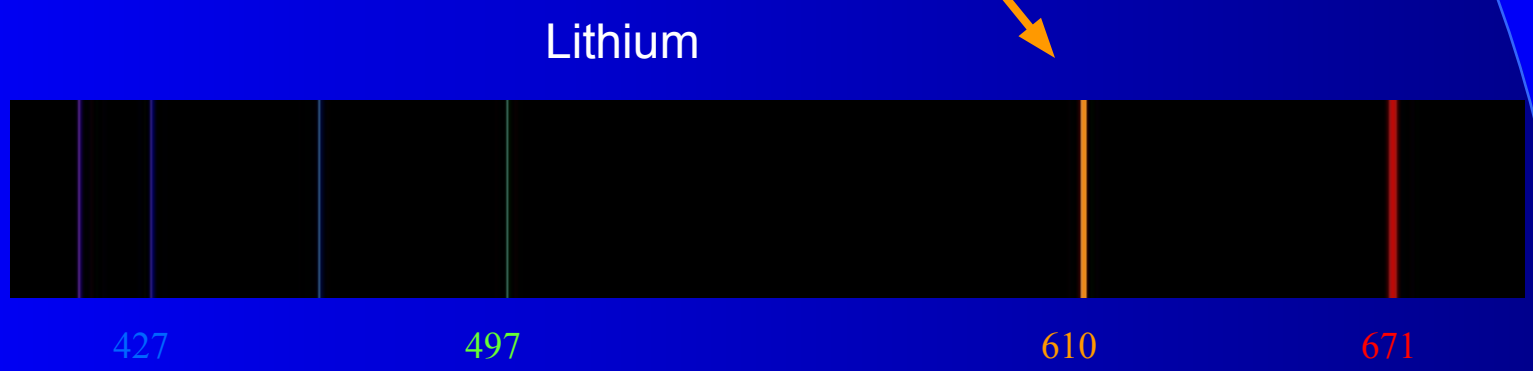
Spectral Lines

- Lithium's fuchsia flame emission is due to
- Sharp lines at 427 and 497 nm
- A principal line at 671nm



Spectral Lines

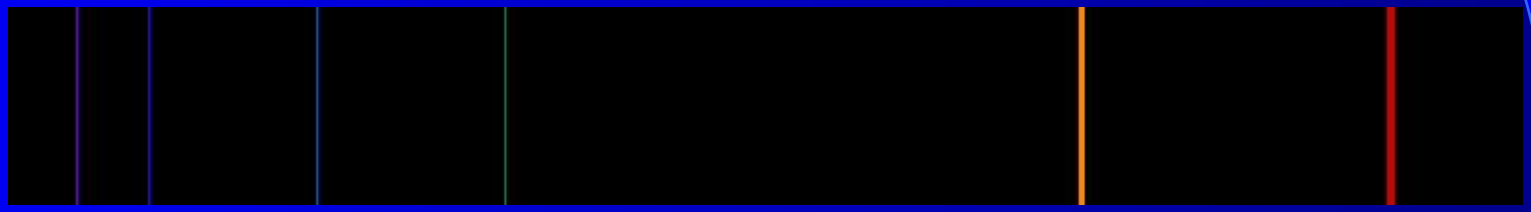
- Lithium's fuchsia flame emission is due to
- Sharp lines at 427 and 497 nm
- A principal line at 671nm
- A diffuse line at 610 nm



Spectral Lines

- Lithium's fuchsia flame emission is due to
- Sharp lines at 427 and 497 nm
- A principal line at 671nm
- A diffuse line at 610 nm
- Hmm…notice anything interesting about the spectral categories I listed?

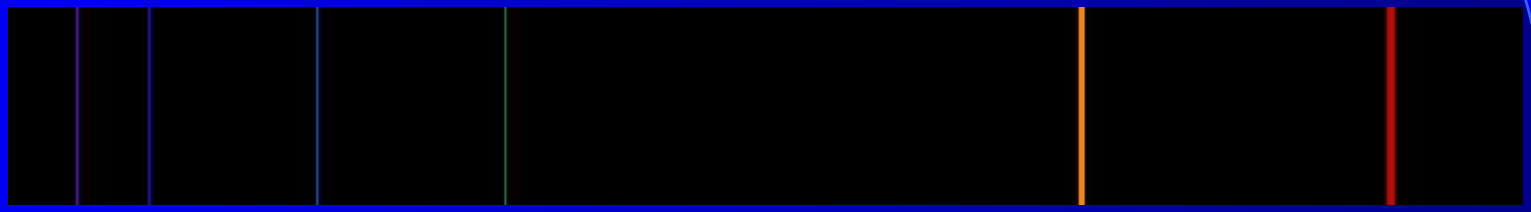
Lithium



Spectral Lines

- Lithium's fuchsia flame emission is due to
- Sharp lines at 427 and 497 nm
- A principal line at 671nm
- A diffuse line at 610 nm
- Hmm…notice anything interesting about the spectral categories I listed?
- The next category is fundamental lines…

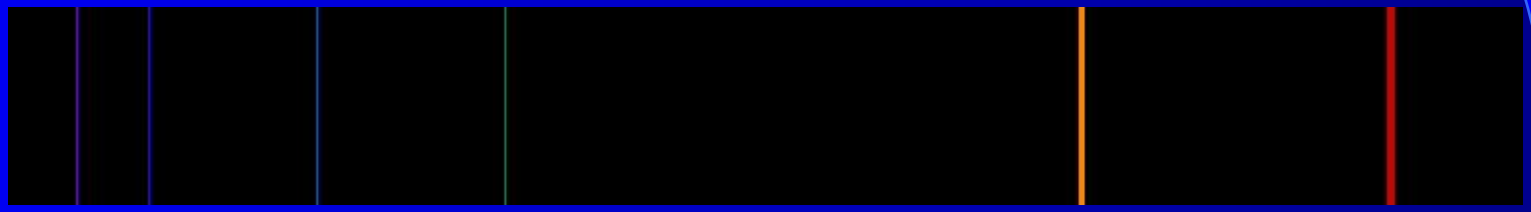
Lithium

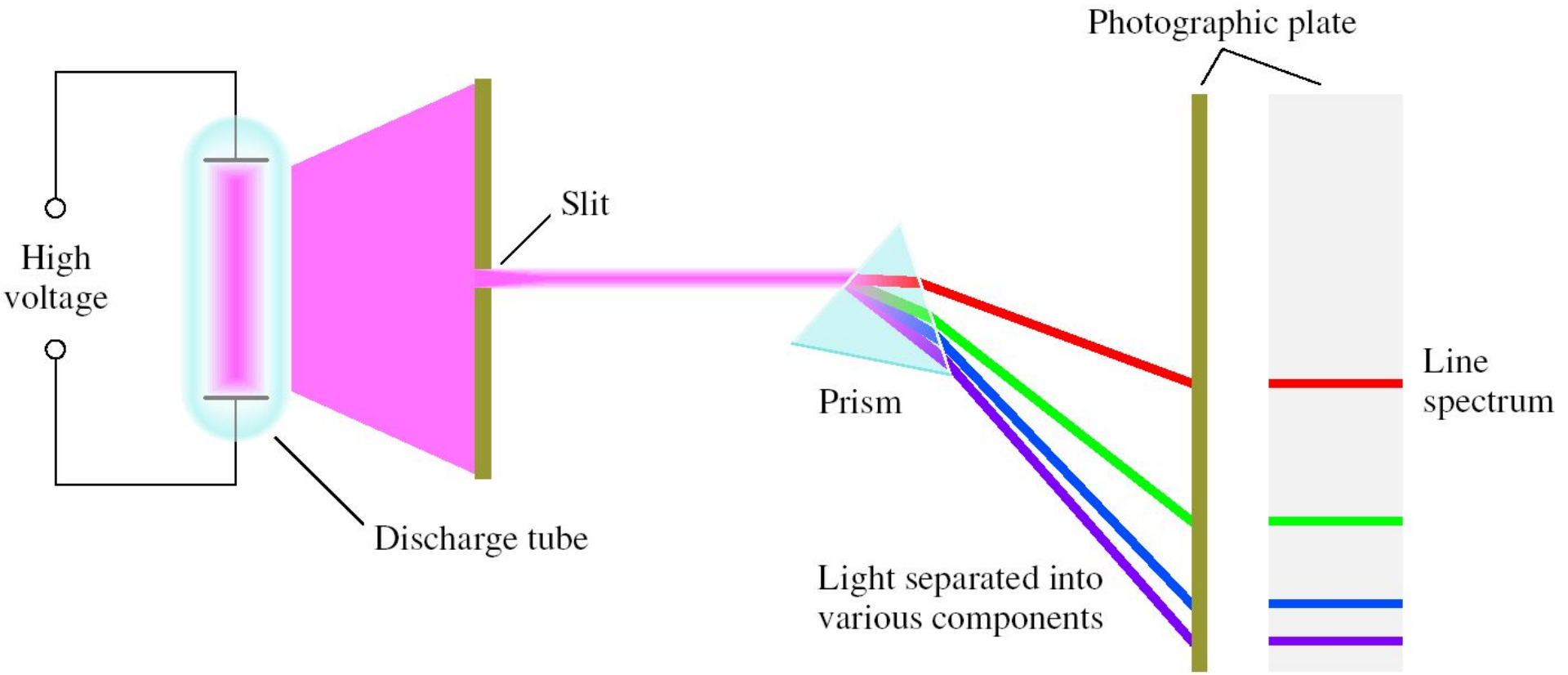


Spectral Lines

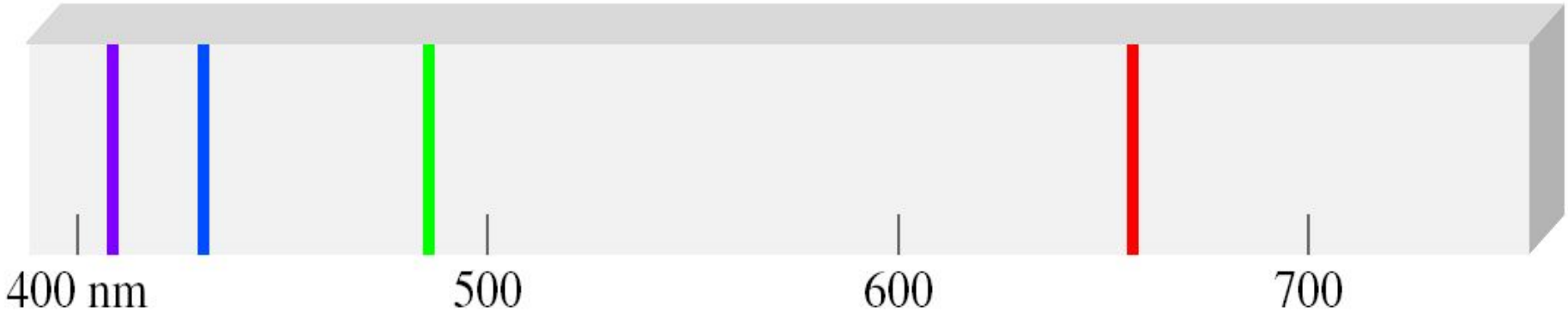
- Lithium's fuchsia flame emission is due to
- Sharp lines at 427 and 497 nm
- A principal line at 671nm
- A diffuse line at 610 nm
- Hmm…notice anything interesting about the spectral categories I listed?
- The next category is fundamental lines…

Lithium



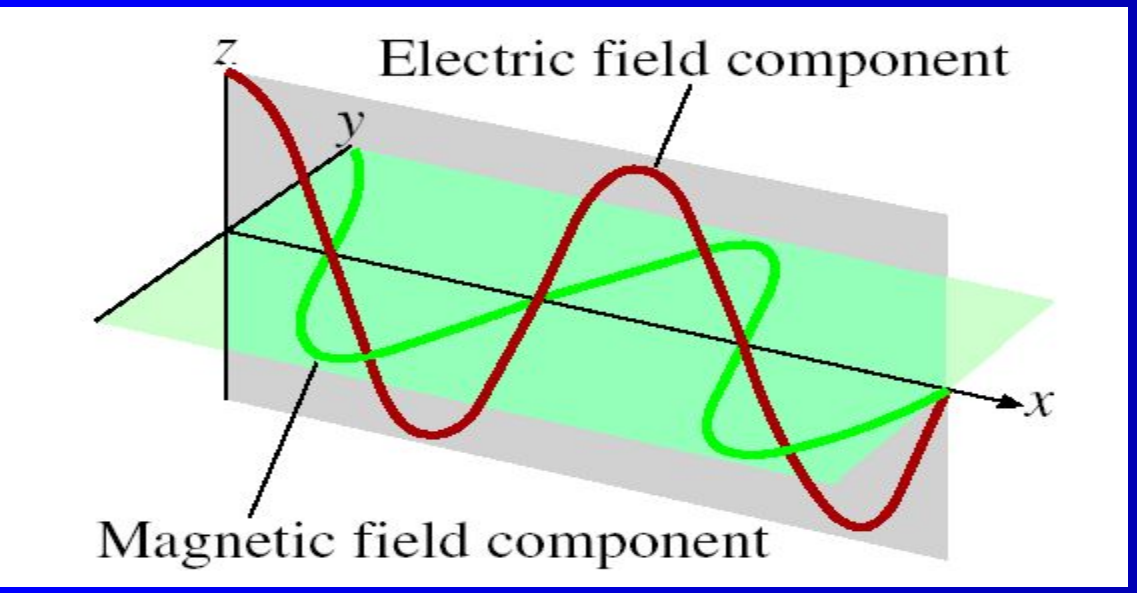


Line Emission Spectrum of Hydrogen Atoms



James Clerk Maxwell (1873)

visible light consists of electro - magnetic waves



Electromagnetic radiation is the emission and transmission of energy in the form of electromagnetic waves.

Speed of light (c) in vacuum = 3.00×10^8 m/s

All electromagnetic radiation

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

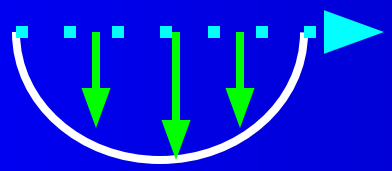
Electromagnetic Radiation

Electromagnetic Radiation

- Visible lights are part of the electromagnetic radiation continuum
- Electromagnetic radiation is characterized by a photon that has an electric field and a magnetic field that grow and collapse at a regular frequency

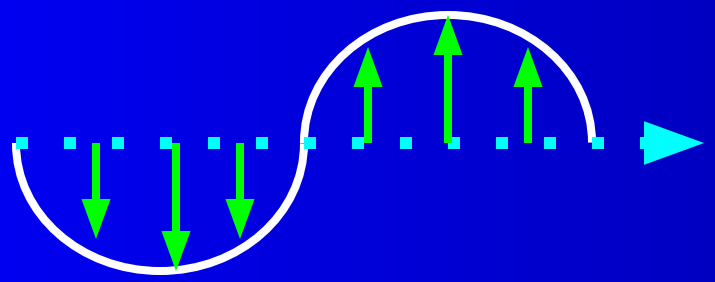
Electromagnetic Radiation

- Visible lights are part of the electromagnetic radiation continuum
- Electromagnetic radiation is characterized by a photon that has an electric field and a magnetic field that grow and collapse at a regular frequency



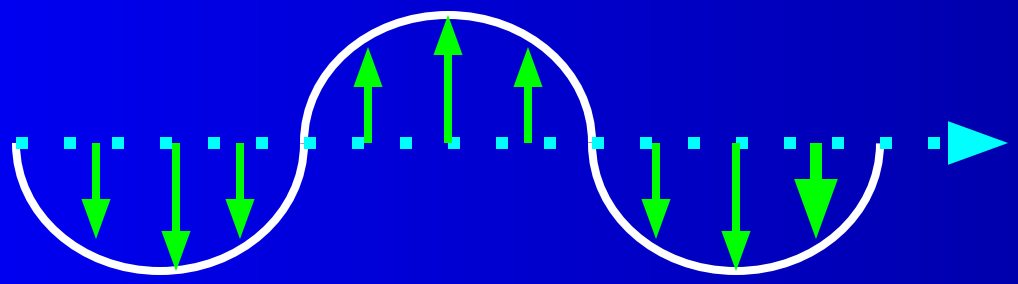
Electromagnetic Radiation

- Visible lights are part of the electromagnetic radiation continuum
- Electromagnetic radiation is characterized by a photon that has an electric field and a magnetic field that grow and collapse at a regular frequency



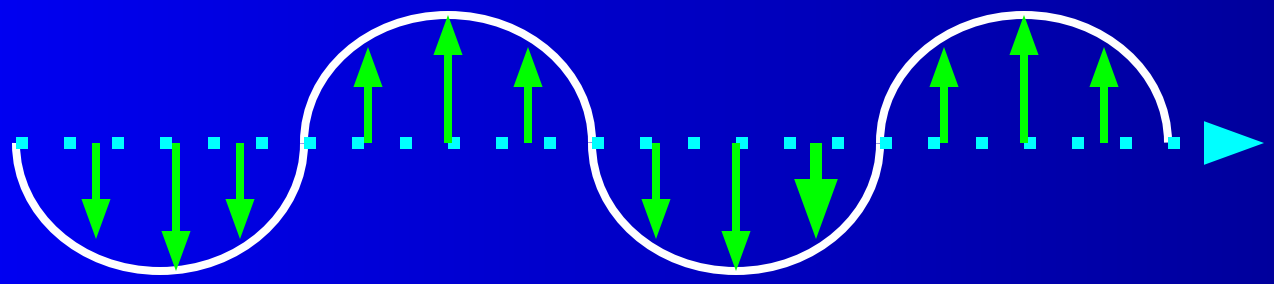
Electromagnetic Radiation

- Visible lights are part of the electromagnetic radiation continuum
- Electromagnetic radiation is characterized by a photon that has an electric field and a magnetic field that grow and collapse at a regular frequency



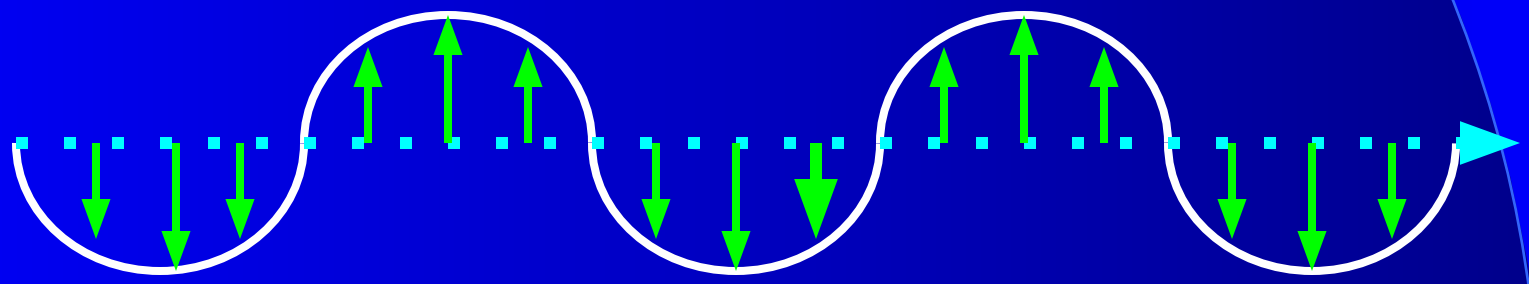
Electromagnetic Radiation

- Visible lights are part of the electromagnetic radiation continuum
- Electromagnetic radiation is characterized by a photon that has an electric field and a magnetic field that grow and collapse at a regular frequency



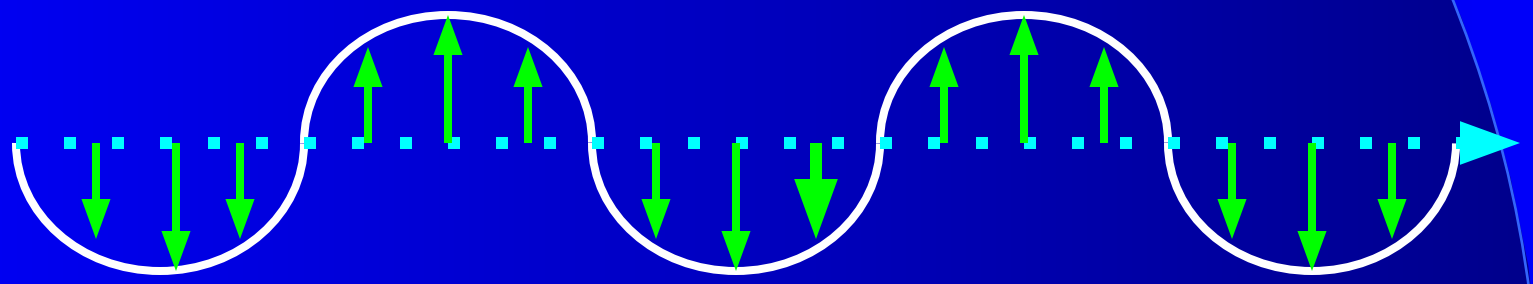
Electromagnetic Radiation

- Visible lights are part of the electromagnetic radiation continuum
- Electromagnetic radiation is characterized by a photon that has an electric field and a magnetic field that grow and collapse at a regular frequency



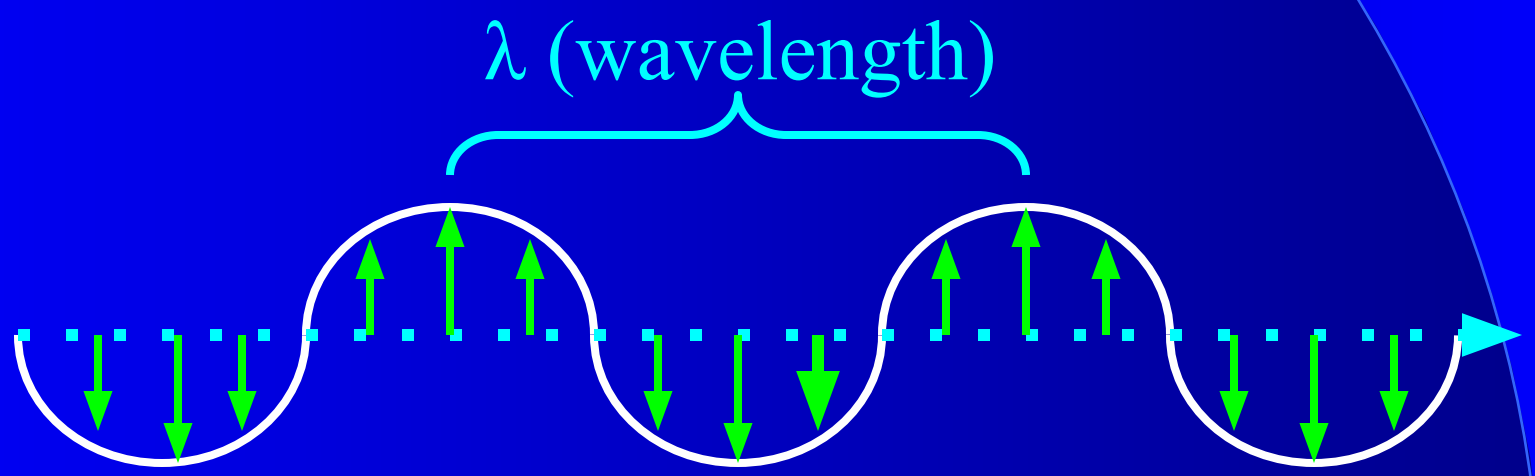
Electromagnetic Radiation

- Radiation is often described by its wavelength, the distance from one crest to the next



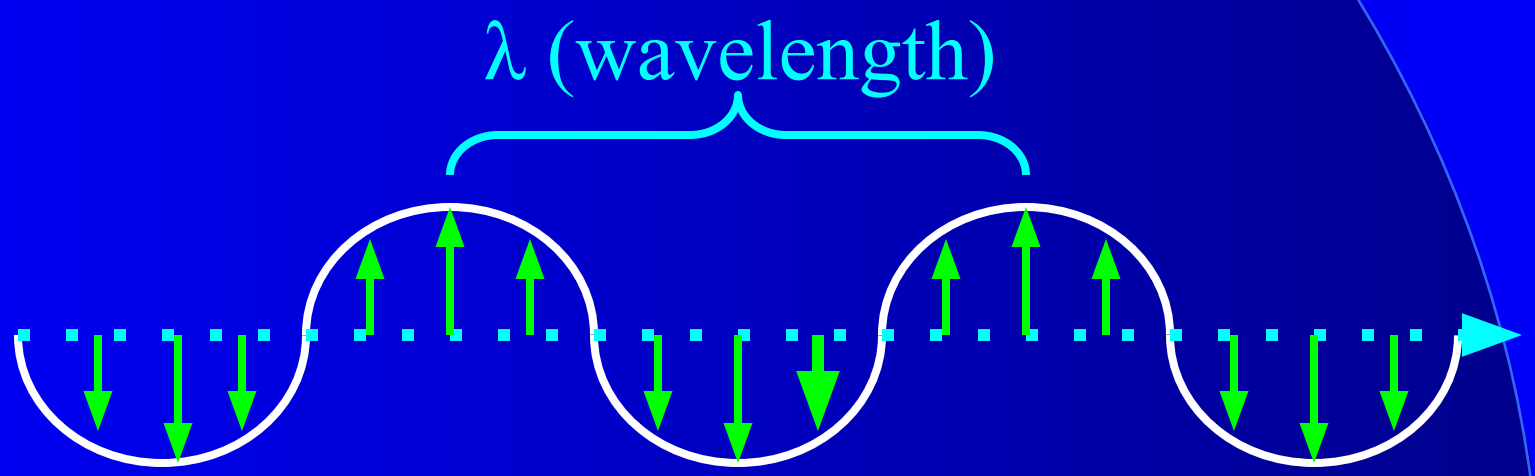
Electromagnetic Radiation

- Radiation is often described by its wavelength, the distance from one crest to the next



Electromagnetic Radiation

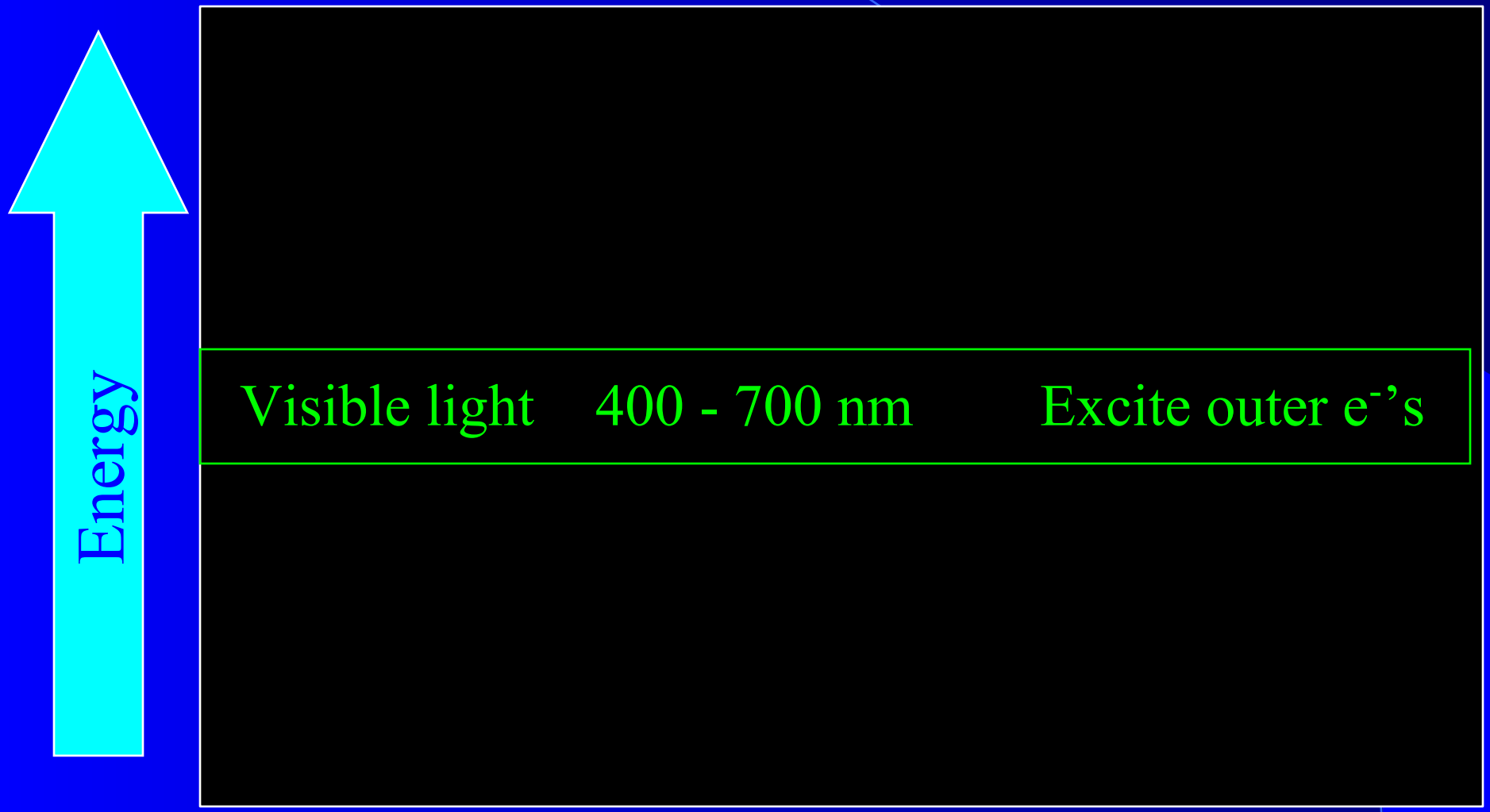
- Radiation is often described by its wavelength, the distance from one crest to the next
- The longer the wavelength, the lower the radiation energy



The Electromagnetic Spectrum

- Different categories of radiation are based on what equipment it takes to produce or detect them
- The most obvious type of radiation is visible light
- Its wavelength range is from 400 - 700 nm

The Electromagnetic Spectrum



The Electromagnetic Spectrum

Ultraviolet	10 - 400 nm	Break bonds
Visible light	400 - 700 nm	Excite outer e^-'s

The Electromagnetic Spectrum

Energy

X-rays	10 pm - 10 nm	Excite inner e^-'s
Ultraviolet	10 - 400 nm	Break bonds
Visible light	400 - 700 nm	Excite outer e^-'s

The Electromagnetic Spectrum

Energy

γ-rays	< 10 pm	Nuclear changes
X-rays	10 pm - 10 nm	Excite inner e^-'s
Ultraviolet	10 - 400 nm	Break bonds
Visible light	400 - 700 nm	Excite outer e^-'s

The Electromagnetic Spectrum

γ-rays	< 10 pm	Nuclear changes
X-rays	10 pm - 10 nm	Excite inner e^-'s
Ultraviolet	10 - 400 nm	Break bonds
Visible light	400 - 700 nm	Excite outer e^-'s
Infrared	700 nm - 500 μm	Vibrate bonds

The Electromagnetic Spectrum

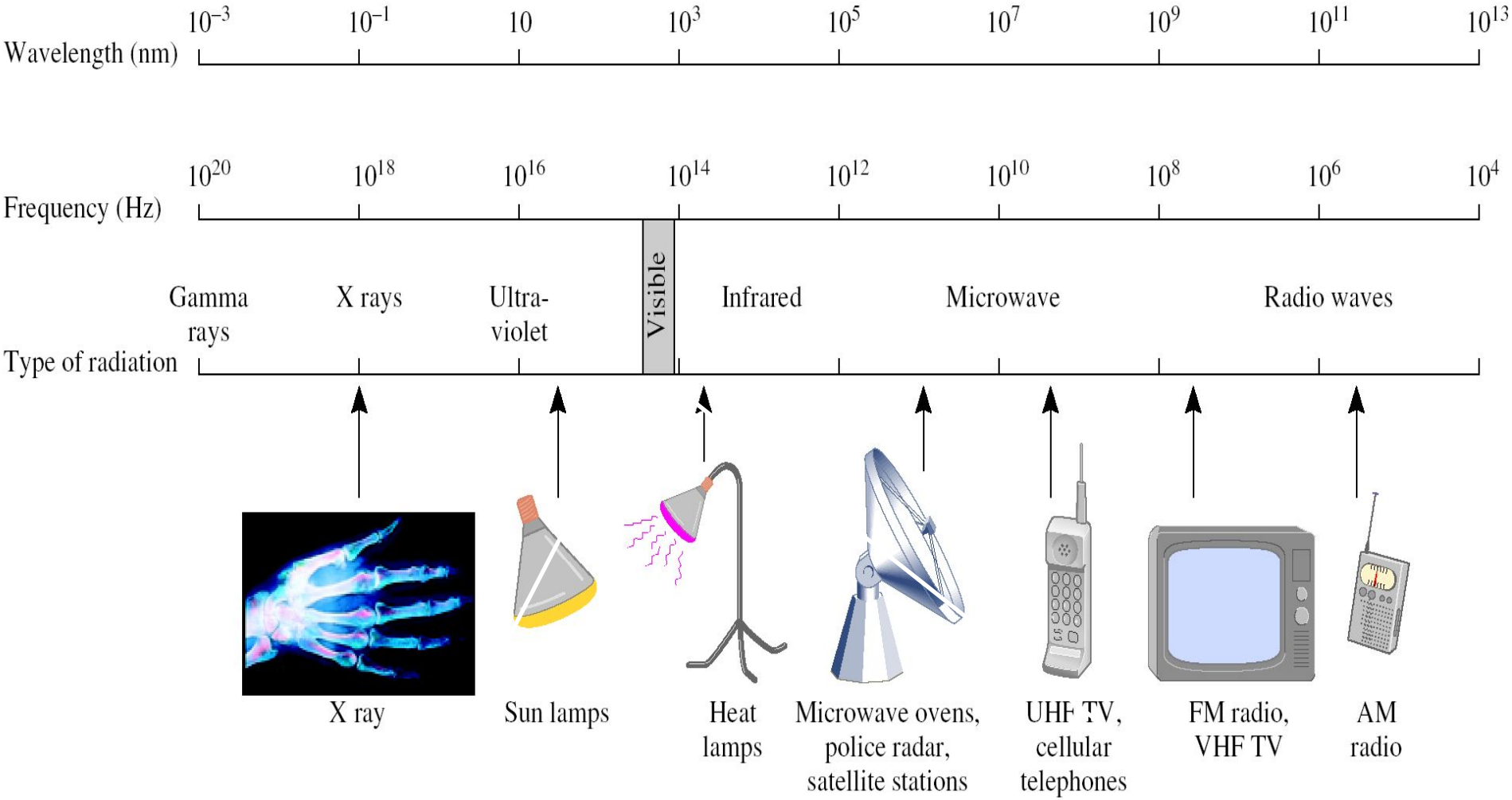
Energy

γ-rays	< 10 pm	Nuclear changes
X-rays	10 pm - 10 nm	Excite inner e^-'s
Ultraviolet	10 - 400 nm	Break bonds
Visible light	400 - 700 nm	Excite outer e^-'s
Infrared	700 nm - 500 μm	Vibrate bonds
Microwaves	500 μm - 10 cm	Flip e^- spins

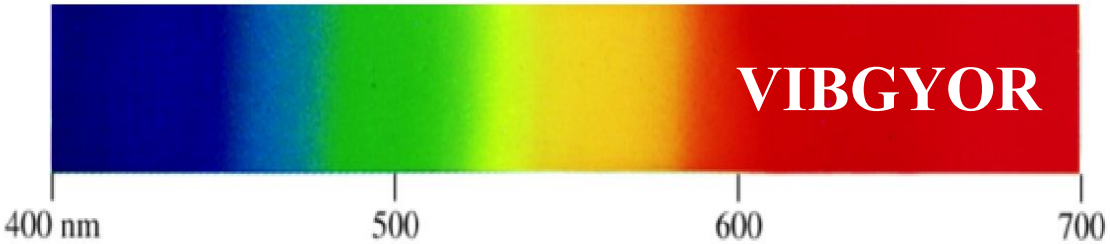
The Electromagnetic Spectrum

Energy

γ-rays	< 10 pm	Nuclear changes
X-rays	10 pm - 10 nm	Excite inner e^-'s
Ultraviolet	10 - 400 nm	Break bonds
Visible light	400 - 700 nm	Excite outer e^-'s
Infrared	700 nm - 500 μm	Vibrate bonds
Microwaves	500 μm - 10 cm	Flip e^- spins
Radio waves	> 10 cm	Flip nuclear spins


Wavelength (nm)
10^{-3} 10^{-1} 10 10^{3} 10^{5} 10^{7} 10^{9} 10^{11} 10^{13}
Frequency (Hz)
10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6} 10^{4}
Type of radiation
Gamma rays
X rays
Ultra-violet
Visible
Infrared
Microwave
Radio waves
X ray
Sun lamps
Heat lamps
Microwave ovens, police radar, satellite stations
UHF TV, cellular telephones
FM radio, VHF TV
AM radio

(a)


VIBGYOR
400 nm
500
600
700

Frequency-Wavelength Conversions

- Wavelength and frequency are related via a simple equation

c, the speed of light, is 3.0×10^8 m/s

Frequency-Wavelength Conversions

- Wavelength and frequency are related via a simple equation

$$\lambda = \frac{c}{\nu}$$

c, the speed of light, is 3.0×10^8 m/s

Frequency-Wavelength Conversions

- Wavelength and frequency are related via a simple equation

$$\lambda = \frac{c}{\nu}$$

c, the speed of light, is 3.0×10^8 m/s

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{c}{\nu}$$

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{c}{\nu}$$

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{c}{5.00 \times 10^{14}\ \text{Hz}}$$

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{c}{5.00 \times 10^{14}\ \text{Hz}}$$

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{c}{5.00 \times 10^{14}\ \text{Hz}}$$

c is 3.0×10^{8} m/s

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8} \text{ m/s}}{5.00 \times 10^{14} \text{ Hz}}$$

c is 3.0×10^{8} m/s

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8} \text{ m/s}}{5.00 \times 10^{14} \text{ Hz}}$$

c is 3.0×10^{8} m/s

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8}\ \text{m/s}}{5.00 \times 10^{14}\ \text{Hz}}$$

Hz is the same as 1/s

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8}\ \text{m/s}}{5.00 \times 10^{14}\ /\text{s}}$$

Hz is the same as 1/s

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8}\ \text{m/s}}{5.00 \times 10^{14}\ /\text{s}}$$

Hz is the same as 1/s

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8}\ \text{m/s}}{5.00 \times 10^{14}\ /\text{s}}$$

Cancel units

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8}\ \mathrm{m}/\cancel{\mathrm{s}}}{5.00 \times 10^{14}\ /\cancel{\mathrm{s}}}$$

Cancel units

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = \frac{3.0 \times 10^{8}\ \mathrm{m}/\cancel{\mathrm{s}}}{5.00 \times 10^{14}\ /\cancel{\mathrm{s}}}$$

Do the math

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = 6.0 \times 10^{-7} \text{ m}$$

Do the math

Frequency-Wavelength Conversions

- What's the wavelength of radiation that has a frequency of 5.00×10^{14} Hz?

$$\lambda = 6.0 \times 10^{-7} \text{ m}$$

That's the same as 600 nm and corresponds to yellow-orange light

A photon has a frequency of 6.0 x 10^4 Hz. Convert this frequency into wavelength (nm). Does this frequency fall in the visible region?

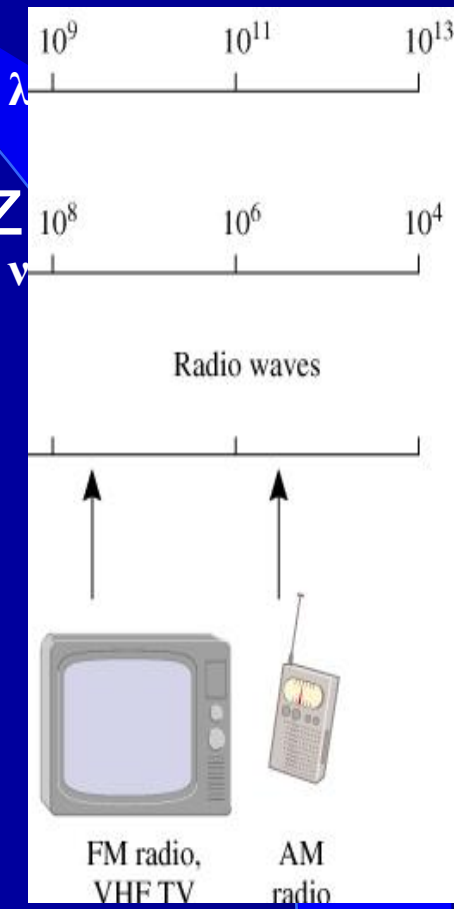
$$\lambda \times \nu = c$$

$$\lambda = c/\nu$$

$$= 3.00 \times 10^8 \text{ m/s} / 6.0 \times 10^4 \text{ Hz}$$

$$= 5.0 \times 10^3 \text{ m}$$

$$= 5.0 \times 10^{12} \text{ nm}$$



Mystery # 1, "Heated Solids Problem"

- The energy E of a single quantum of energy is

$E = h \times \nu$
$h = 6.63 \times 10^{-34}$ J•s, Planck's constant
ν = frequency of radiation

- Because $c = \nu \lambda$ or $\nu = c / \lambda$,

so, $E = h \times c / \lambda$

- According to quantum theory, energy is always emitted in multiple of *hv* ; *e.g.*, *hv, 2hv, 3hv ..... but never 1.67 hv or 4.98 hv.*

Analogies of concept of quantization

- Money system is based on “quantum” of value called “paisa”

- Processes in living system,
  - hens lay ‘quantized’ eggs
  - a pregnant cat give birth to an integer number of kittens, not to one-half or three-quarters of a kitten

Mystery # 2, "Photoelectric Effect" Solved by Einstein in 1905

Light has both:

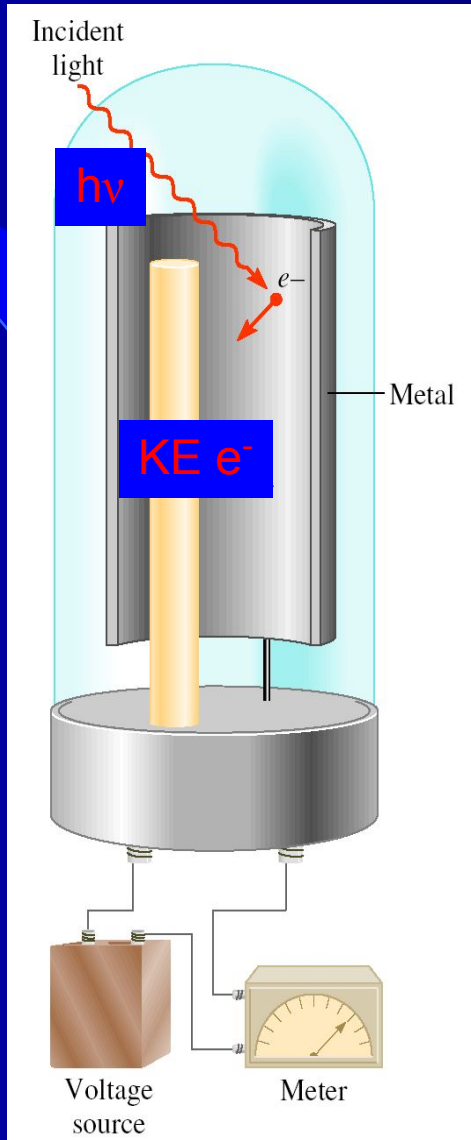
1. wave nature
2. particle nature

Photon is a "particle" of light

$$h\nu = \text{KE} + \text{BE}$$

$$\text{KE} = h\nu - \text{BE}$$

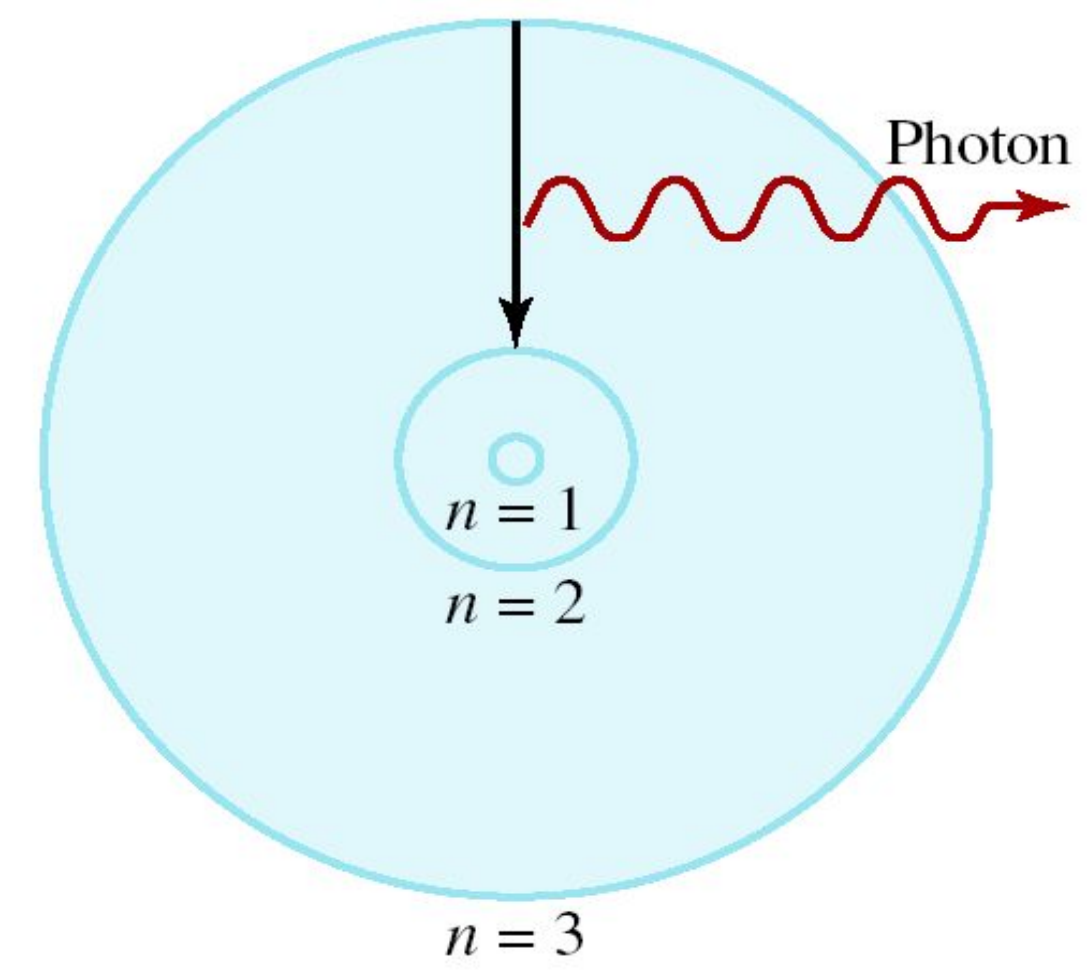
where KE is the kinetic energy of the ejected electron and BE is the binding energy of the electron in the metal.



Bohr's Model of the Atom (1913)

1. e^- can only have specific (quantized) energy values
2. light is emitted as e^- moves from one energy level to a lower energy level

$$E_n = -R_H\left(\frac{1}{n^2}\right)$$



n (principal quantum number) = 1, 2, 3,…

R_H (Rydberg constant) = 2.18×10^{-18} J

TABLE 7.1 The Various Series in Atomic Hydrogen Emission Spectrum

Series	n_f	n_i	Spectrum Region
Lyman	1	2, 3, 4, . . .	Ultraviolet
Balmer	2	3, 4, 5, . . .	Visible and ultraviolet
Paschen	3	4, 5, 6, . . .	Infrared
Brackett	4	5, 6, 7, . . .	Infrared

Calculate the wavelength (in nm) of a photon emitted by a hydrogen atom when its electron drops from the *n* = 5 state to the *n* = 3 state.

$$E_{\text{photon}} = \Delta E = R_{\text{H}}\left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$$

$$= 2.18 \text{ x } 10^{-18} \text{ J x } (1/25 - 1/9)$$

$$= -1.55 \text{ x } 10^{-19} \text{ J}$$

$$E_{\text{photon}} = h \text{ x c} / \lambda$$

$$\lambda = h \text{ x } c / E_{\text{photon}}$$

$$= 6.63 \text{ x } 10^{-34} \text{ (J}\cancel{\cdot}\text{s)} \text{ x } 3.00 \text{ x } 10^{8} \text{ (m/s)}\cancel{/}1.55 \text{ x } 10^{-19}\text{J}\cancel{/}$$

$$= 1280 \text{ nm}$$

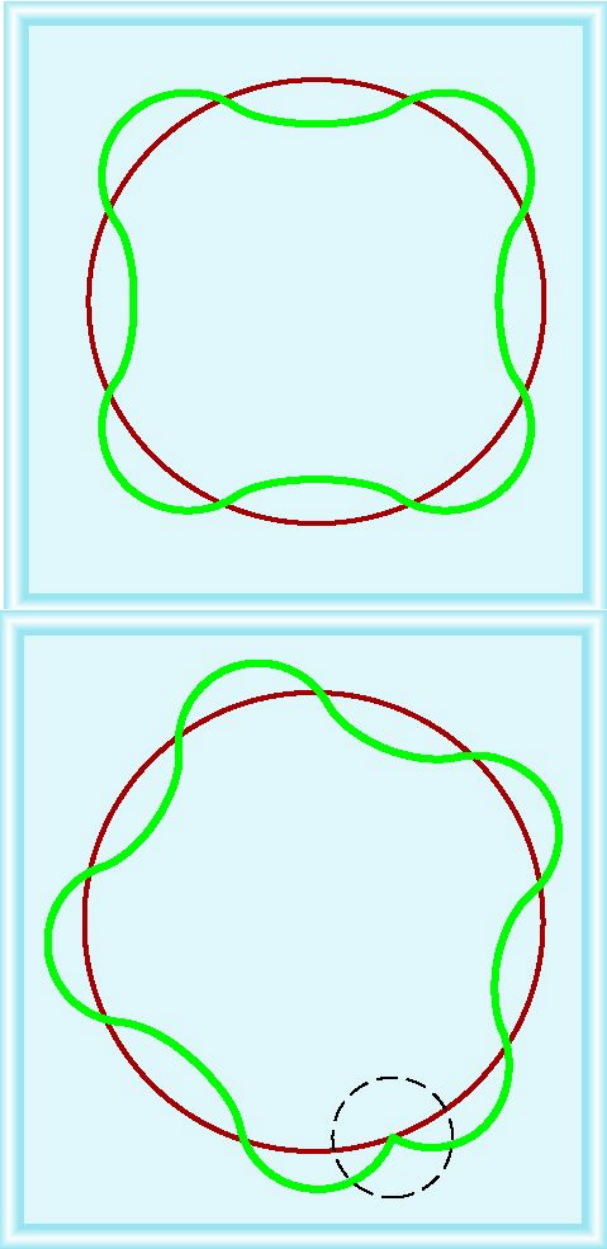
Why is e^- energy quantized?

De Broglie (1924) reasoned that e^- is both particle and wave.

$$2\pi r = n\lambda \qquad \lambda = \frac{h}{mu}$$

u = velocity of e-

m = mass of e-



Quantum Mechanics

- Bohr's approach did not account for the emission spectra of atoms containing more than one electrons (He, Li).
- When electrons are wavelike, how can the "**position**" of a wave be specified?
- To describe the problem of trying to locate a subatomic particle that behaves like a wave, Werner Heisenberg formulated the ***Heisenberg uncertainty principle***.

It is impossible to know simultaneously both the momentum p (defined as mass times velocity) and the position of a particle with certainty.

Quantum Mechanics

$$(\Delta x)(\Delta p) \geq \frac{h}{4\pi}$$

where, Δx is the uncertainties in measuring the position, and Δp is the uncertainties in measuring the momentum.

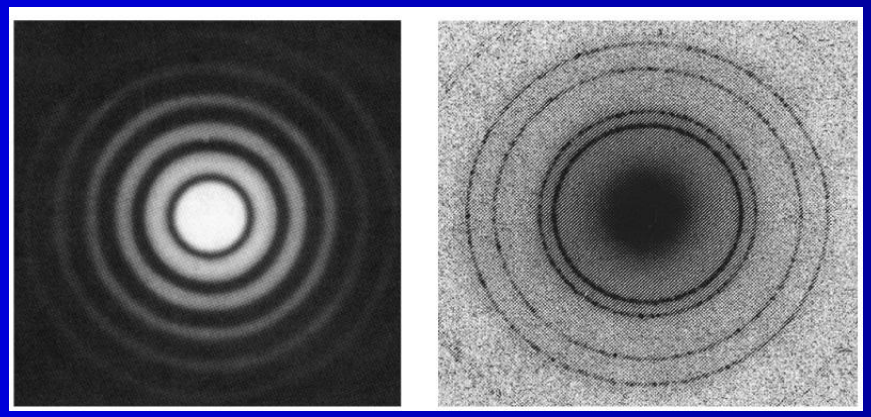
Schrodinger Wave Equation

In 1926 Schrodinger wrote an equation that described both the particle and wave nature of the e^- ($E\psi = H\psi$)

Wave function (y) describes:

1. energy of e^- with a given ψ. ψ^2 probability of finding e^- in a volume of space

Schrodinger's equation can only be solved exactly for the hydrogen atom. Must approximate its solution for multi-electron systems.



X-ray, & e^- diffraction on Al foil

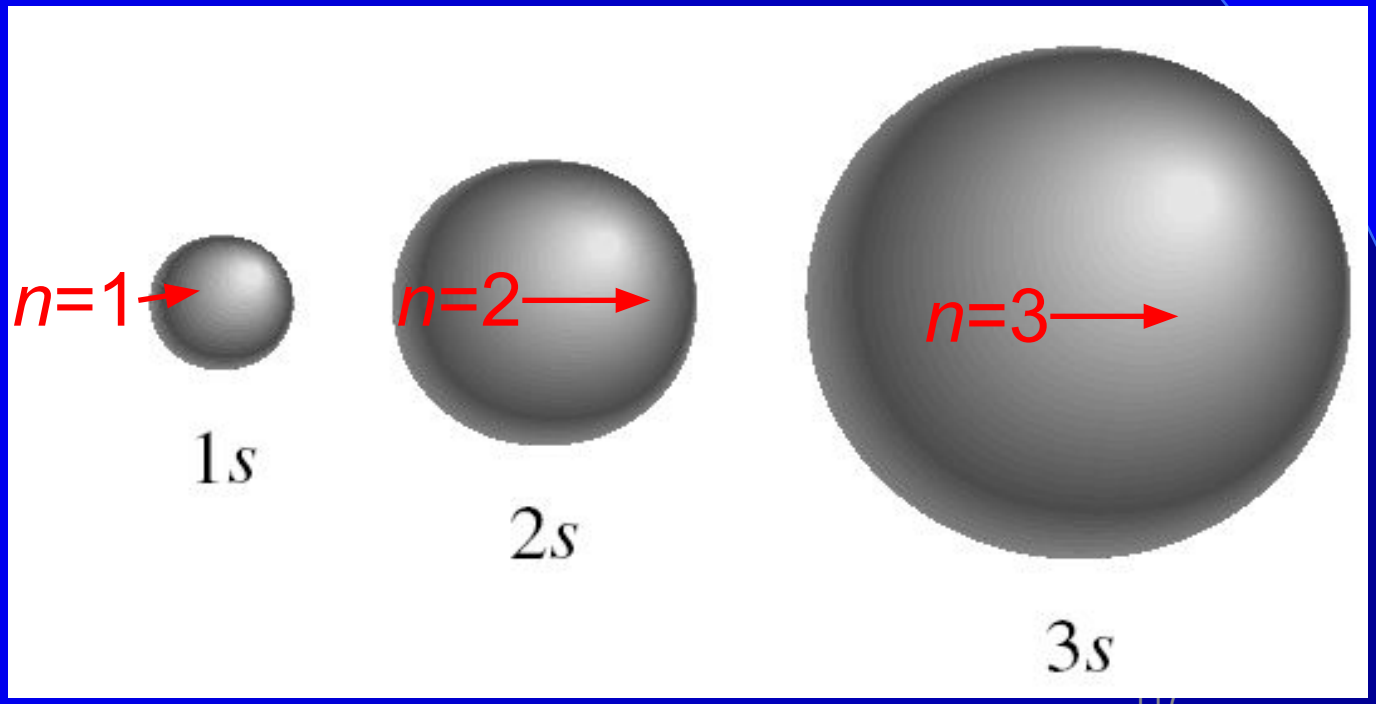
Schrodinger Wave Equation

ψ is a function of three numbers called ***quantum numbers*** (n, l, m_l, m_s)

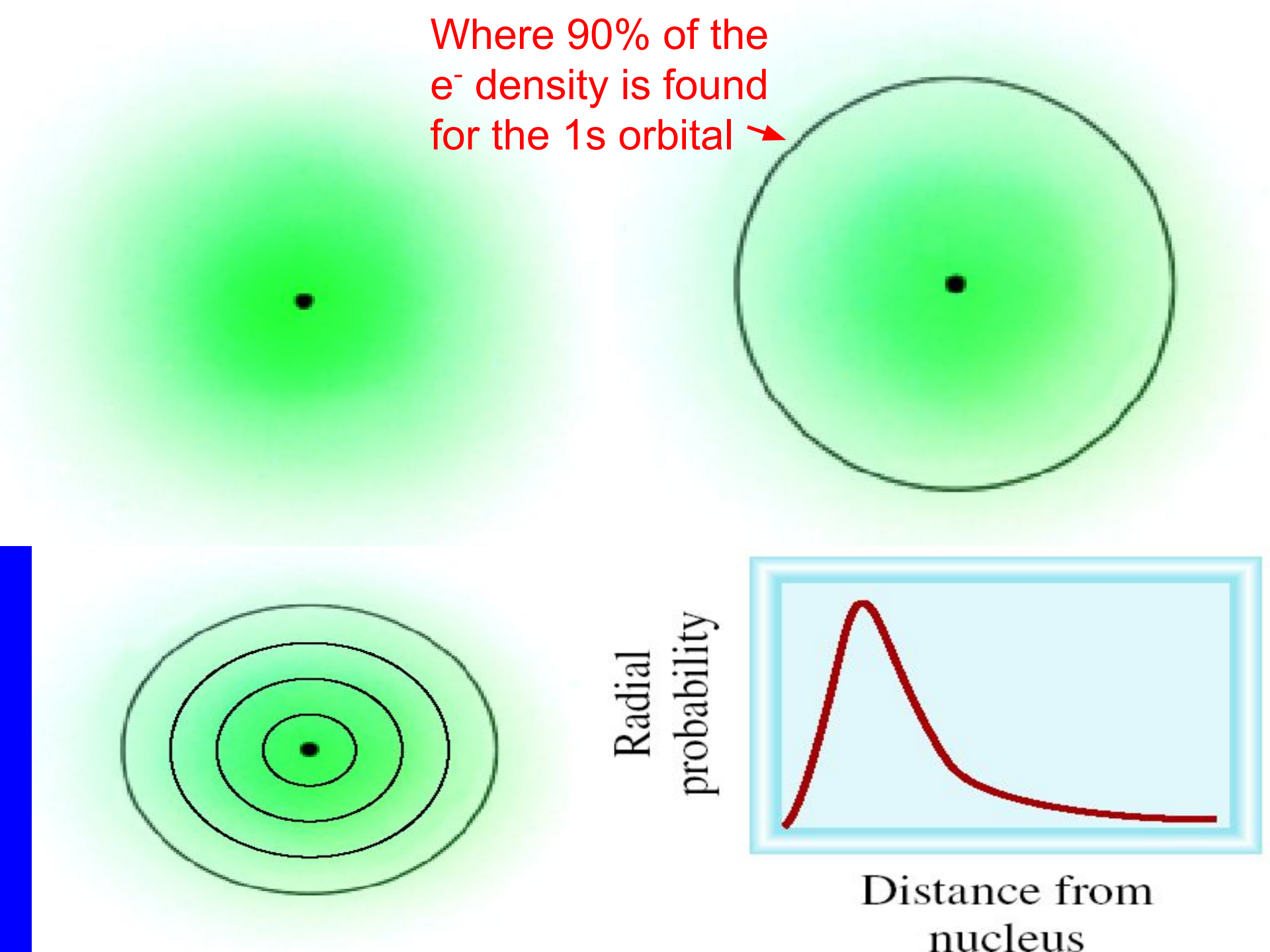
principal quantum number n

n = 1, 2, 3, 4, ….

Distance of e^- from the nucleus



Where 90% of the e^- density is found for the 1s orbital



Schrodinger Wave Equation

quantum numbers: (n, l, m_l, m_s)

angular momentum quantum number l

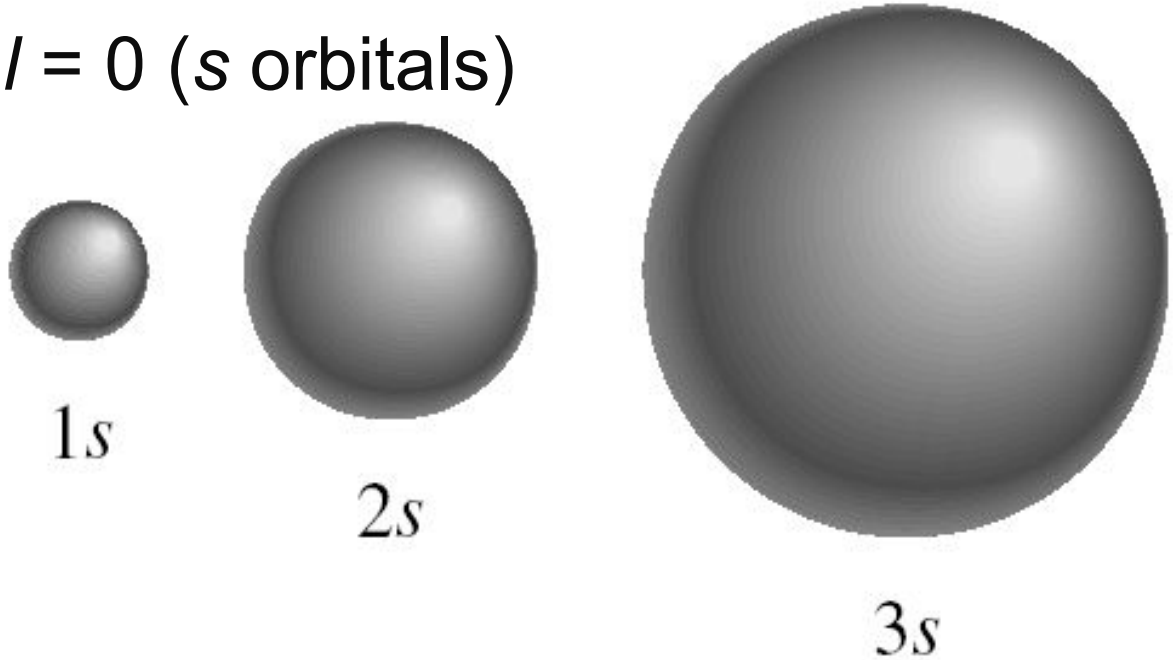
for a given value of n, $l = 0, 1, 2, 3, \ldots n-1$

$n = 1, l = 0$
$n = 2, l = 0$ **or** 1
$n = 3, l = 0, 1,$ **or** 2

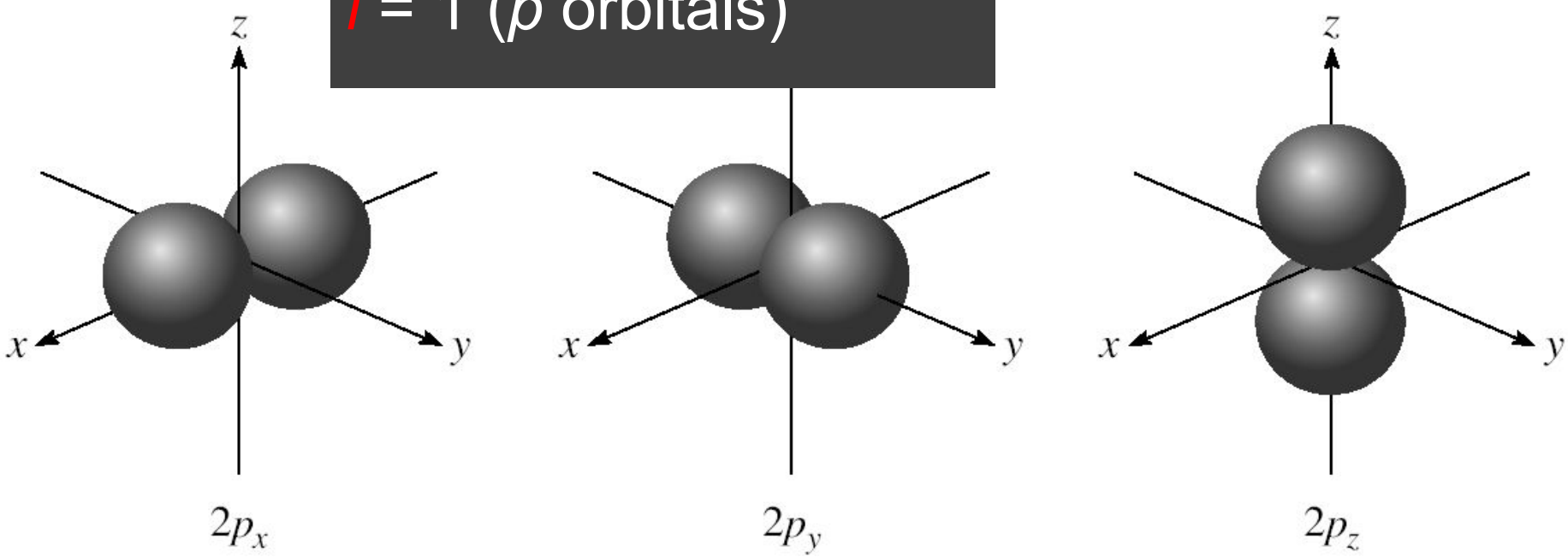
$l = 0$ *s* orbital
$l = 1$ *p* orbital
$l = 2$ *d* orbital
$l = 3$ *f* orbital

Shape of the "volume" of space that the e^- occupies

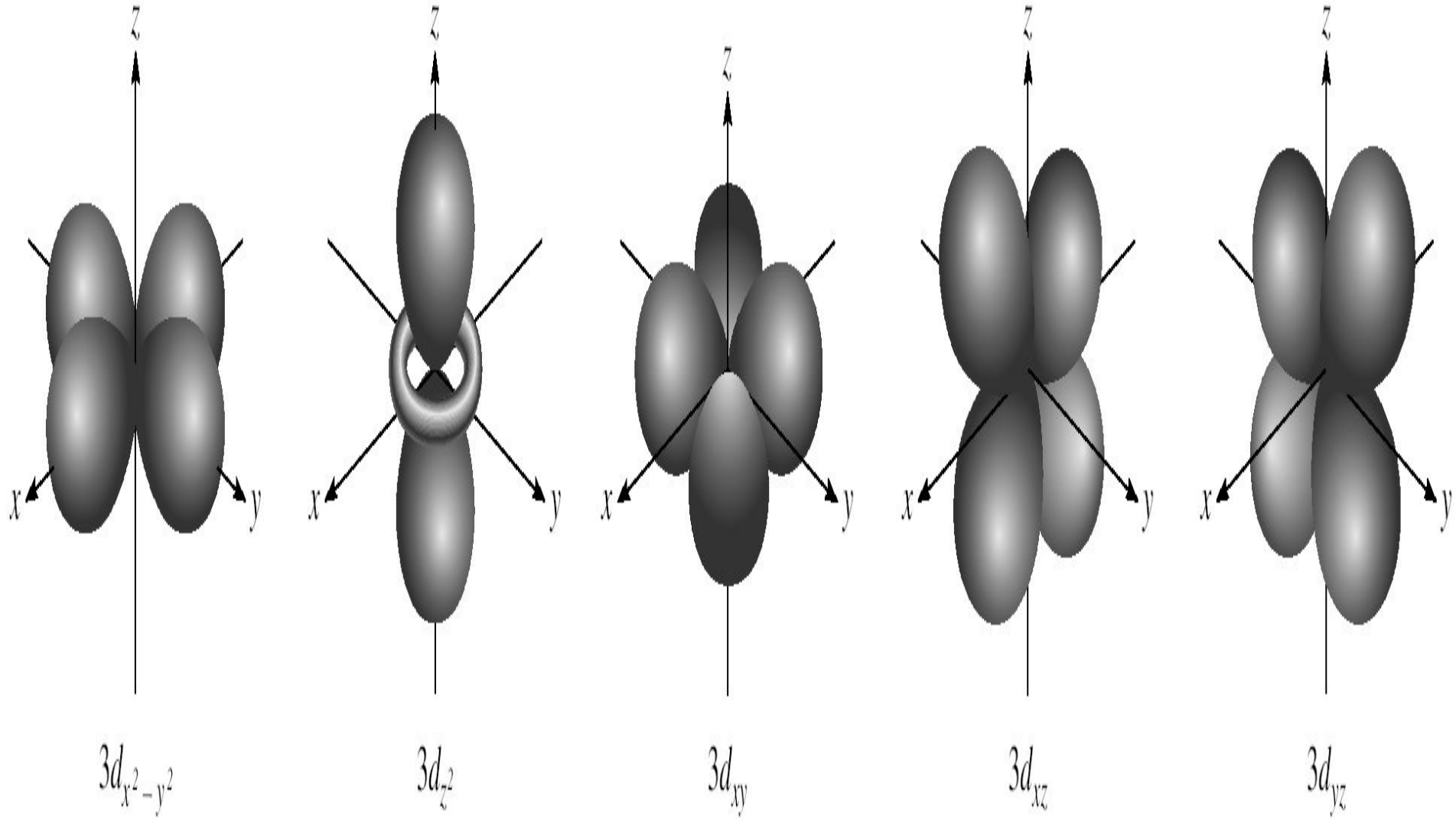
l = 0 (s orbitals)



l = 1 (p orbitals)



l = 2 (*d* orbitals)



Schrodinger Wave Equation

quantum numbers: (n, l, m_l, m_s)

magnetic quantum number m_l

for a given value of *l*

m_l = -*l*, …., 0, …. +*l*

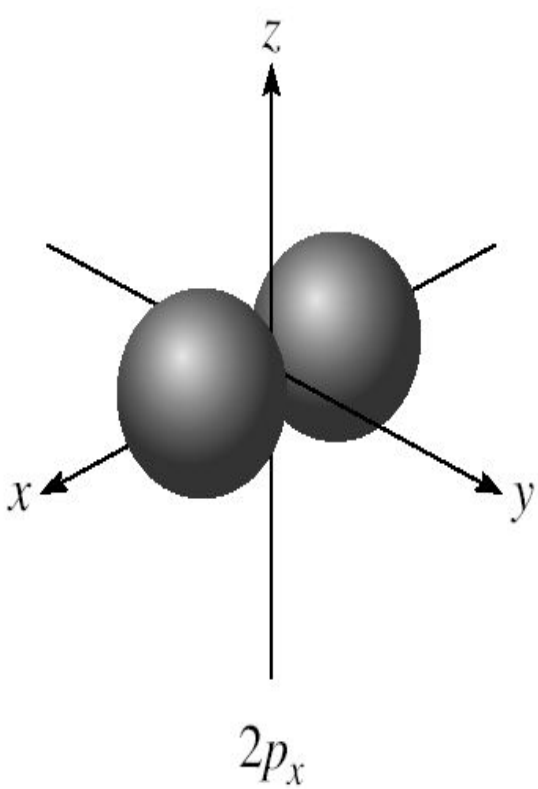
if *l* = 1 (p orbital), m_l = -1, 0, **or** 1

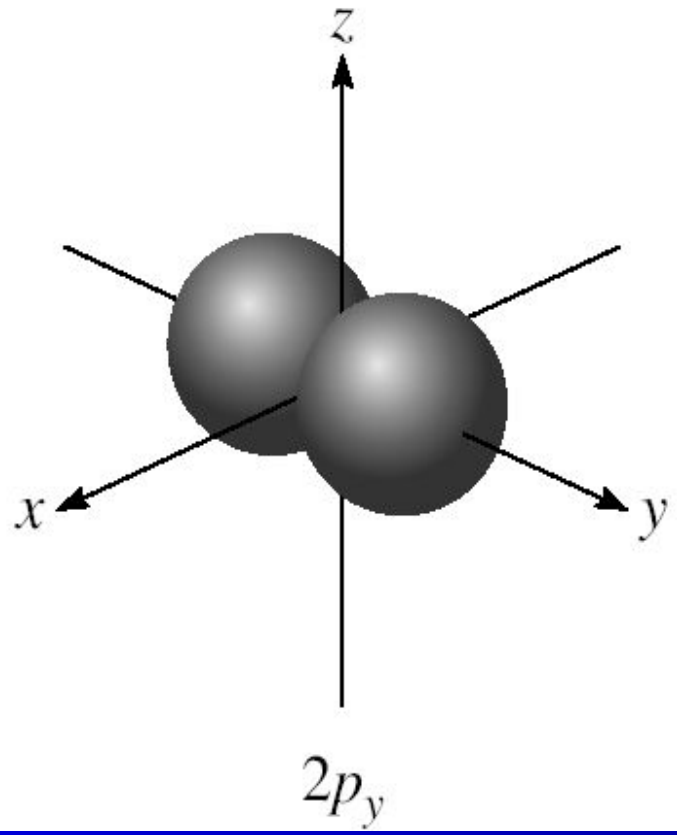
if *l* = 2 (d orbital), m_l = -2, -1, 0, 1, **or** 2

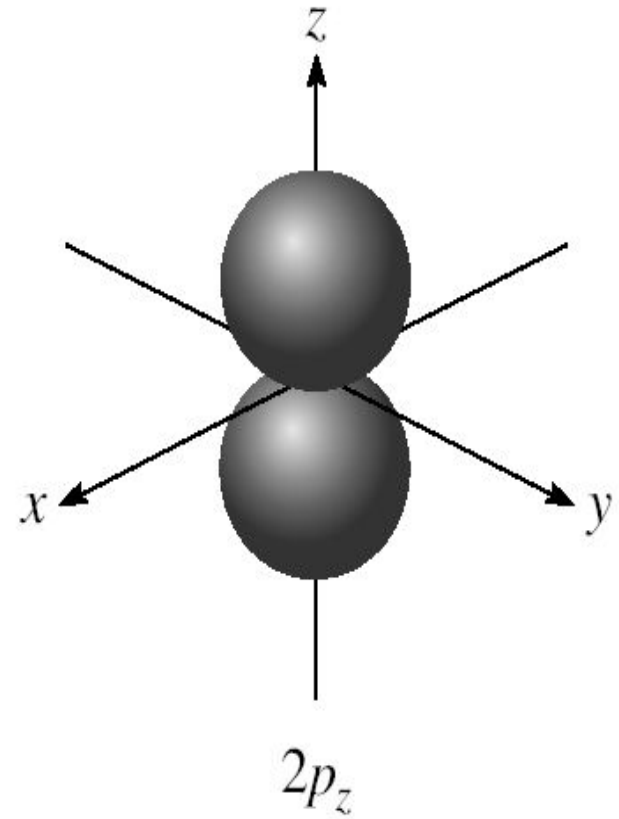
Orientation of the orbital in space

m_l = -1, 0, **or** 1

3 orientations is space

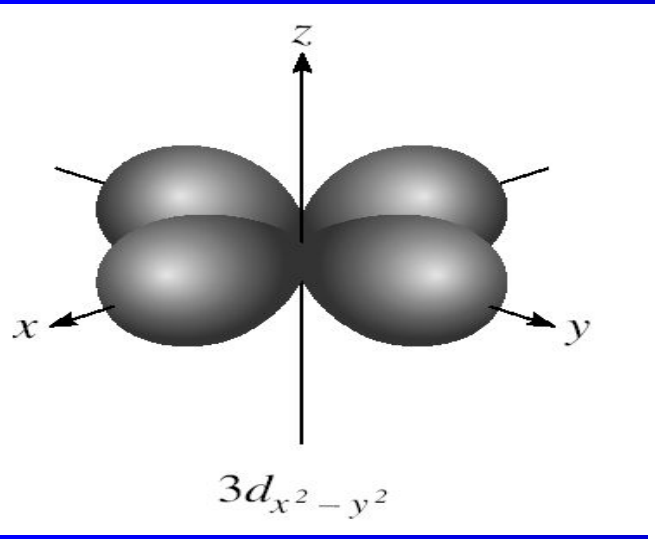


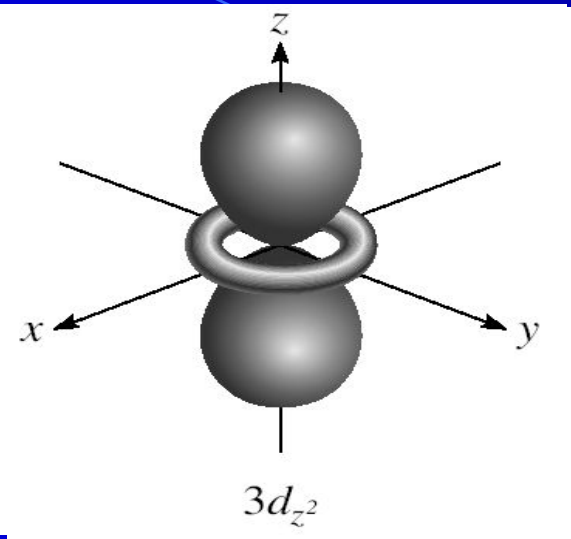


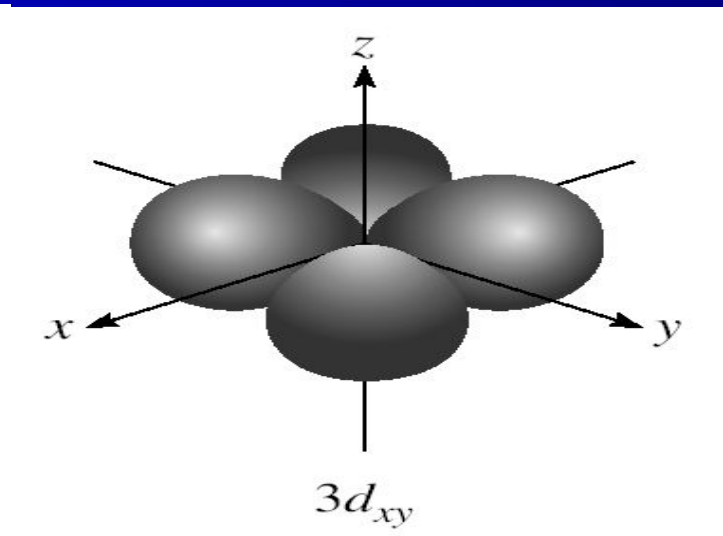


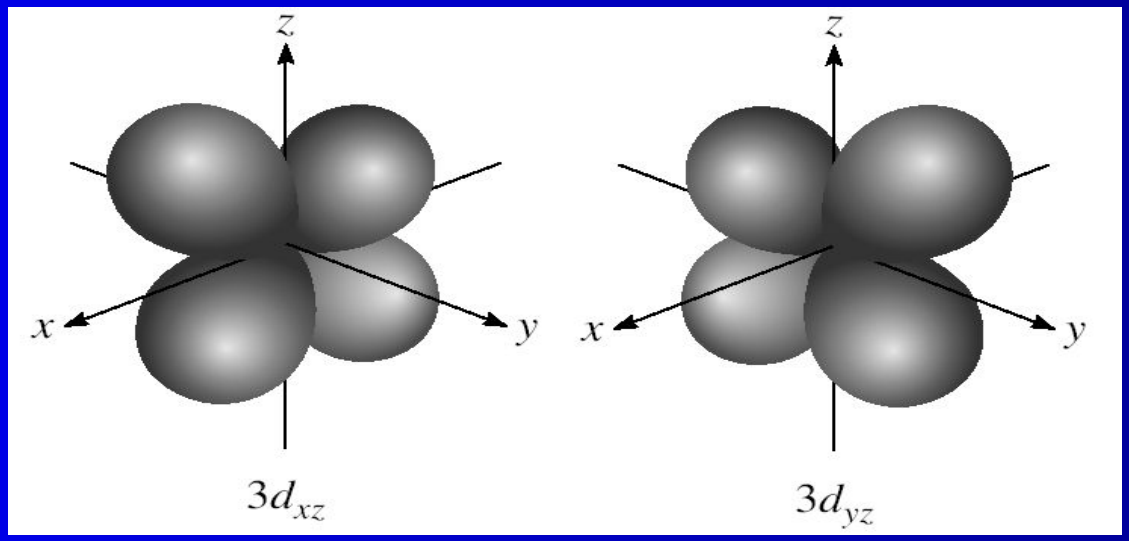
m_l = -2, -1, 0, 1, **or** 2

5 orientations is space







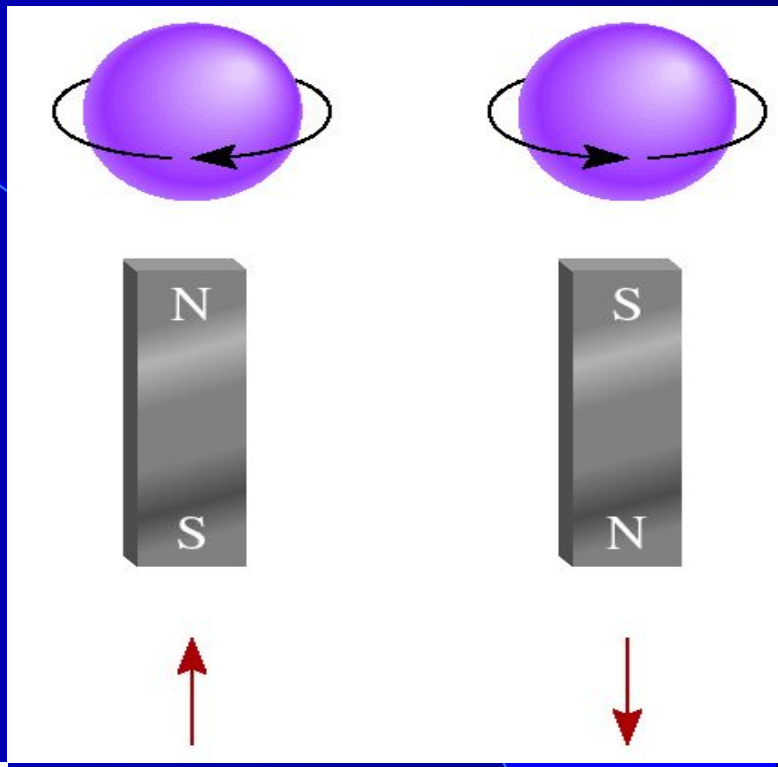


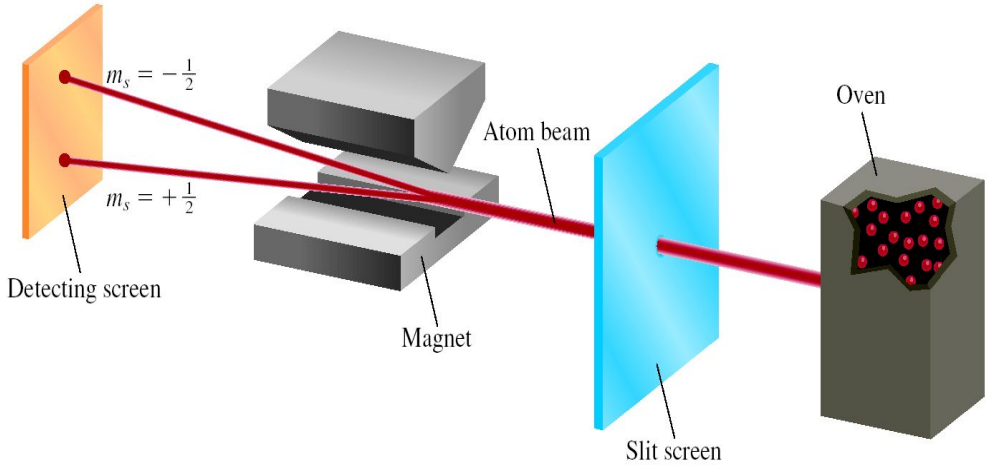
Schrodinger Wave Equation

(n, l, m_l, m_s)

spin quantum number m_s

$m_s = +½$ **or** $-½$





$m_s = +½$ $m_s = -½$

Schrodinger Wave Equation

quantum numbers: (n, l, m_l, m_s)

Existence (and energy) of electron in atom is described by its ***unique*** wave function ψ.

Pauli exclusion principle - no two electrons in an atom can have the same four quantum numbers.

Each seat is uniquely identified (E, R12,S8)
Each seat can hold only one individual at a time

TABLE 7.2 Relation Between Quantum Numbers and Atomic Orbitals

n	ℓ	m_ℓ	Number of Orbitals	Atomic Orbital Designations
1	0	0	1	$1s$
2	0	0	1	$2s$
	1	−1, 0, 1	3	$2p_x$, $2p_y$, $2p_z$
3	0	0	1	$3s$
	1	−1, 0, 1	3	$3p_x$, $3p_y$, $3p_z$
	2	−2, −1, 0, 1, 2	5	$3d_{xy}$, $3d_{yz}$, $3d_{xz}$, $3d_{x^2-y^2}$, $3d_{z^2}$
⋮	⋮	⋮	⋮	⋮

Schrodinger Wave Equation

quantum numbers: (n, l, m_l, m_s)

Shell – electrons with the same value of *n*

Subshell – electrons with the same values of *n* **and** *l*

Orbital – electrons with the same values of *n, l*, **and** m_l

How many electrons can an orbital hold?

If *n, l,* and m_l are fixed, then m_s = ½ or - ½

$\psi = (n, l, m_l, ½)$ or $\psi = (n, l, m_l, -½)$

An orbital can hold 2 electrons

Electron addresses

Electron addresses

- #1 Shell number, n
- Average distance from nucleus

Electron addresses

- #1 Shell number, n
- #2 Subshell type, l
- Average distance from nucleus
- Region shape

Electron addresses

- #1 Shell number, n
- #2 Subshell type, l
- #3 Orbital, m

- Average distance from nucleus
- Region shape
- Region orientation

Electron addresses

- #1 Shell number, n
- #2 Subshell type, l
- #3 Orbital, m
- #4 Spin, s

- Average distance from nucleus
- Region shape
- Region orientation
- Direction of e^- rotation

Electron addresses

- #1 Shell number, n
- #2 Subshell type, l
- #3 Orbital, m
- #4 Spin, s

- Average distance from nucleus
- Region shape
- Region orientation
- Direction of e^- rotation

These four address components (n, l, m, and s) are called quantum numbers in more formal treatments

#1 - Electron Shells

- Electrons are arranged in shells according to how far out, on average, they are from the nucleus
- These can be visualized as similar to the space occupied by the layers of an onion

Shell Populations

- The innermost shell can hold 2 e^-'s
- The second shell can hold 8 e^-'s
- The third shell can hold 18 e^-'s
- The fourth shell can hold 32 e^-'s
- See the pattern?

2

8

18

32

2

8

18

32

First, note the difference between successive numbers.

2

6

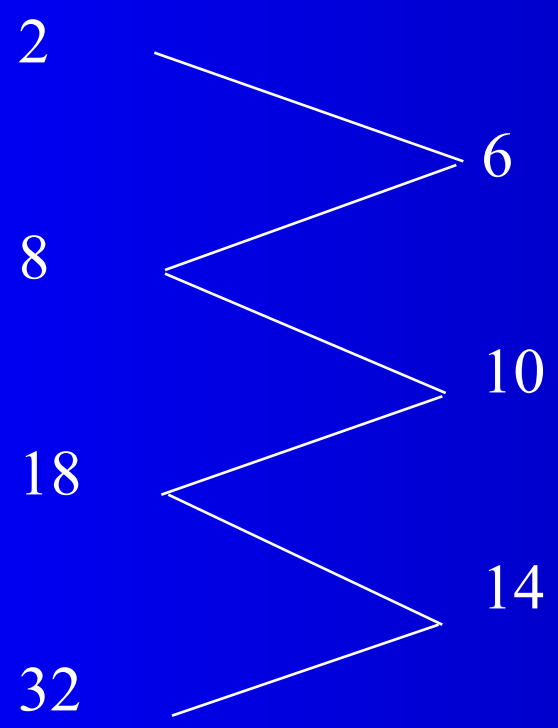
8

10

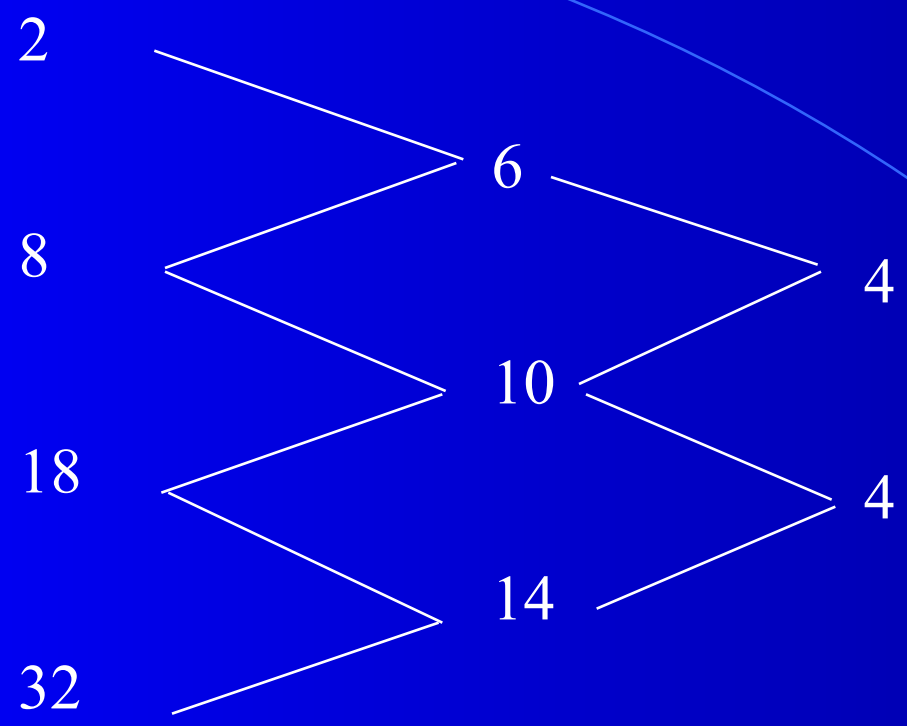
18

14

32



Now, repeat the process


2
8
18
32
6
10
14
4
4

2

6

8

4

10

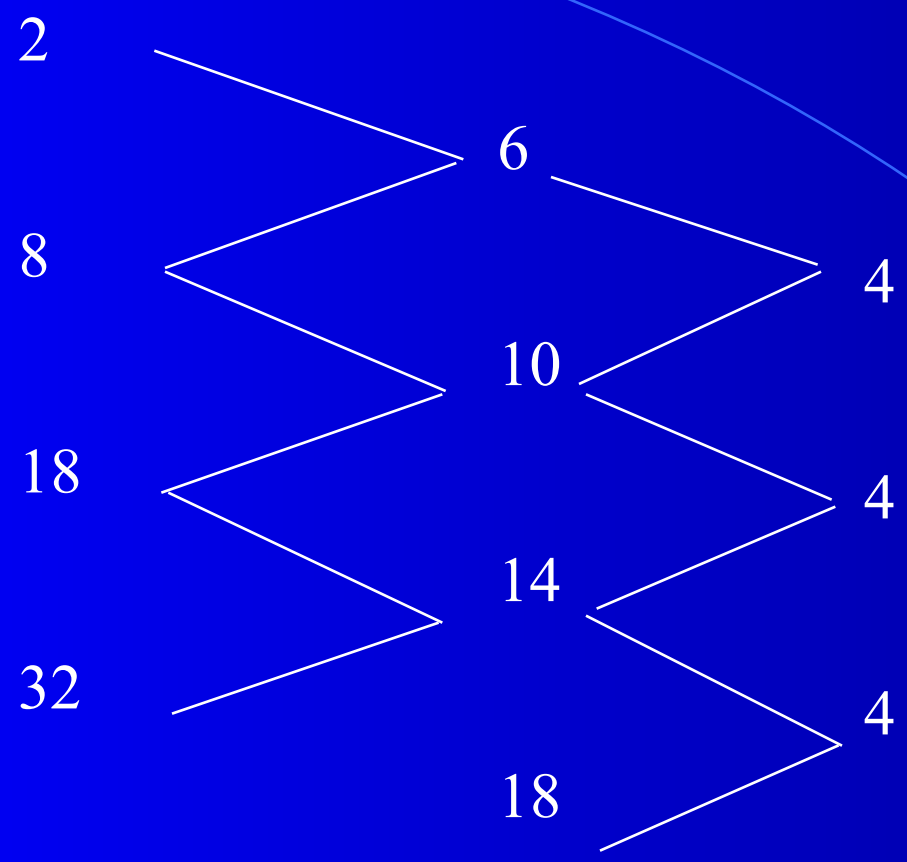
18

4

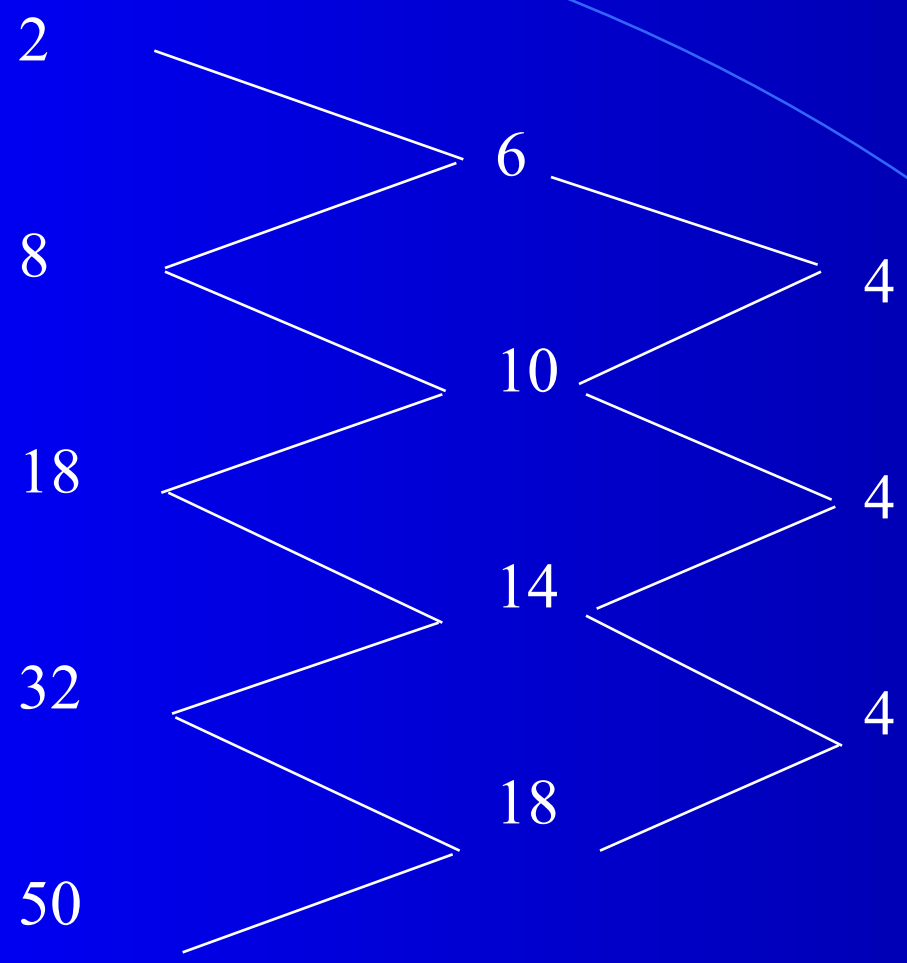
14

32

See the pattern?



Aha!



Aha!

2

8

18

32

50

To extract the underlying formula, divide each number by 2

$2/2 = 1$

$8/2 = 4$

$18/2 = 9$

$32/2 = 16$

$50/2 = 25$

To extract the underlying formula, divide each number by 2

$2/2 = 1$

$8/2 = 4$

$18/2 = 9$

$32/2 = 16$

$50/2 = 25$

Note that this is now a series of perfect squares of integers...

$2/2 = 1 = 1^2$

$8/2 = 4 = 2^2$

$18/2 = 9 = 3^2$

$32/2 = 16 = 4^2$

$50/2 = 25 = 5^2$

Note that this is now a series of perfect squares of integers...

$2/2 = 1 = 1^2$

$8/2 = 4 = 2^2$

$18/2 = 9 = 3^2$

$32/2 = 16 = 4^2$

$50/2 = 25 = 5^2$

The fomula is $2n^2$ where n is the shell number

Shell population = $2n^2$

Shell population = $2n^2$

- 1st shell
- $2\ (1^2) = 2\ (1) = 2$

Shell population = $2n^2$

- 1st shell
- 2nd shell

- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$

Shell population = $2n^2$

- 1st shell
- 2nd shell
- 3rd shell

- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$
- $2\ (3^2) = 2\ (9) = 18$

Shell population = $2n^2$

- 1st shell
- 2nd shell
- 3rd shell
- 4th shell

- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$
- $2\ (3^2) = 2\ (9) = 18$
- $2\ (4^2) = 2\ (16) = 32$

Shell population = $2n^2$

- 1st shell
- 2nd shell
- 3rd shell
- 4th shell
- 5th shell

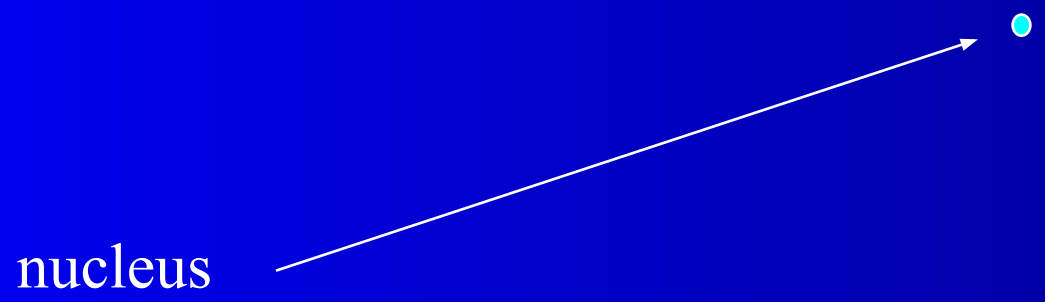
- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$
- $2\ (3^2) = 2\ (9) = 18$
- $2\ (4^2) = 2\ (16) = 32$
- $2\ (5^2) = 2\ (25) = 50$

#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$

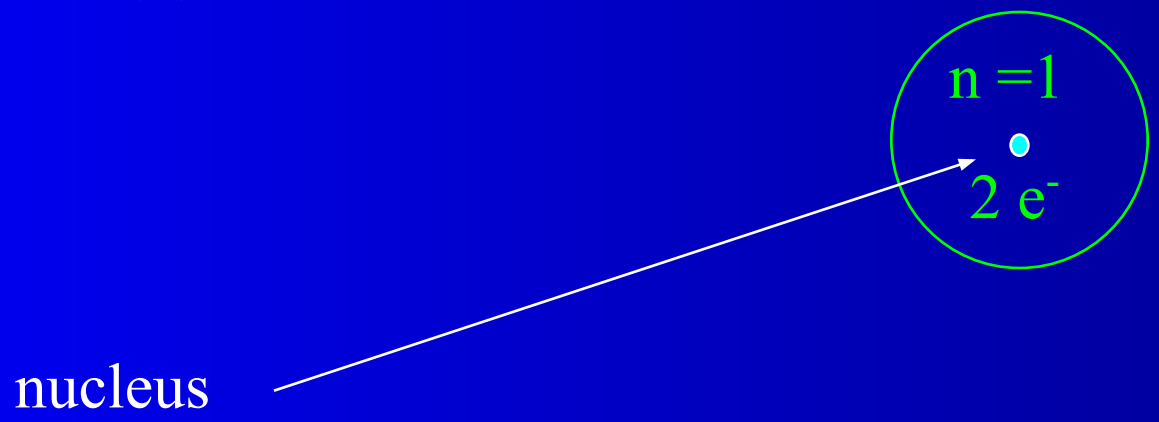
#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



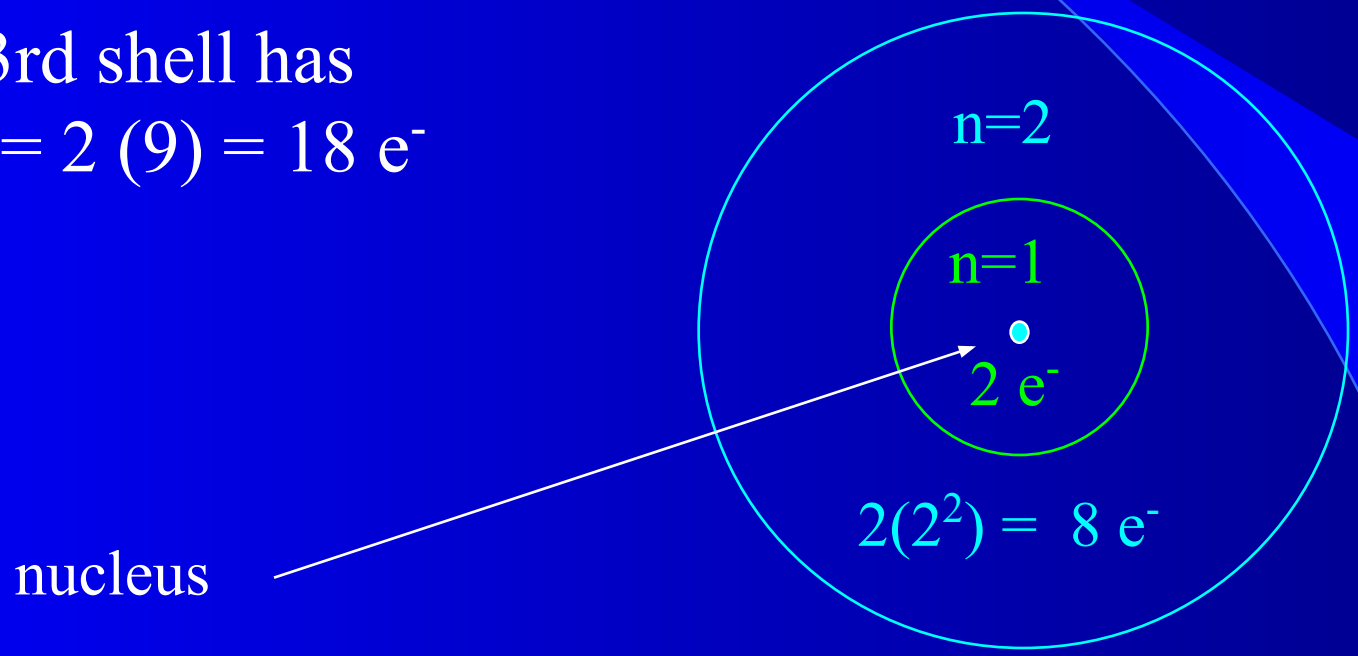
#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



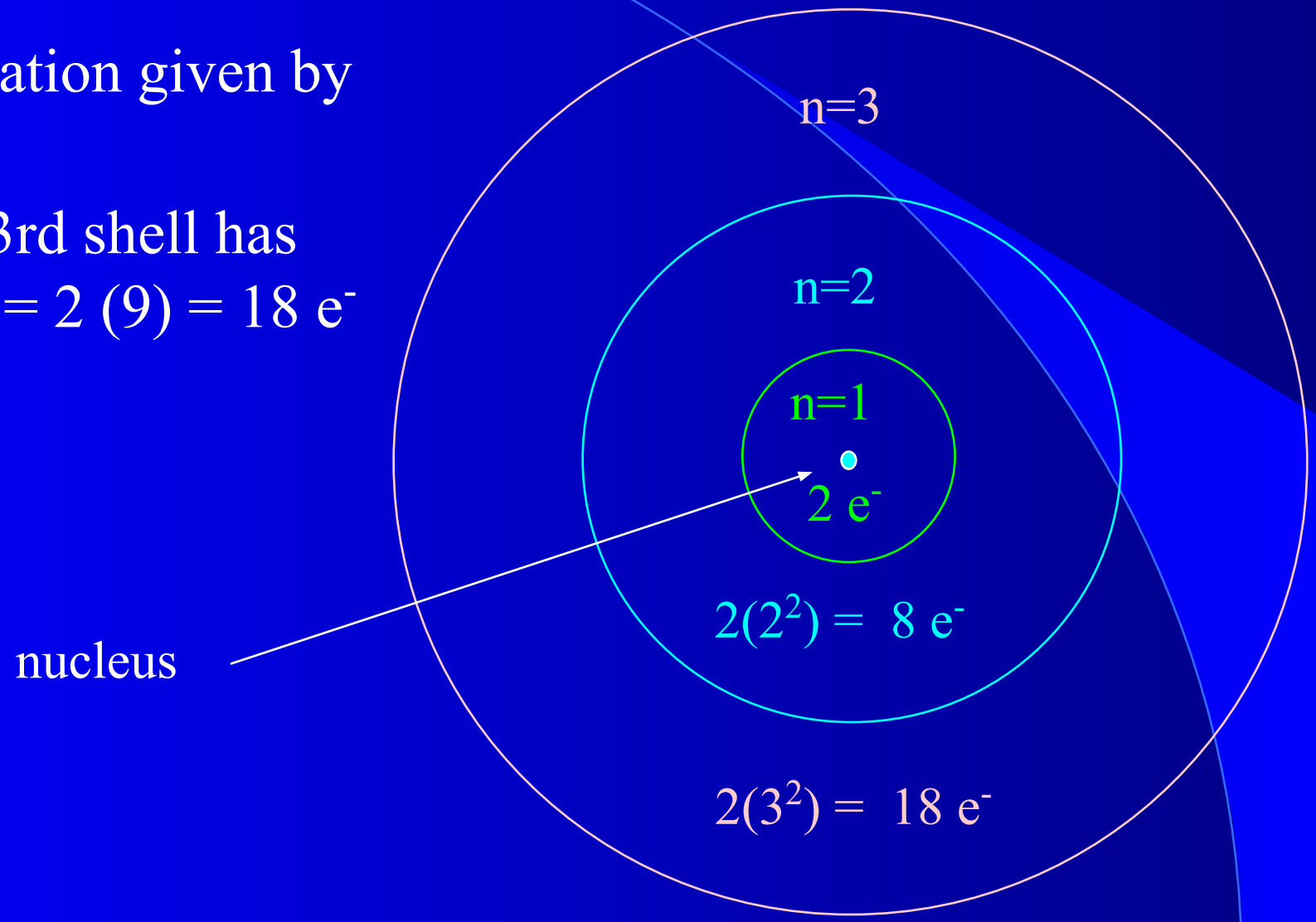
#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



How many electrons make up the 6th shell?

1. 18
2. 36
3. 72
4. 144

Shell population = $2n^2$

Shell population = $2n^2$

- 1st shell
- $2\ (1^2) = 2\ (1) = 2$

Shell population = $2n^2$

- 1st shell
- 2nd shell

- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$

Shell population = $2n^2$

- 1st shell
- 2nd shell
- 3rd shell

- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$
- $2\ (3^2) = 2\ (9) = 18$

Shell population = $2n^2$

- 1st shell
- 2nd shell
- 3rd shell
- 4th shell

- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$
- $2\ (3^2) = 2\ (9) = 18$
- $2\ (4^2) = 2\ (16) = 32$

Shell population = $2n^2$

- 1st shell
- 2nd shell
- 3rd shell
- 4th shell
- 5th shell

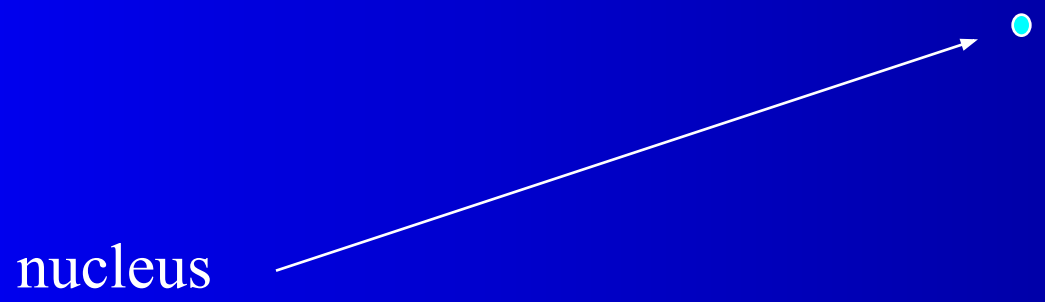
- $2\ (1^2) = 2\ (1) = 2$
- $2\ (2^2) = 2\ (4) = 8$
- $2\ (3^2) = 2\ (9) = 18$
- $2\ (4^2) = 2\ (16) = 32$
- $2\ (5^2) = 2\ (25) = 50$

#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$

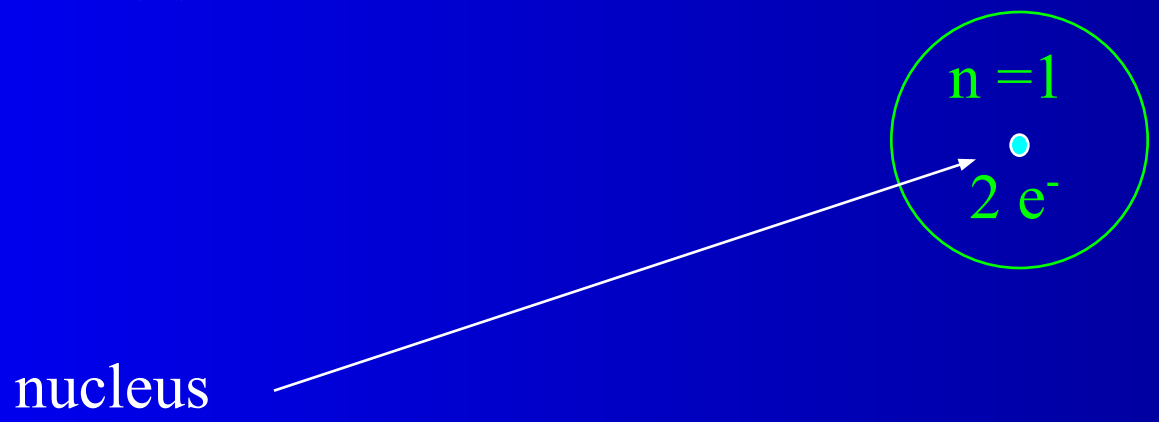
#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



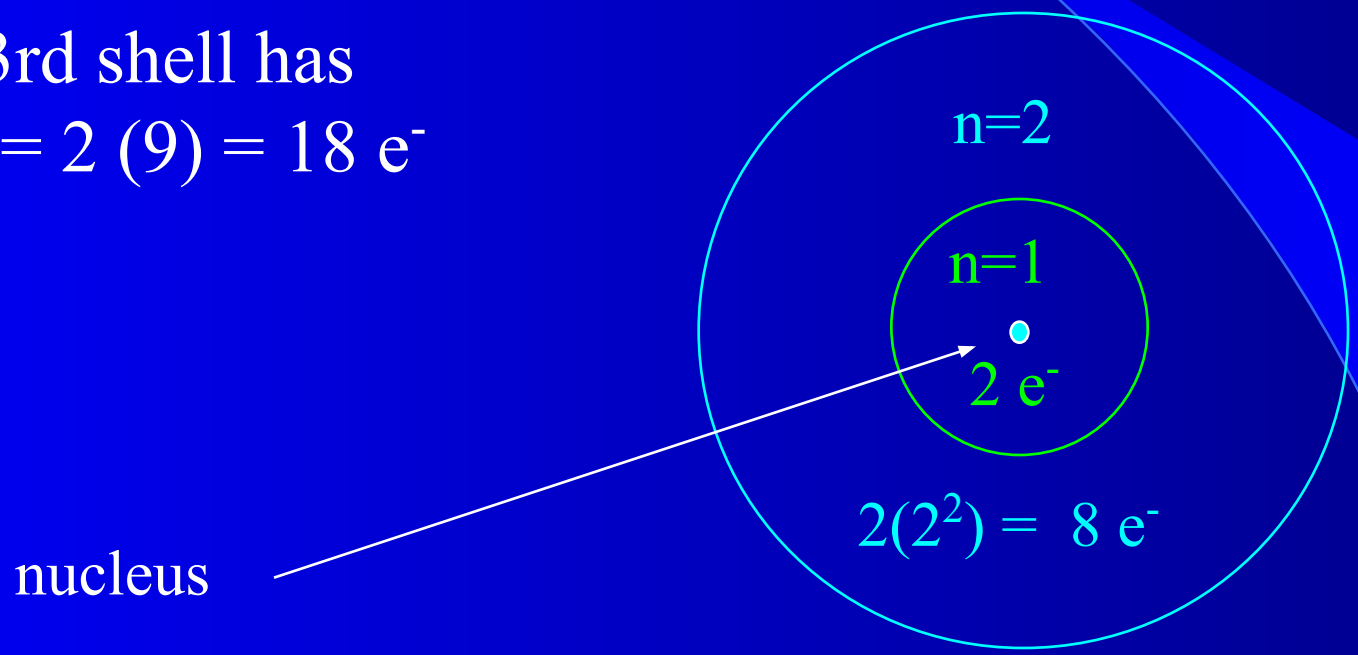
#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



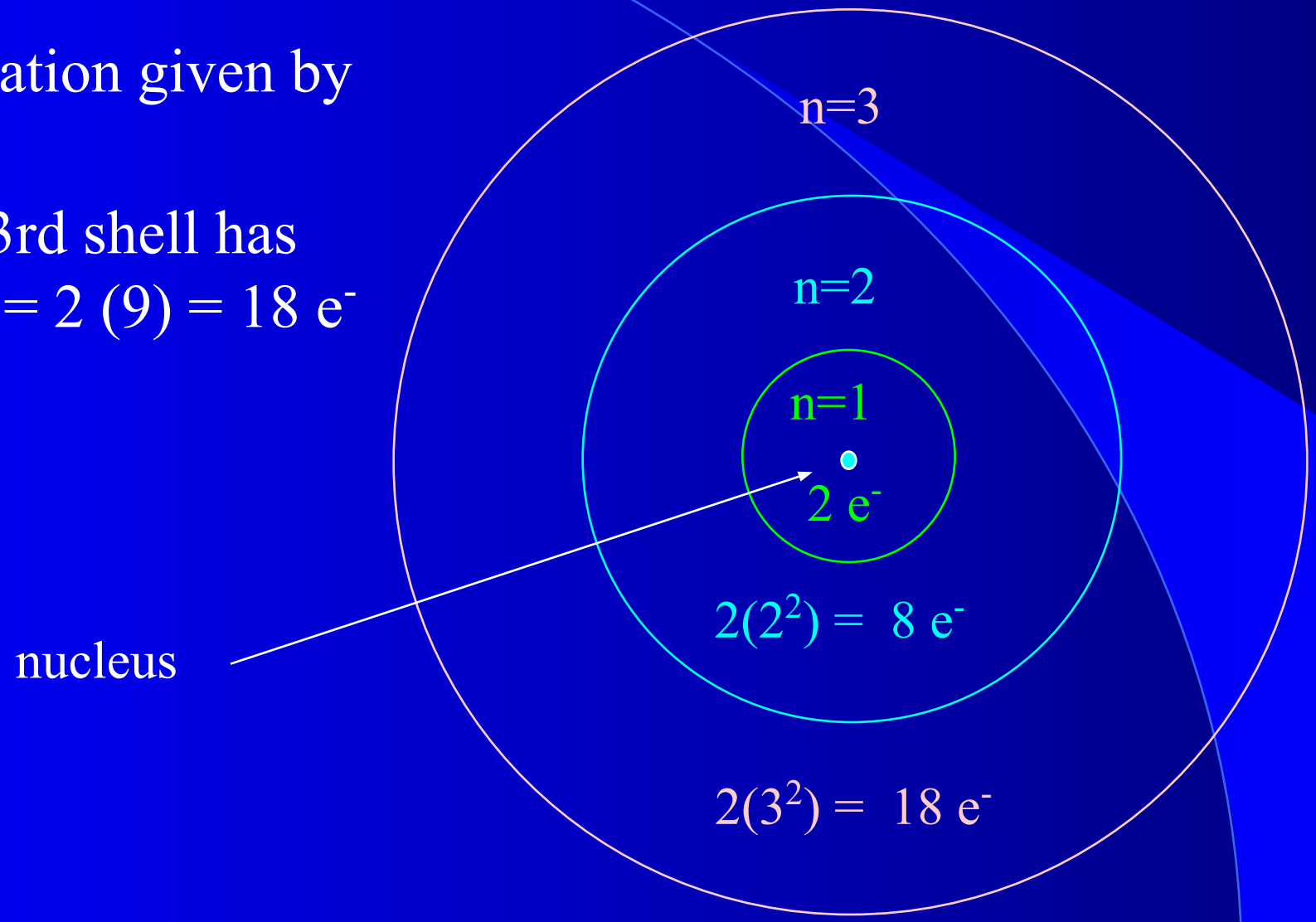
#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



#1 - Electron shells

- Population given by $2n^2$
- E.g., 3rd shell has $2\ (3^2) = 2\ (9) = 18\ e^-$



How many electrons make up the 6th shell?

1. 18
2. 36
3. 72
4. 144

How many electrons make up the 6th shell?

1. 18
2. 36
3. 72
4. 144

$$2(6^2) = 2(36) = 72$$

4-Part electron addresses

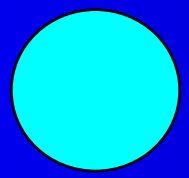
- #1 Shell number, n
- #2 Subshell type, l
- Average distance from nucleus
- Region shape

#2 - Subshells

- Within each shell there are subshells (or sublevels)
- Four kinds to learn
- s spherical (sharp)
- p 2-lobes (principal)
- d 4-lobes (diffuse)
- f 6- or 8-lobes (fundamental)

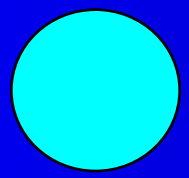
Subshell (sublevel) shapes

Subshell (sublevel) shapes

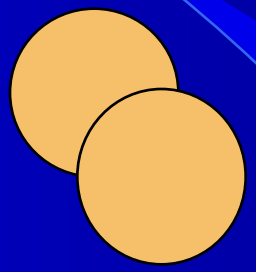


s (1 lobe)

Subshell (sublevel) shapes

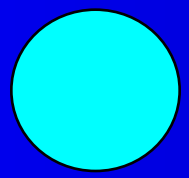


s (1 lobe)

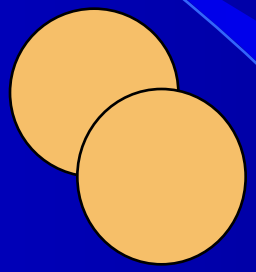


p (2 lobes)

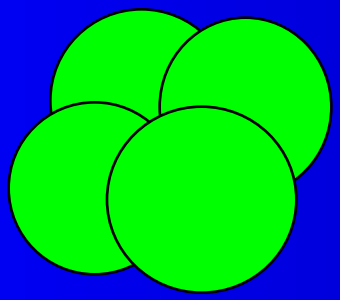
Subshell (sublevel) shapes



s (1 lobe)

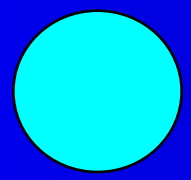


p (2 lobes)

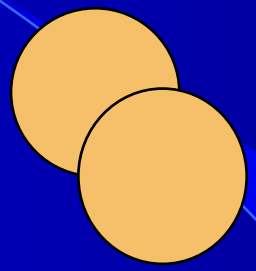


d (4 lobes)

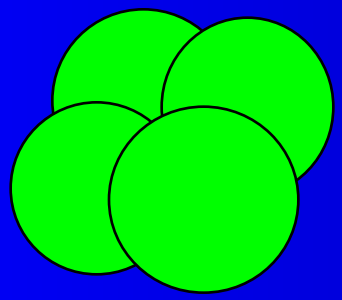
Subshell (sublevel) shapes



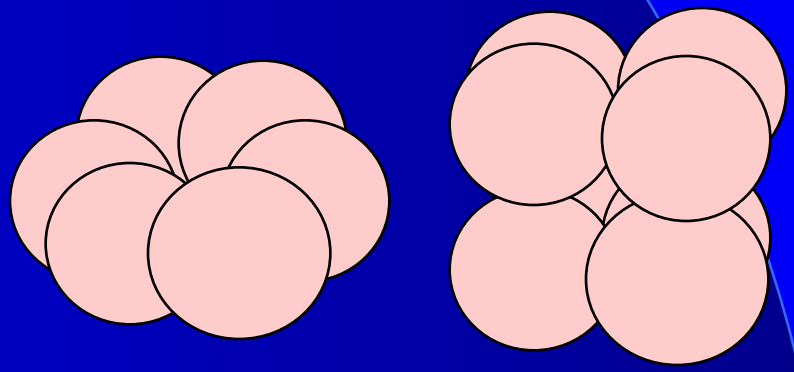
s (1 lobe)



p (2 lobes)



d (4 lobes)



f (6 or 8 lobes)

Available subshells (sublevels)

- 1st shell s
- 2nd shell s p
- 3rd shell s p d
- 4th shell s p d f
- We use numbers to distinguish between subshells of the same type in different layers

Available subshells (sublevels)

- 1st shell 1s
- 2nd shell 2s 2p
- 3rd shell 3s 3p 3d
- 4th shell 4s 4p 4d 4f

Available subshells (sublevels)

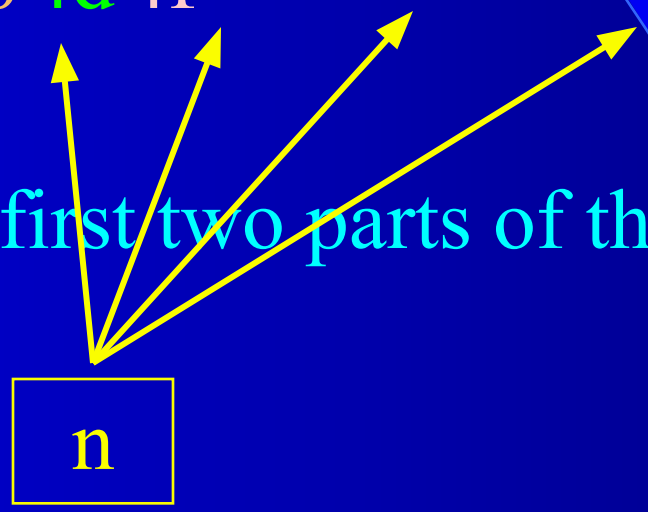
- 1st shell 1s
- 2nd shell 2s 2p
- 3rd shell 3s 3p 3d
- 4th shell 4s 4p 4d 4f

- This completes the first two parts of the electron address

Available subshells (sublevels)

- 1st shell 1s
- 2nd shell 2s 2p
- 3rd shell 3s 3p 3d
- 4th shell 4s 4p 4d 4f

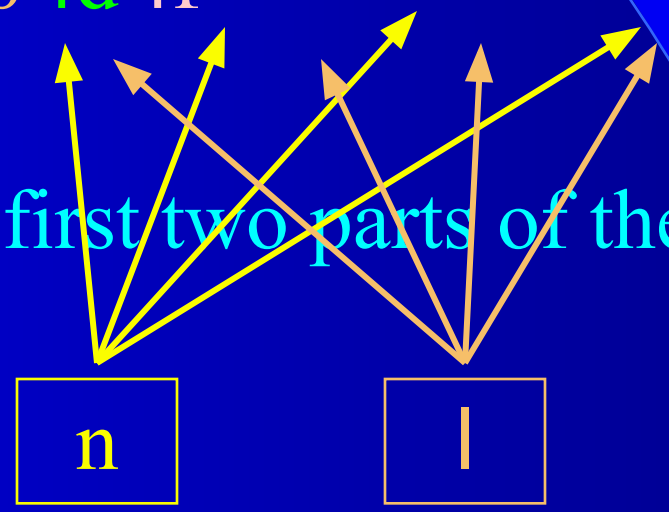
- This completes the first two parts of the electron address



Available subshells (sublevels)

- 1st shell 1s
- 2nd shell 2s 2p
- 3rd shell 3s 3p 3d
- 4th shell 4s 4p 4d 4f

- This completes the first two parts of the electron address

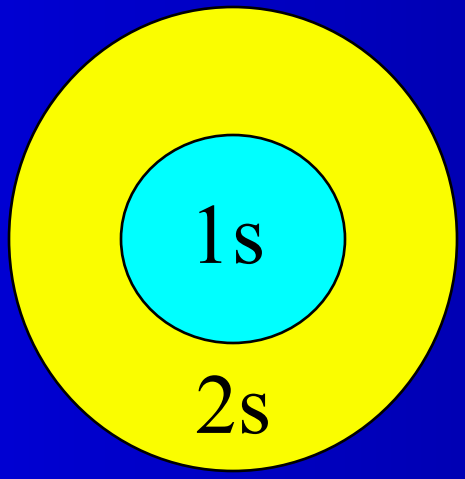


s Subshells

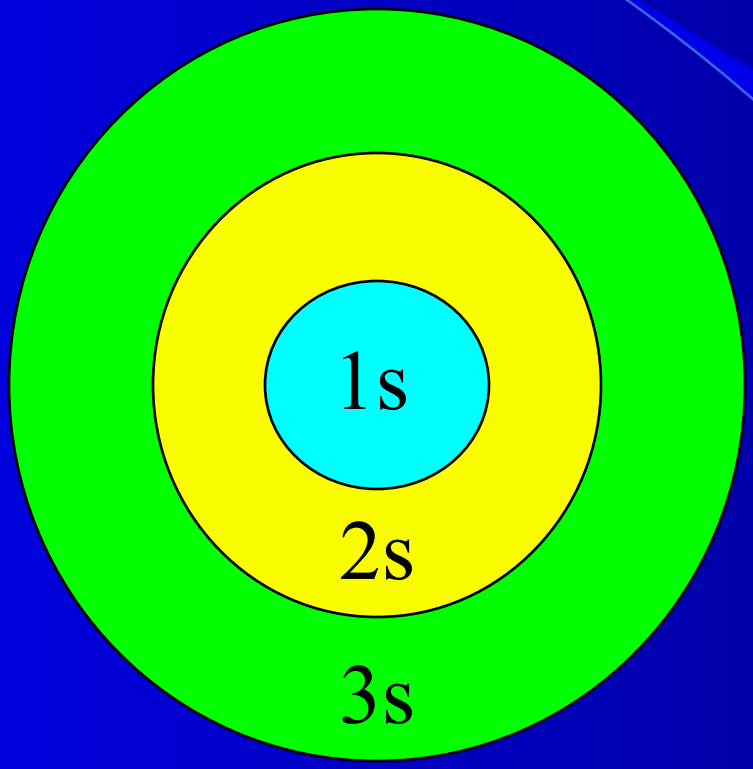
s Subshells

1s

s Subshells

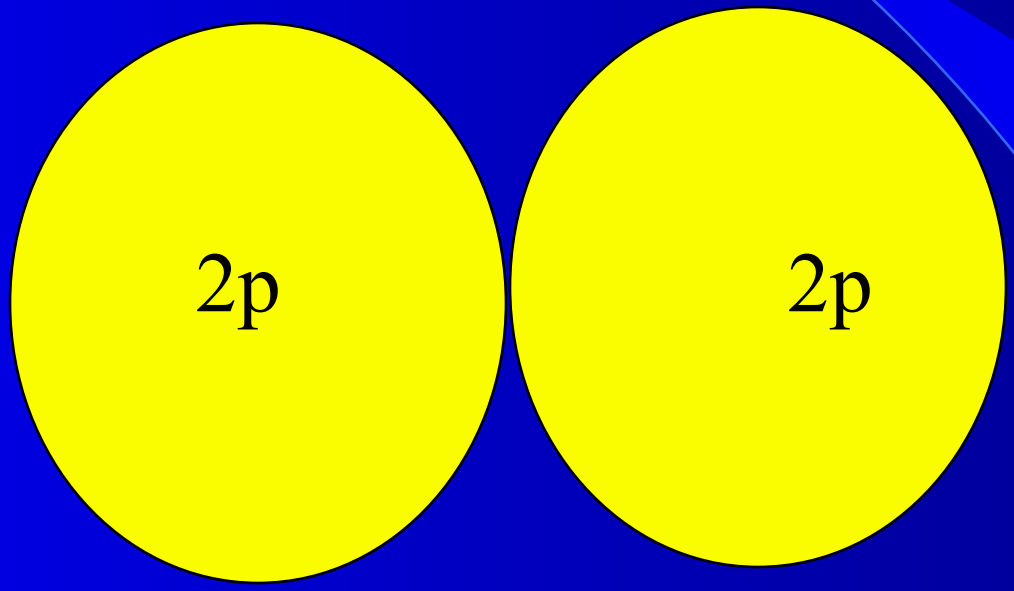


s Subshells

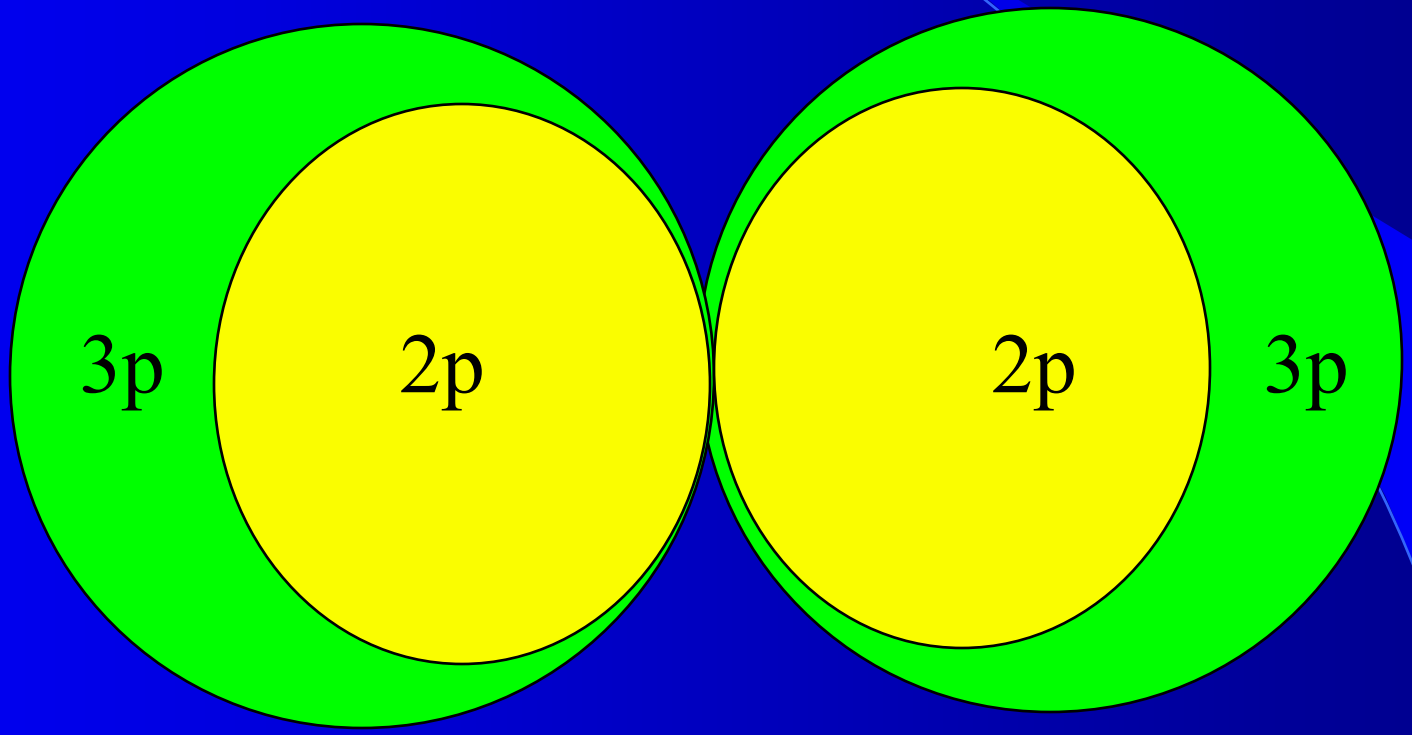


p Subshells

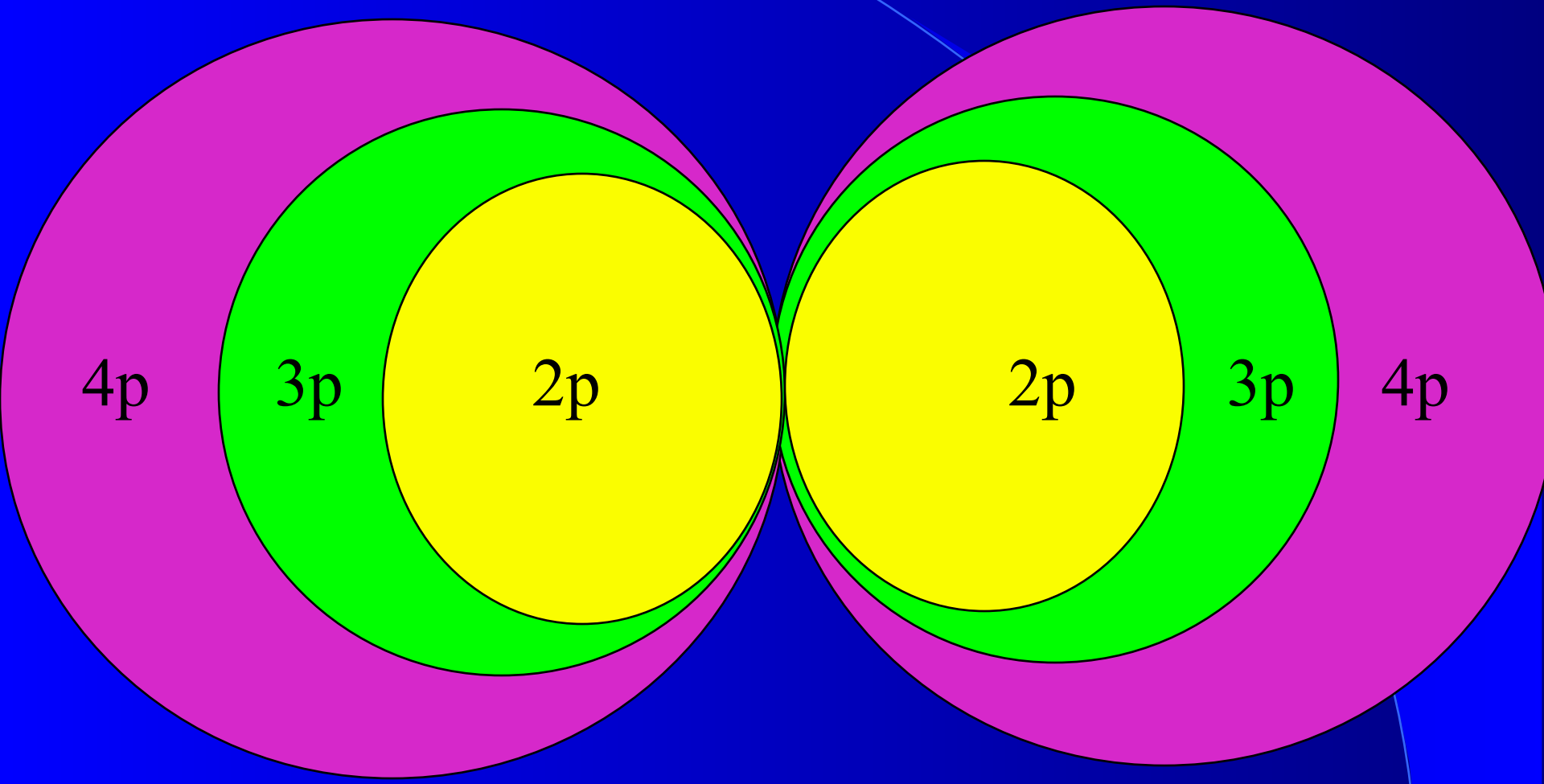
p Subshells



p Subshells



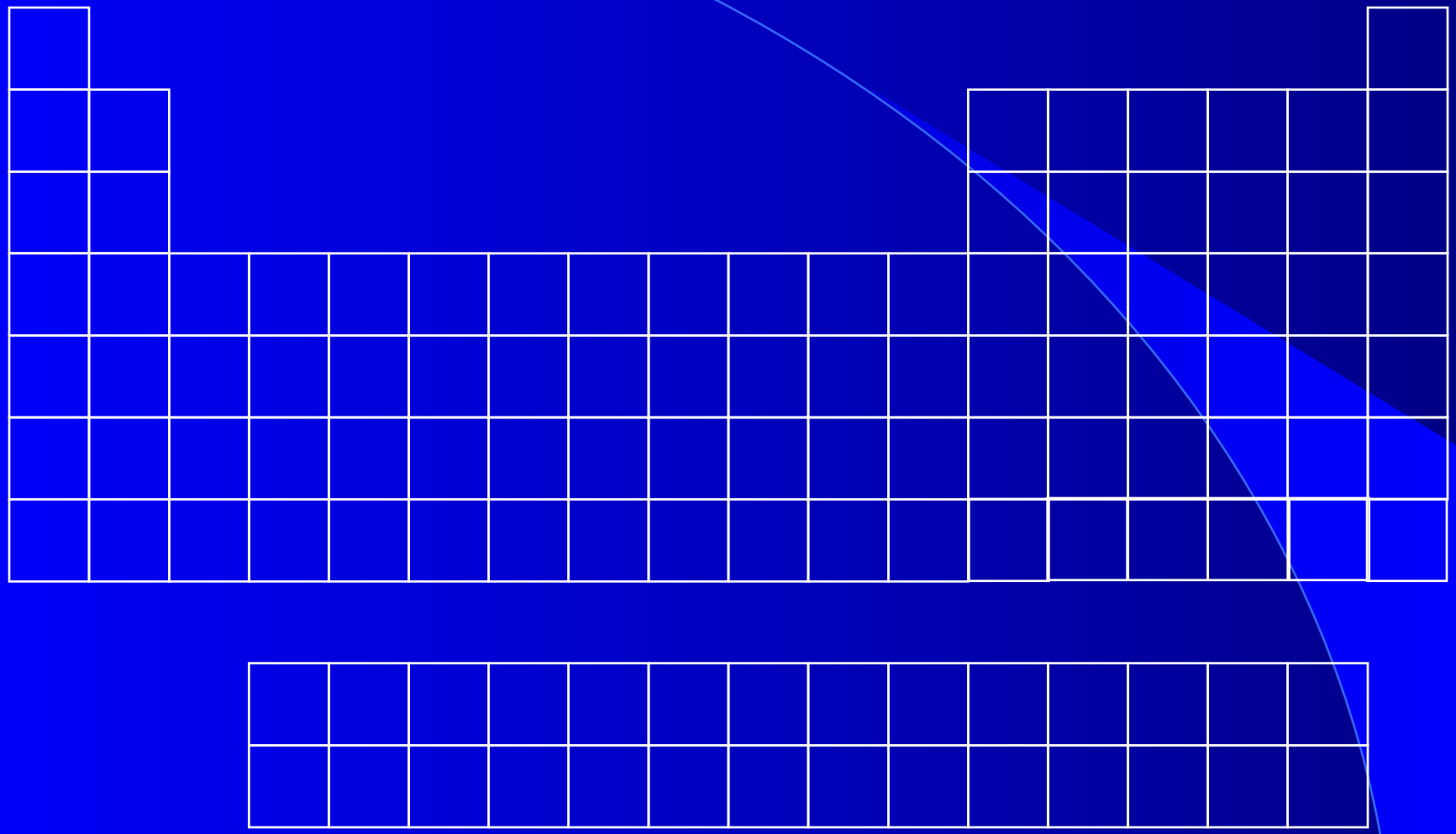
p Subshells



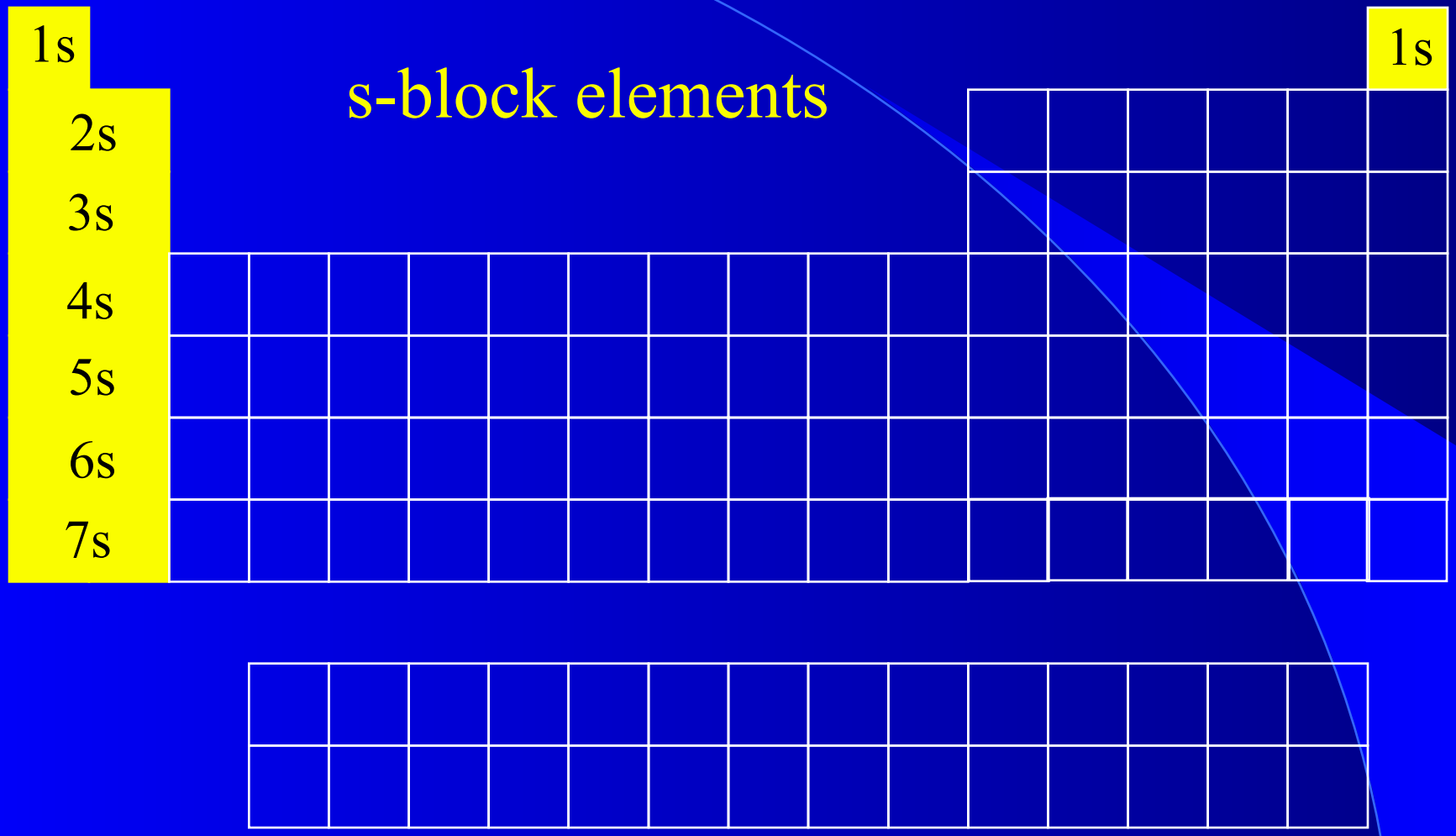
Electron Energies and the Periodic Table

- Periodic properties of elements determined by electron configurations
- First two parts of electron address can be easily seen in the periodic table's shape
- Color and label designate the last electron added

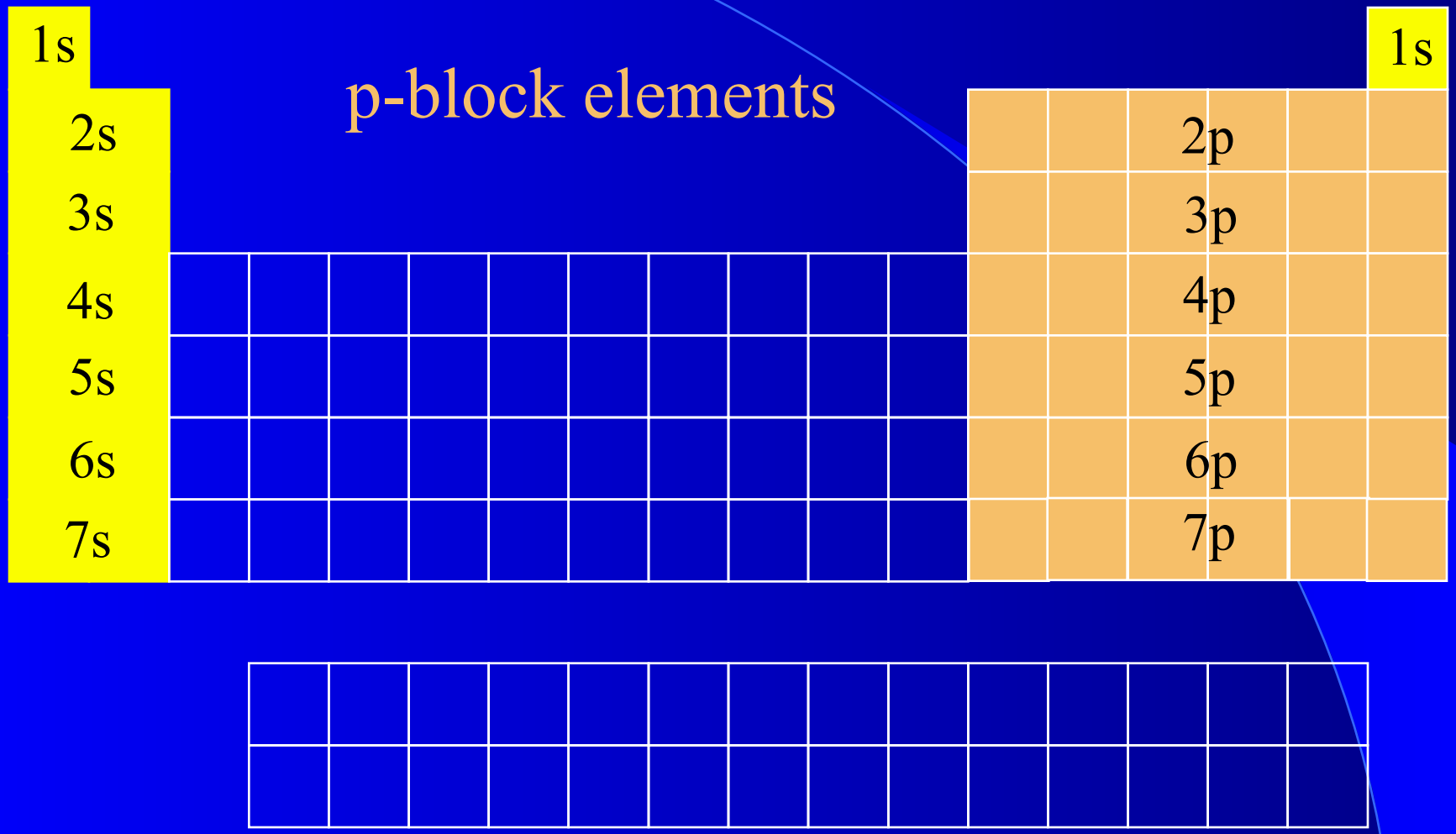
The Periodic Table



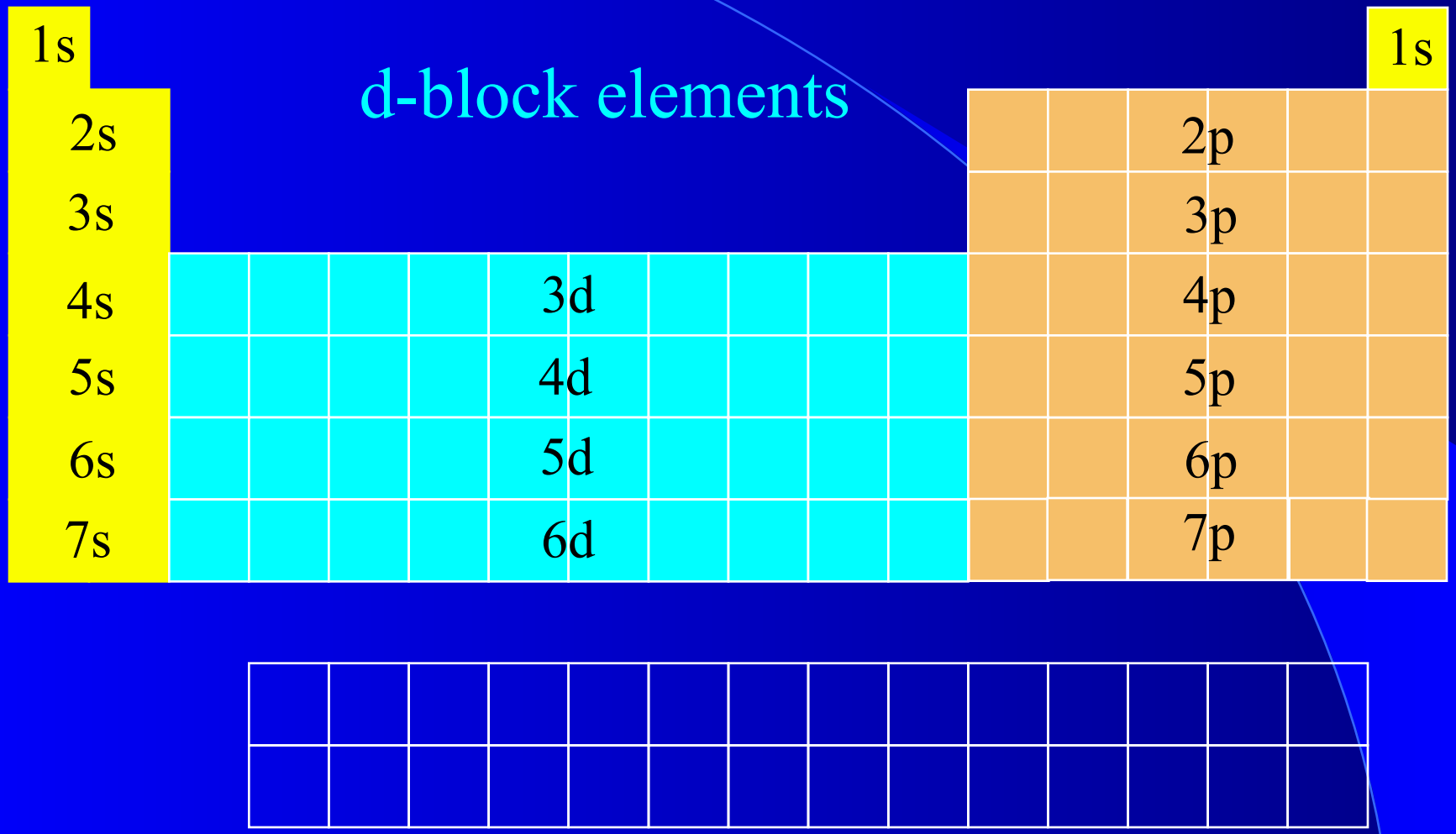
The Periodic Table



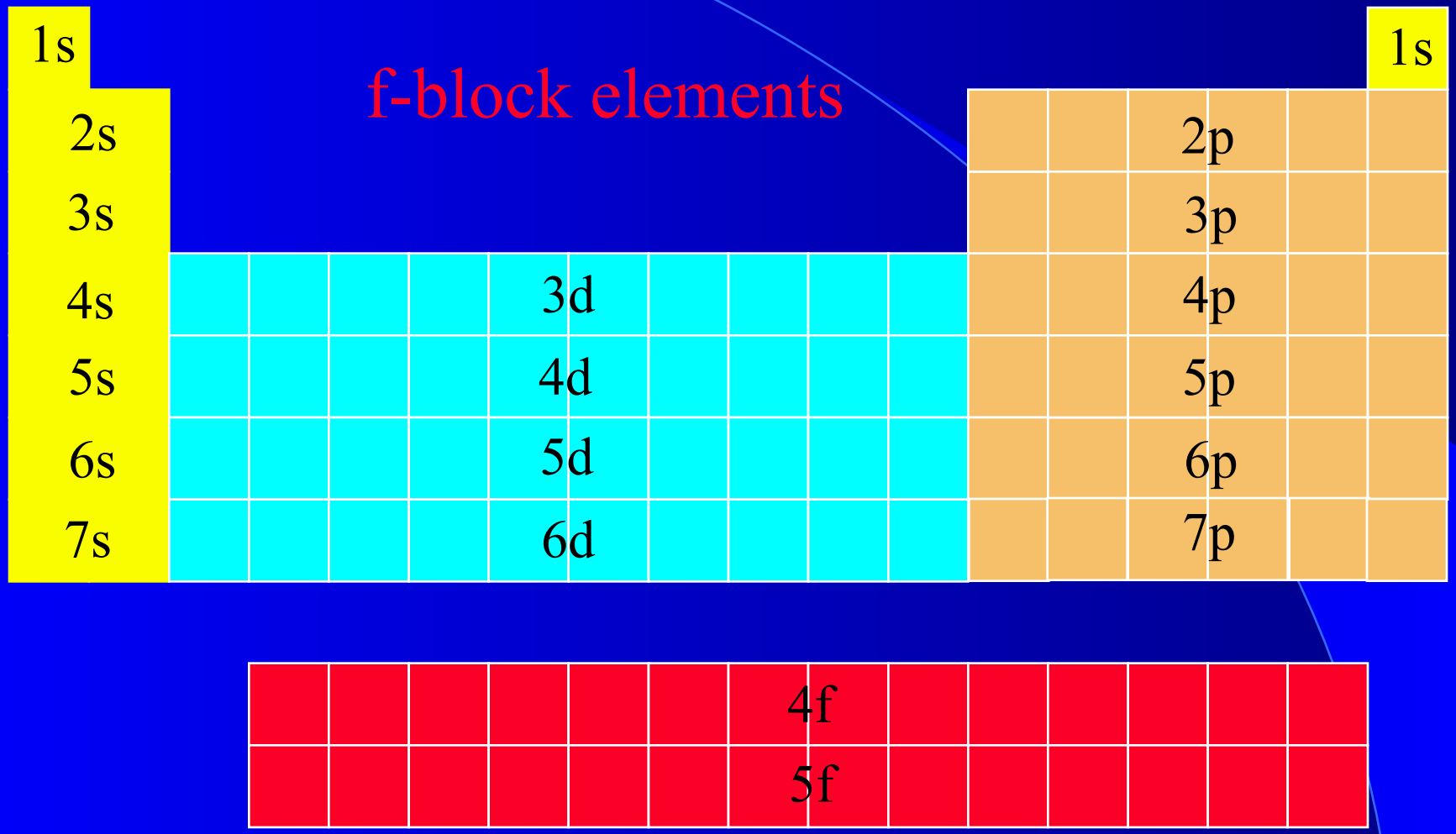
The Periodic Table



The Periodic Table

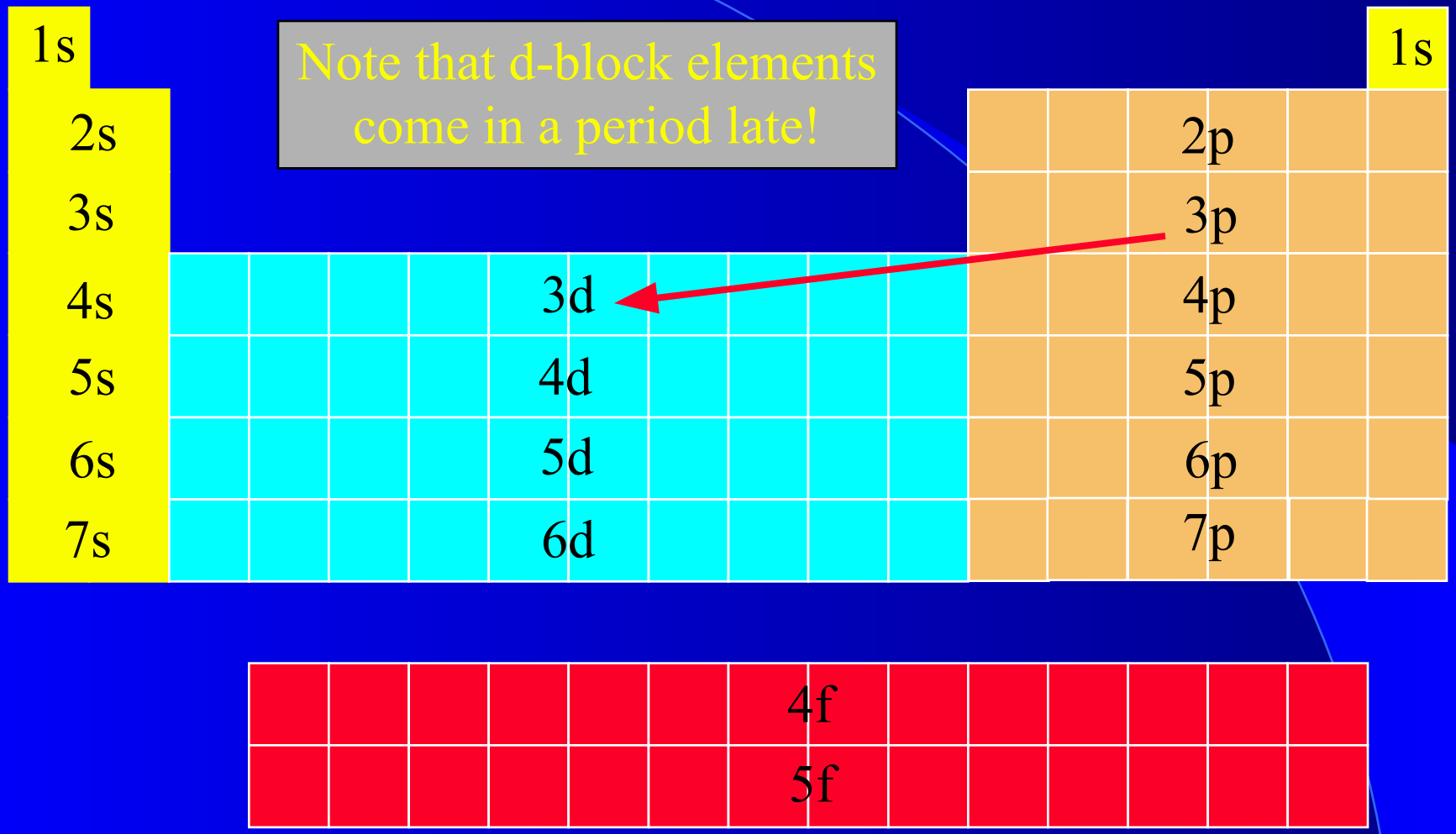


The Periodic Table

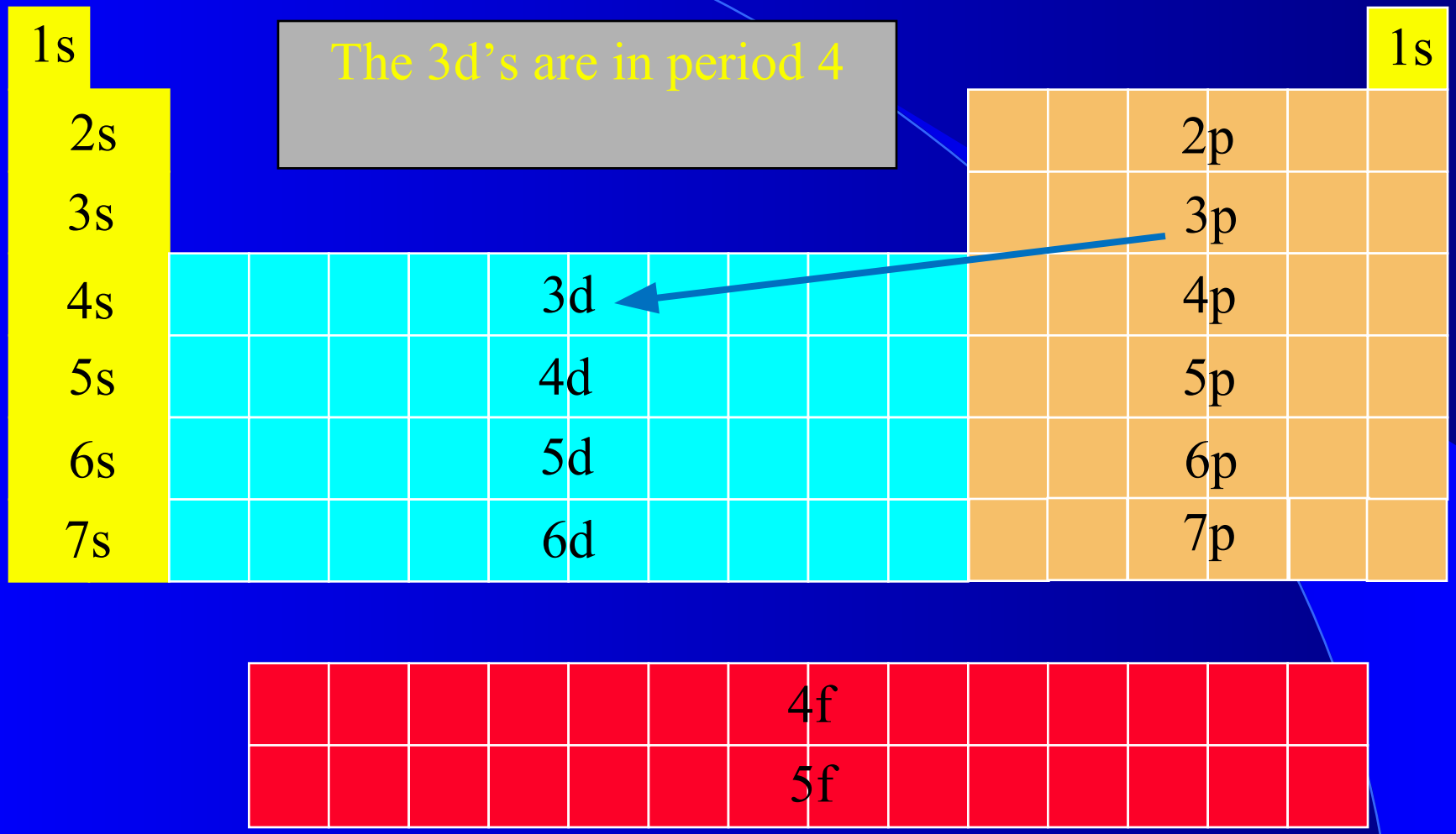


The Periodic Table

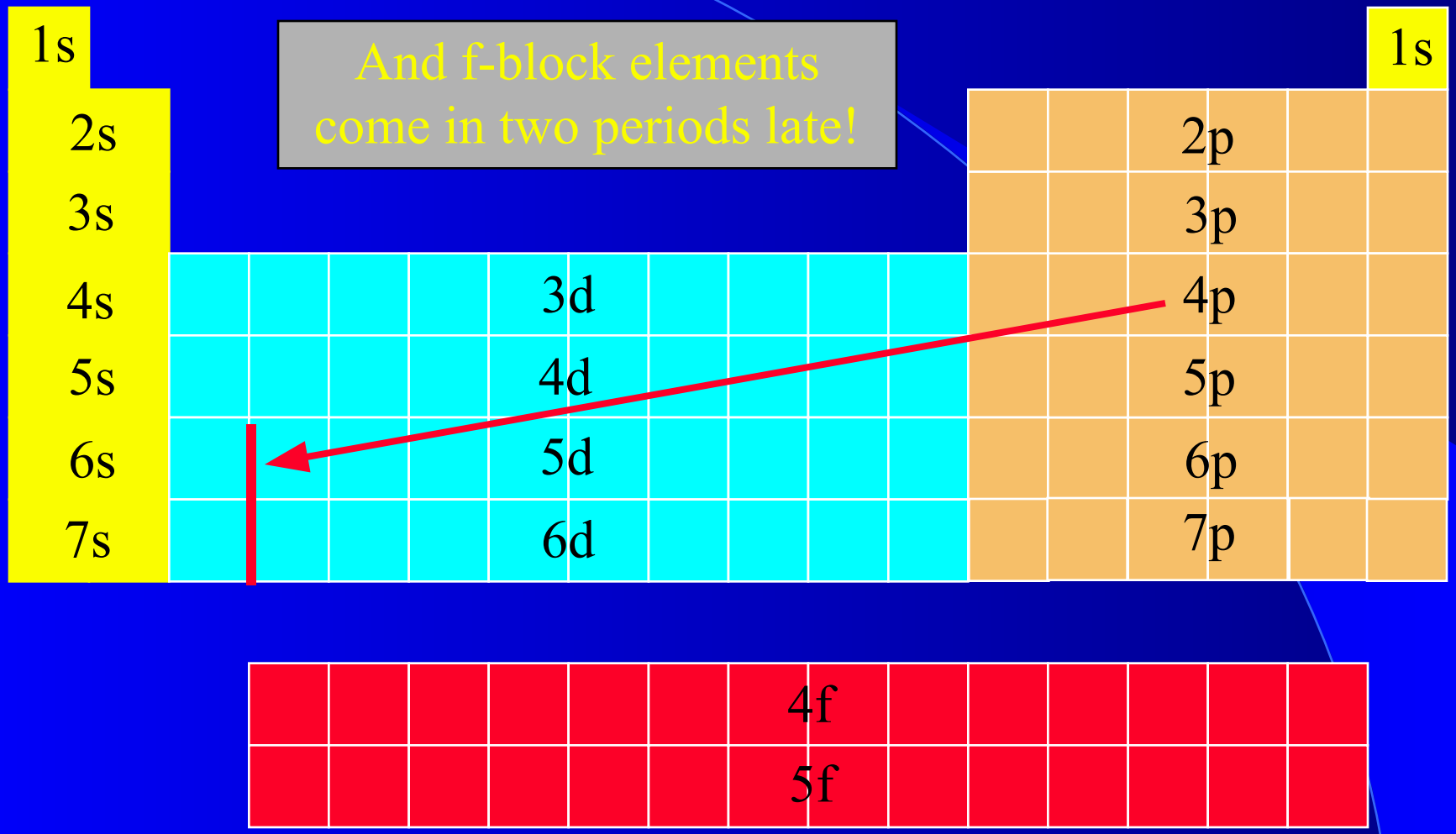
Note that d-block elements come in a period late!



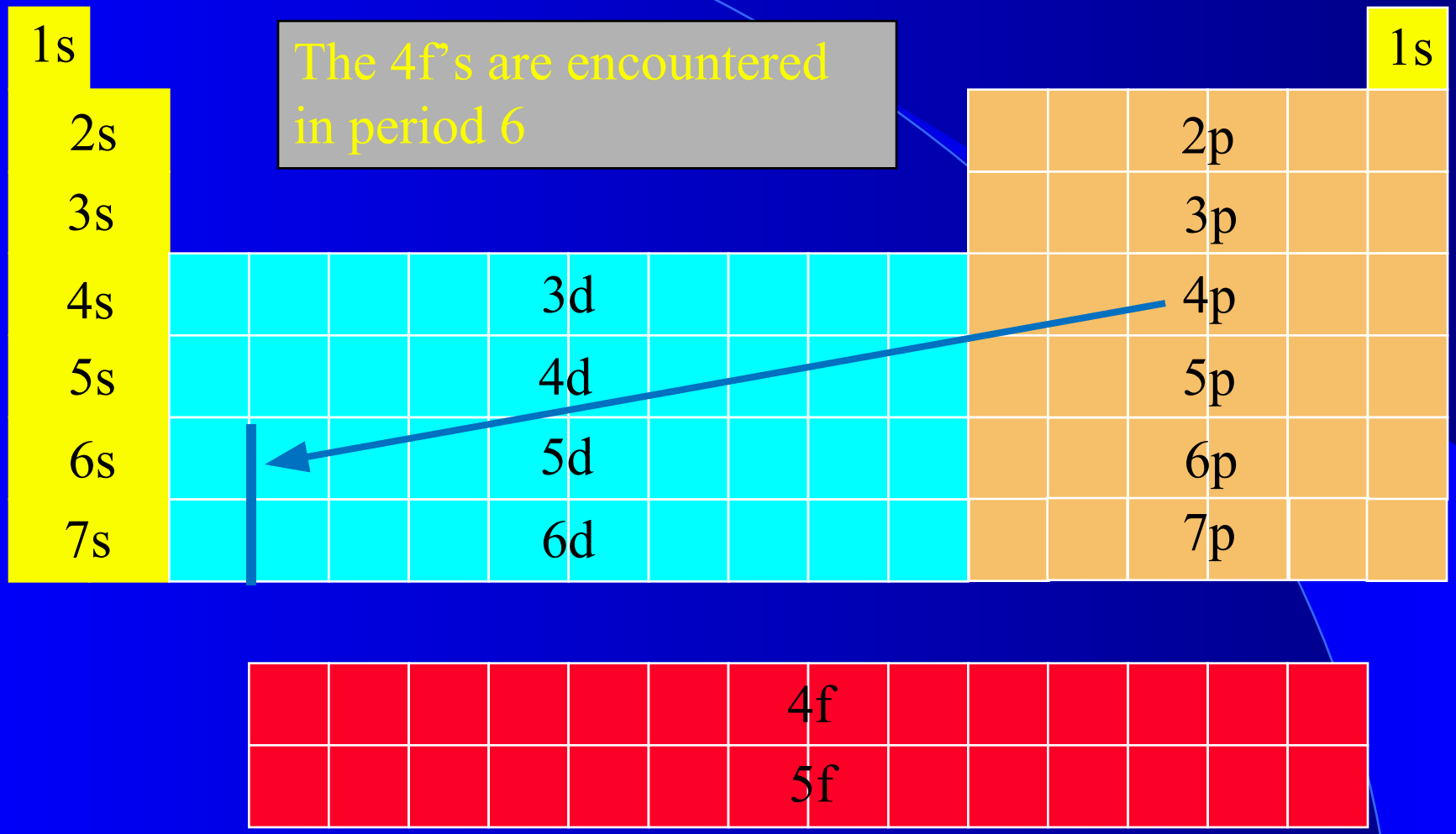
The Periodic Table



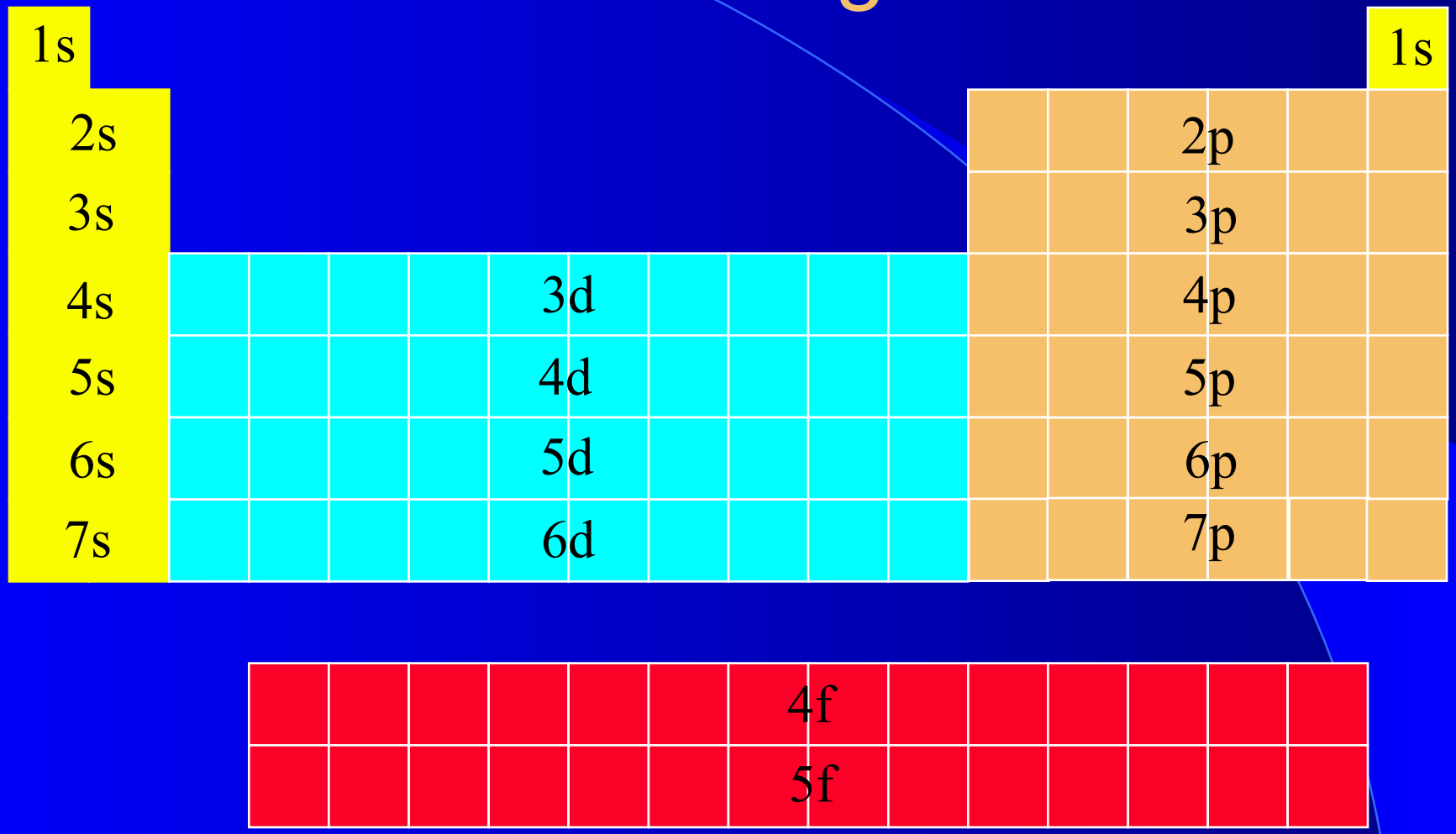
The Periodic Table



The Periodic Table



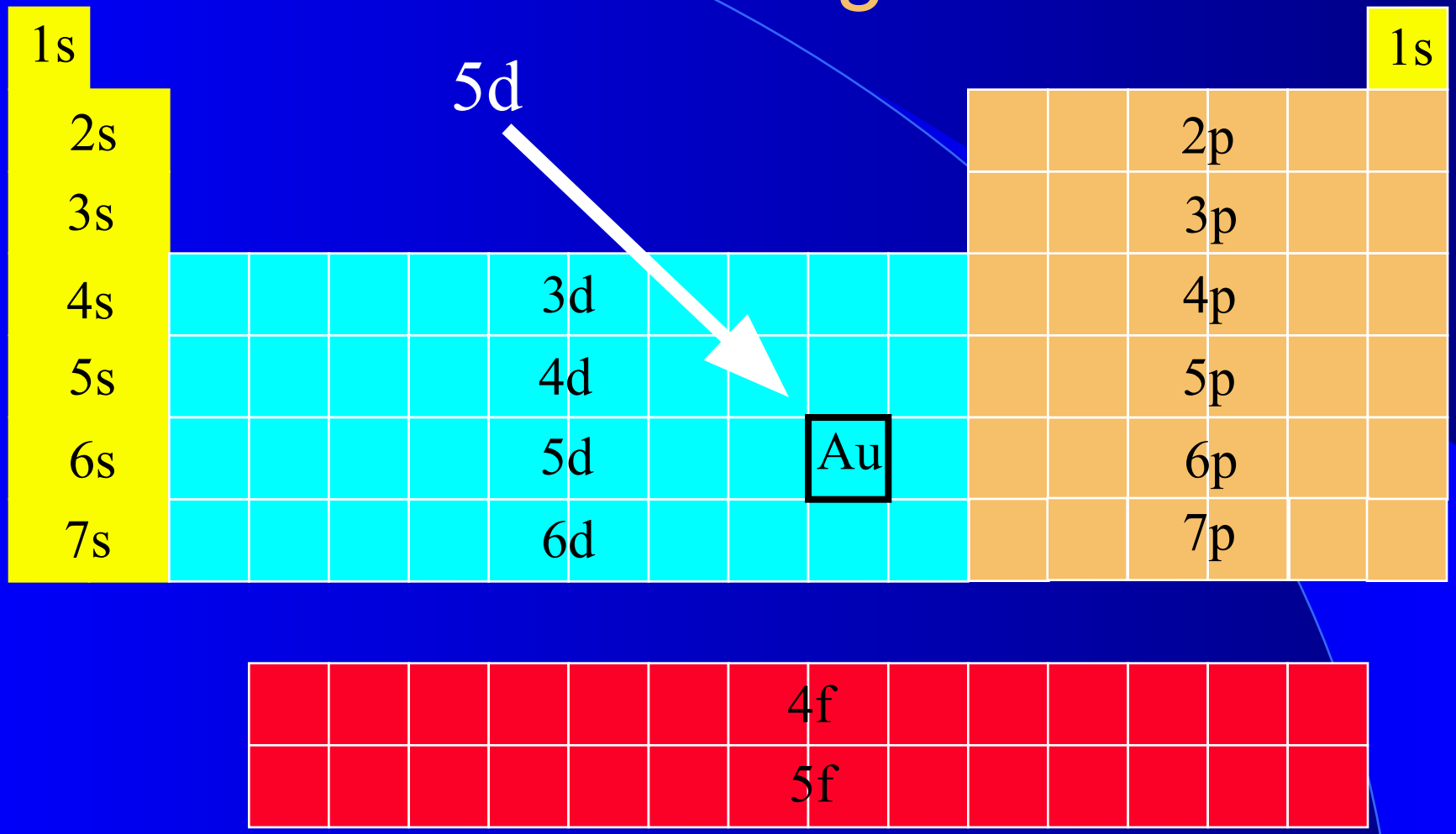
What is the last electron added in an atom of gold?



Which is the last electron added in an atom of gold?

1. 4f
2. 2p
3. 4s
4. 5d

What is the last electron added in an atom of gold?



#3 - Subshell Orientations

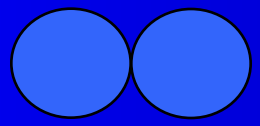
- Subshells (sublevels) have a number of orientations associated with their type
- s subshell 1 orientation
- p subshell 3 orientations
- d subshell 5 orientations
- f subshell 7 orientations

Subshell specifics

- Individual orientations of a subshell are called orbitals
- A subscripted code attached to the subshell letter identifies the specific orbital orientation

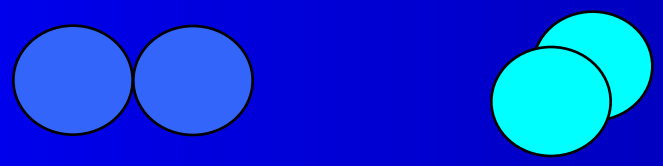
Subshell specifics

- Individual orientations of a subshell are called orbitals
- A subscripted code attached to the subshell letter identifies the specific orbital orientation
- $2p_x$



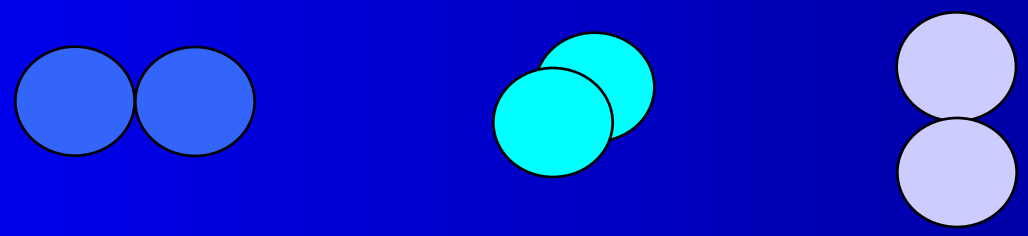
Subshell specifics

- Individual orientations of a subshell are called orbitals
- A subscripted code attached to the subshell letter identifies the specific orbital orientation
- $2p_x$ $2p_y$



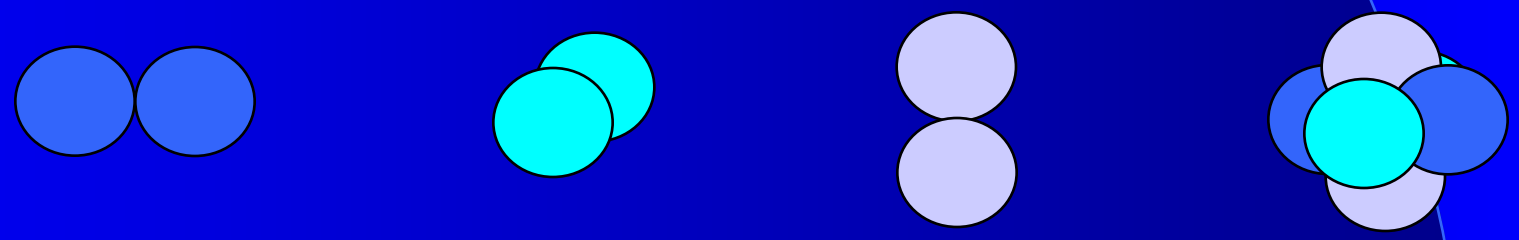
Subshell specifics

- Individual orientations of a subshell are called orbitals
- A subscripted code attached to the subshell letter identifies the specific orbital orientation
- $2p_x$ $2p_y$ $2p_z$



Subshell specifics

- Individual orientations of a subshell are called orbitals
- A subscripted code attached to the subshell letter identifies the specific orbital orientation
- $2p_x$ $2p_y$ $2p_z$ all 3



#4 - Electron Spin

- Electrons can spin clockwise or counterclockwise
- Any given orbital can hold two electrons AS LONG AS THEY HAVE OPPOSITE SPINS
- This is known as the Pauli Exclusion Principle

- Shell Subshell Orbitals e^-'s Total

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2
2	2s	1	2	

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2
2	2s	1	2	
	2p	3	6	

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2
2	2s	1	2	8
	2p	3	6	

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2
2	2s	1	2	8
	2p	3	6	
3	3s	1	2	

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2
2	2s	1	2	8
	2p	3	6	
3	3s	1	2	
	3p	3	6	

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2
2	2s	1	2	8
	2p	3	6	
3	3s	1	2	
	3p	3	6	
	3d	5	10	

- Shell Subshell Orbitals e^-'s Total

1	1s	1	2	2
2	2s	1	2	8
	2p	3	6	
3	3s	1	2	18
	3p	3	6	
	3d	5	10	

Inside a sodium atom

- Let's look at the electron arrangement in a neutral sodium atom.

Inside a sodium atom

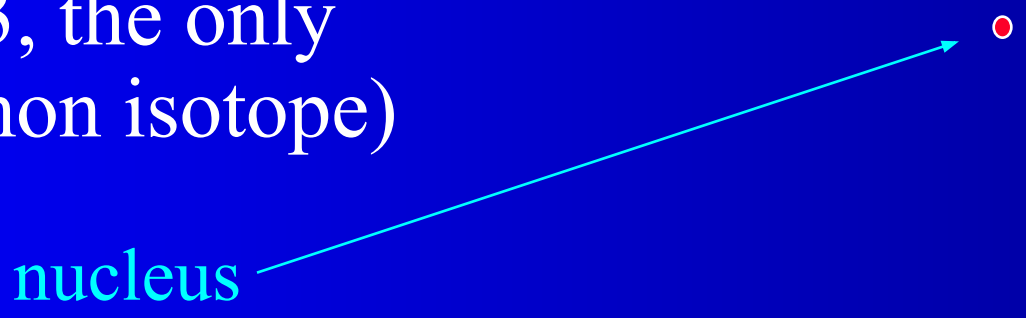
- Let's look at the electron arrangement in a neutral sodium atom. We'll need a total of 11 e^-'s (since sodium's atomic number is 11)

Inside a sodium atom

- In a tiny nucleus, we'll find 11 protons and 12 neutrons (assuming this is an atom of Na-23, the only common isotope)

Inside a sodium atom

- In a tiny nucleus, we'll find 11 protons and 12 neutrons (assuming this is an atom of Na-23, the only common isotope)



Inside a sodium atom

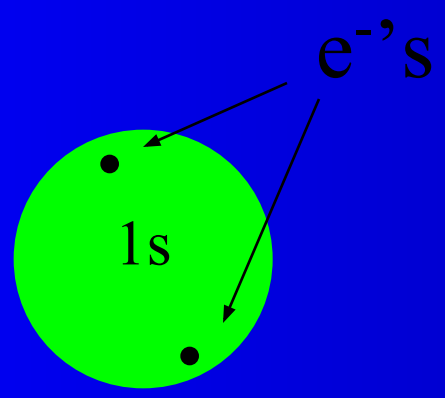
- In a tiny nucleus, we'll find 11 protons and 12 neutrons (assuming this is an atom of Na-23, the only common isotope)

Inside a sodium atom

- The first two of our 11 e^-'s will be found close to the nucleus in a spherical 1s orbital

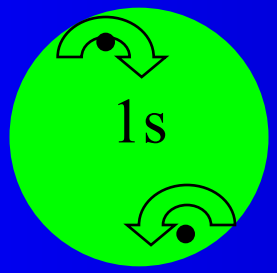
Inside a sodium atom

- The first two of our 11 e^-'s will be found close to the nucleus in a spherical 1s orbital.



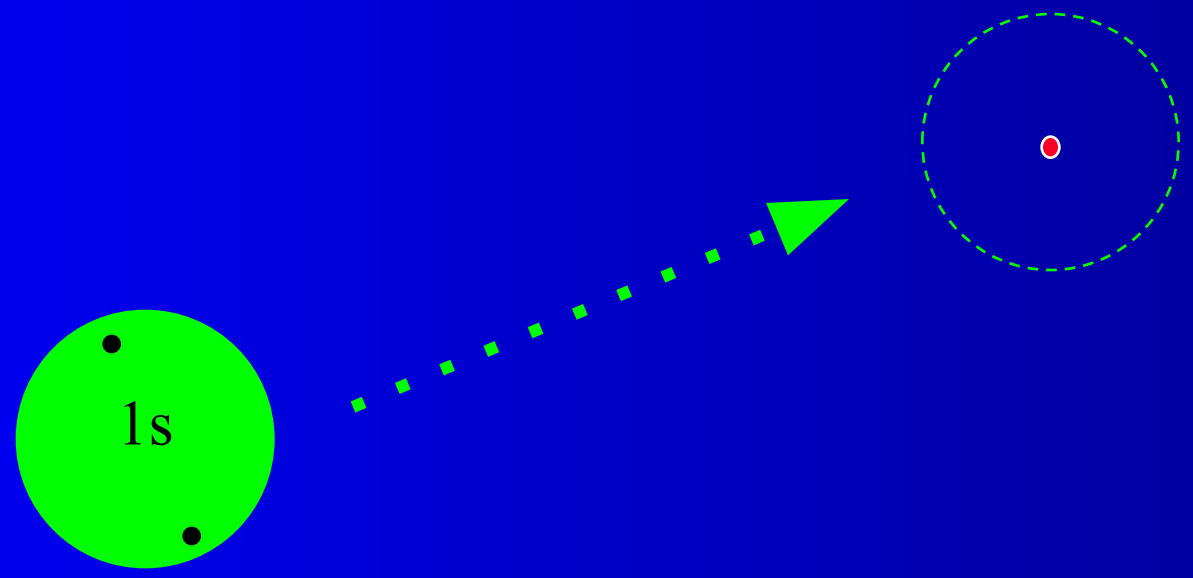
Inside a sodium atom

- The first two of our 11 e^-'s will be found close to the nucleus in a spherical 1s orbital. They have opposite spins.



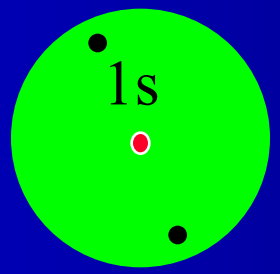
Inside a sodium atom

- The nucleus is at the exact center of the 1s orbital



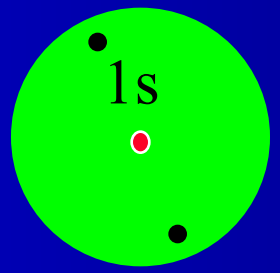
Inside a sodium atom

- The nucleus is at the exact center of the 1s orbital



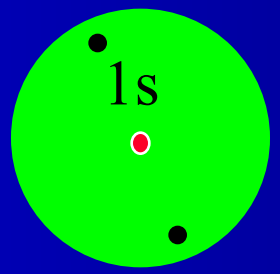
Inside a sodium atom

- This completes the first (n=1) shell.



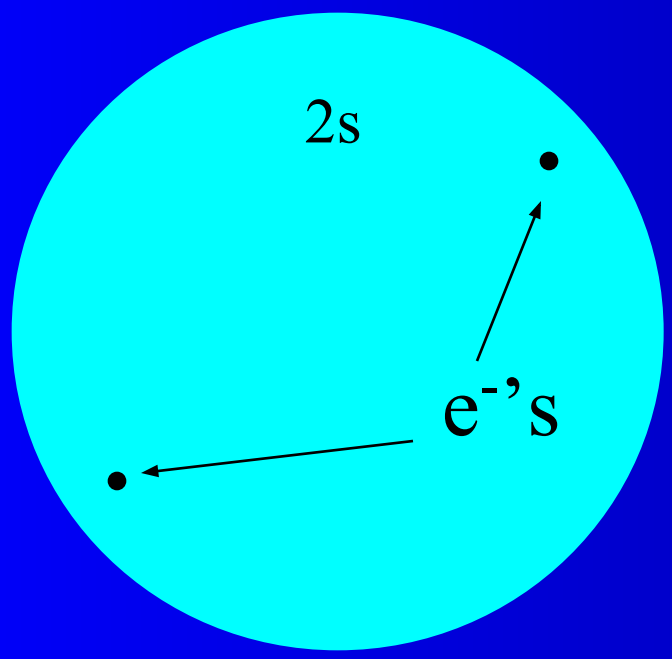
Inside a sodium atom

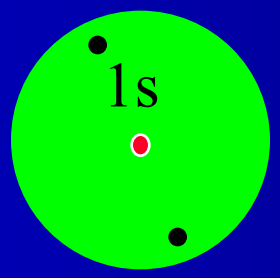
- The next two e^-'s are in a larger spherical 2s subshell



Inside a sodium atom

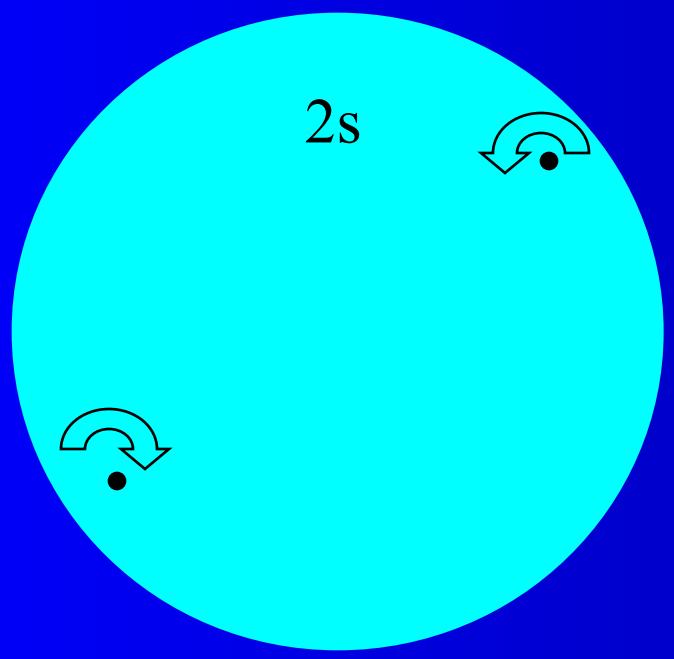
- The next two e^-'s are in a larger spherical 2s subshell

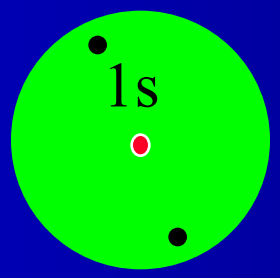




Inside a sodium atom

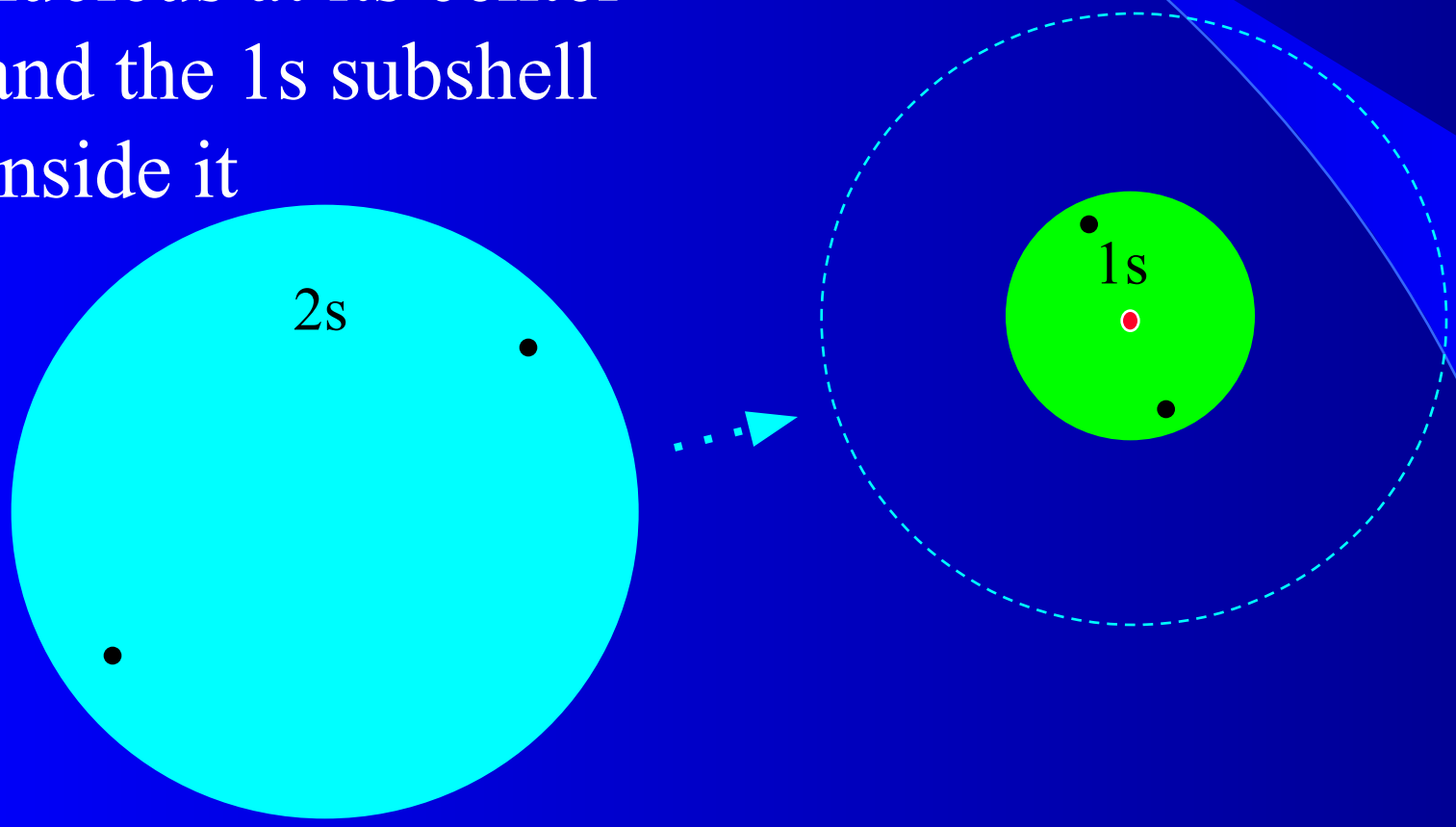
- The two electrons have opposite spins





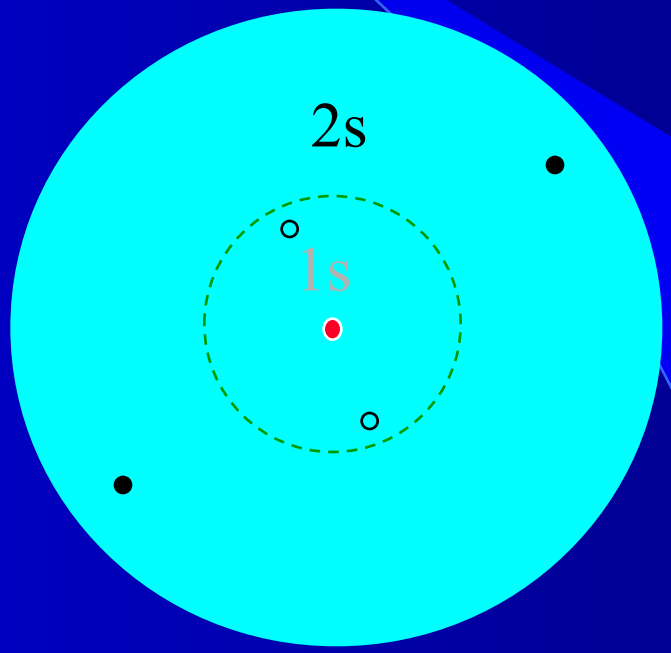
Inside a sodium atom

- The 2s shell has the nucleus at its center and the 1s subshell inside it



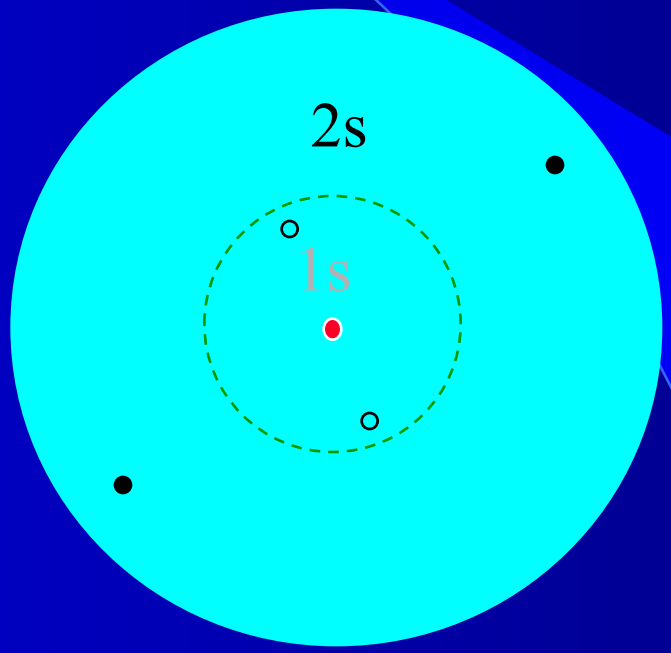
Inside a sodium atom

- The 2s shell has the nucleus at its center and the 1s subshell inside it



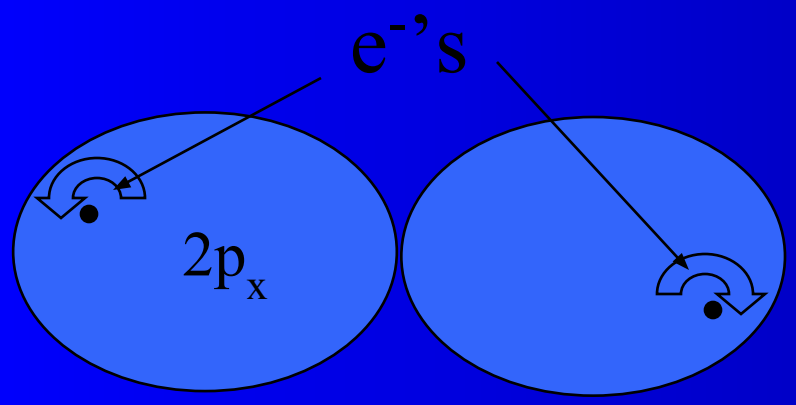
Inside a sodium atom

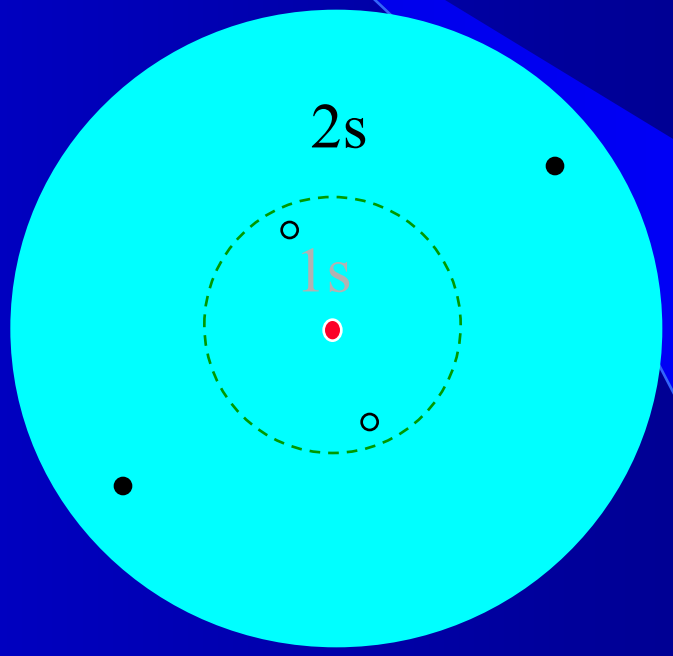
- Now we start adding the three 2p orbitals, each with its specific orientation



Inside a sodium atom

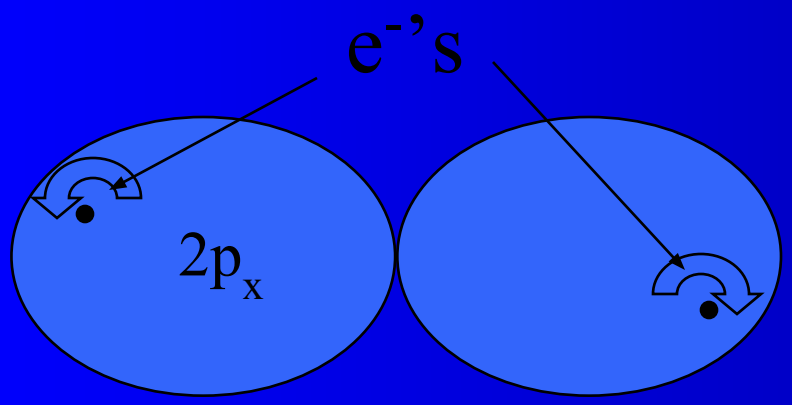
- Now we start adding the three 2p orbitals, each with its specific orientation

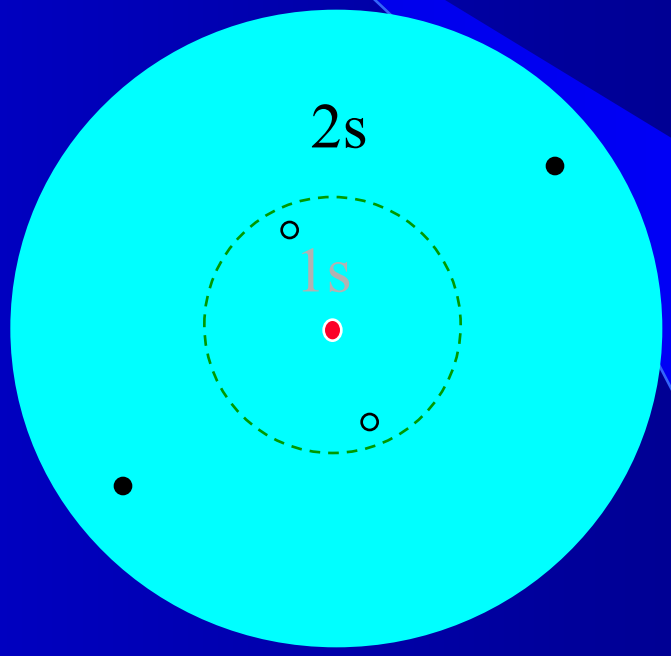




Inside a sodium atom

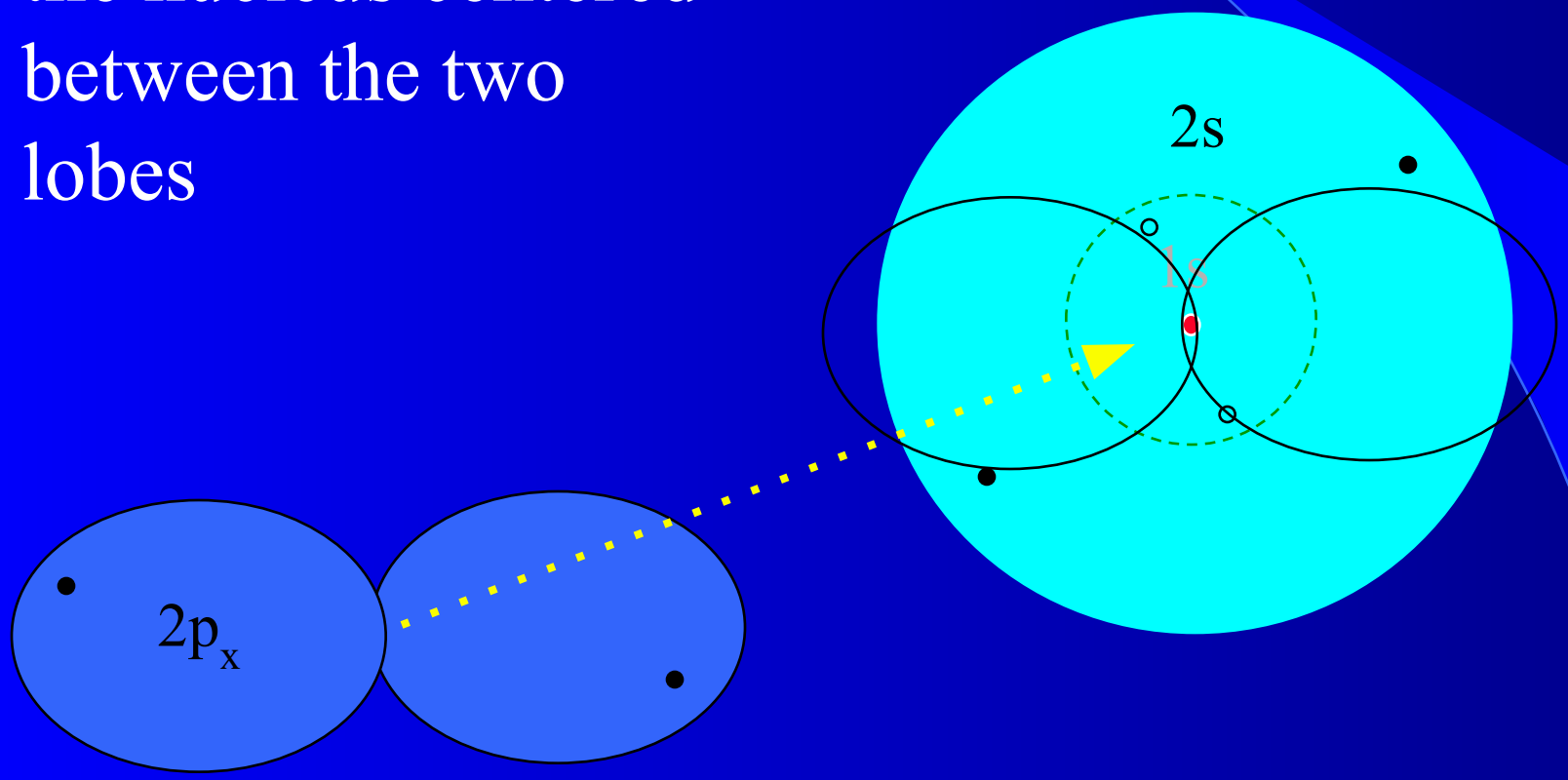
- Now we start adding the three 2p orbitals, each with its specific orientation





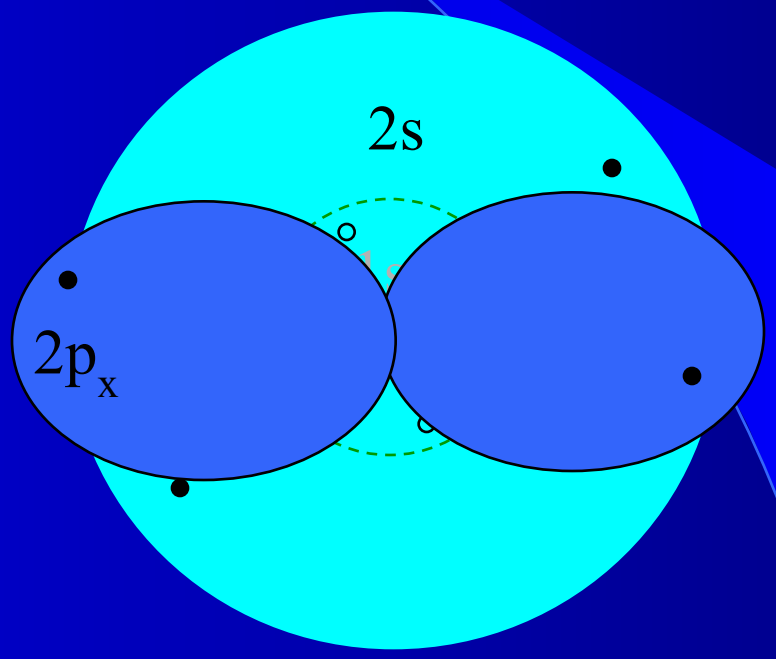
Inside a sodium atom

- Each 2p orbital has the nucleus centered between the two lobes



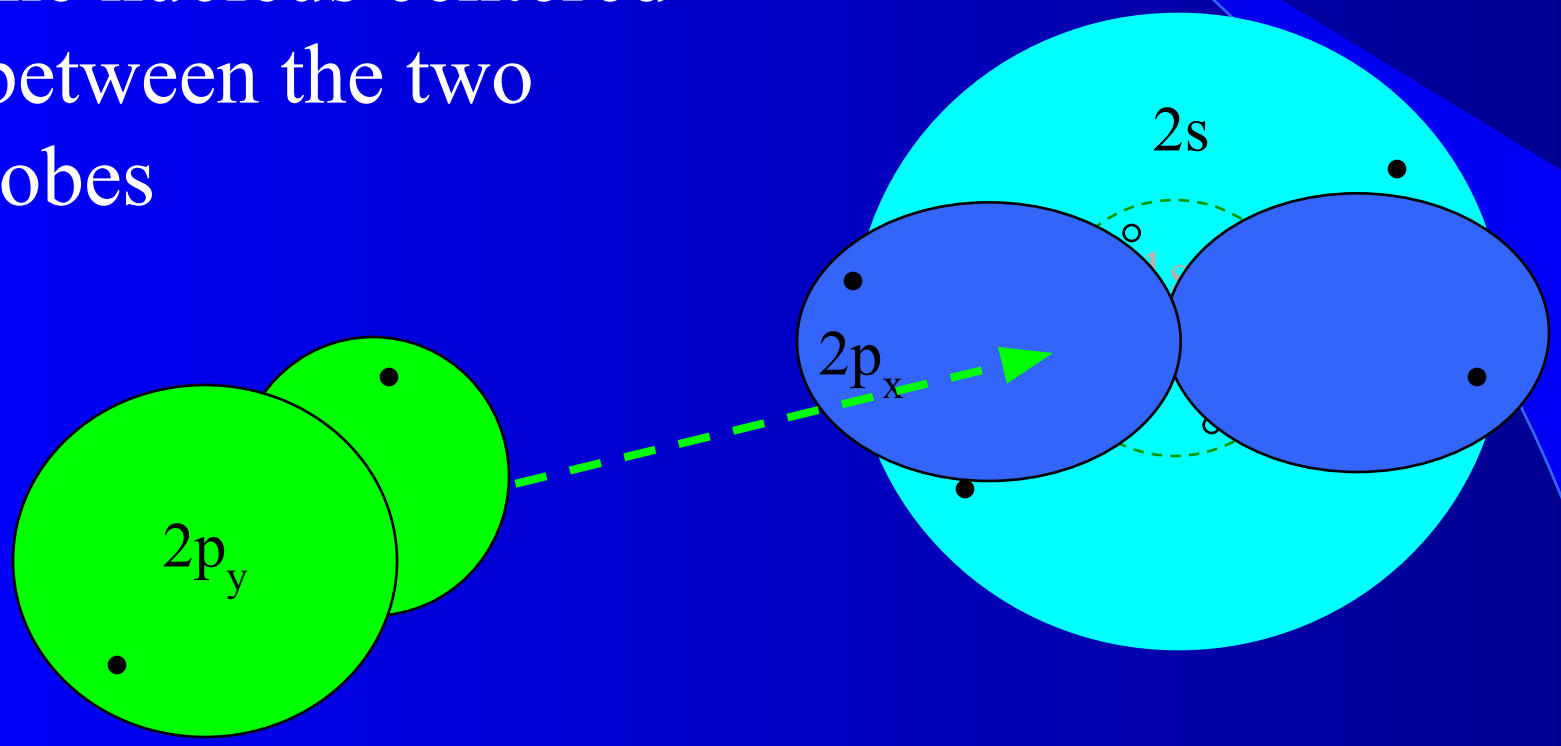
Inside a sodium atom

- Each 2p orbital has the nucleus centered between the two lobes



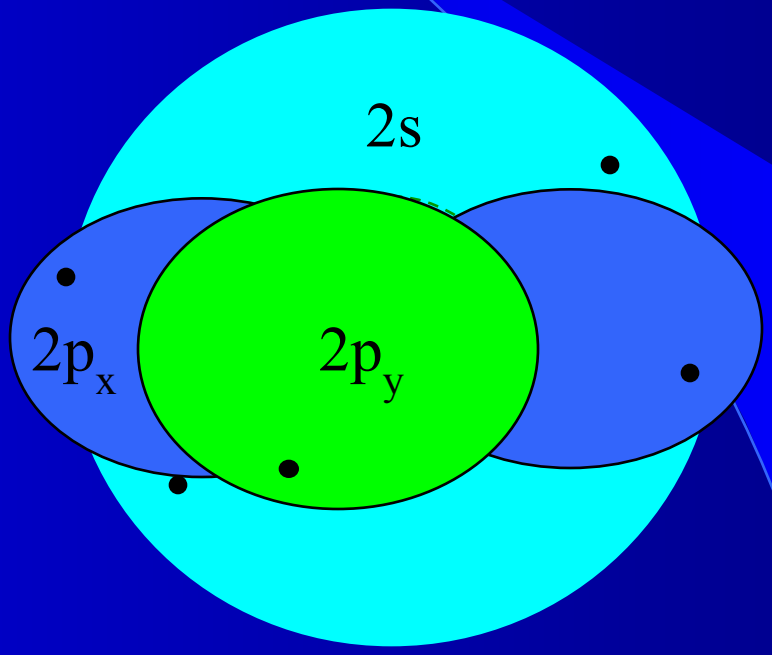
Inside a sodium atom

- Each 2p orbital has the nucleus centered between the two lobes



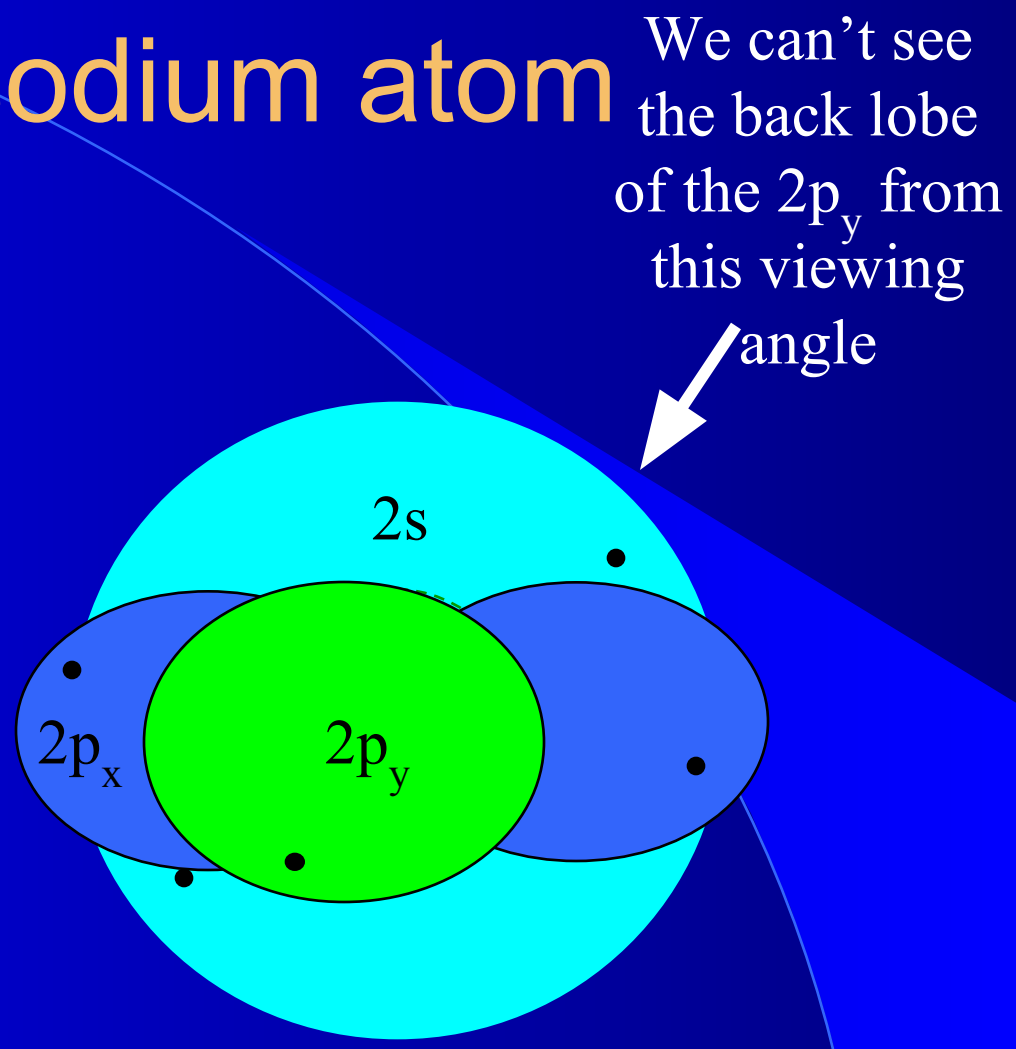
Inside a sodium atom

- Each 2p orbital has the nucleus centered between the two lobes



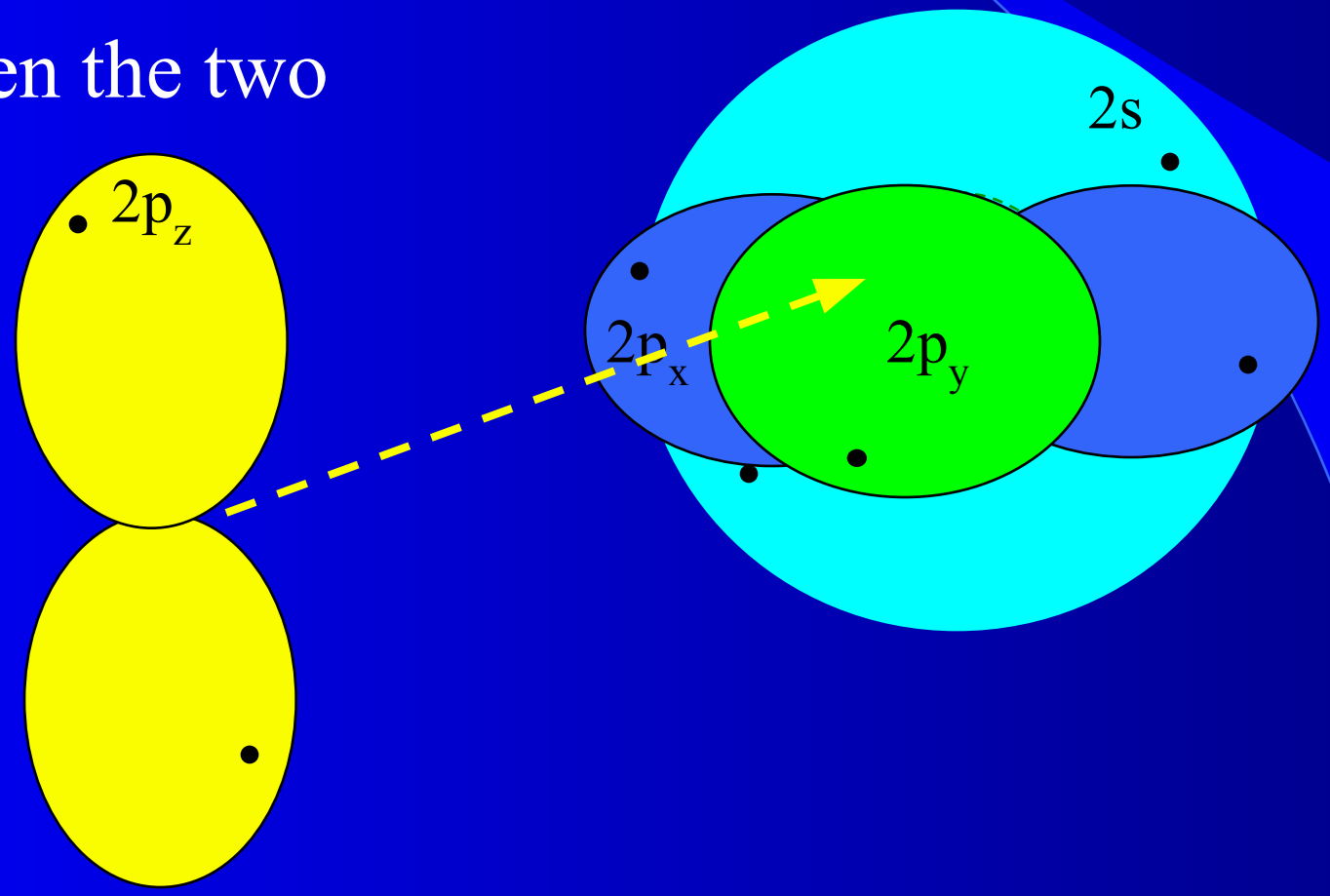
Inside a sodium atom

- Each 2p orbital has the nucleus centered between the two lobes



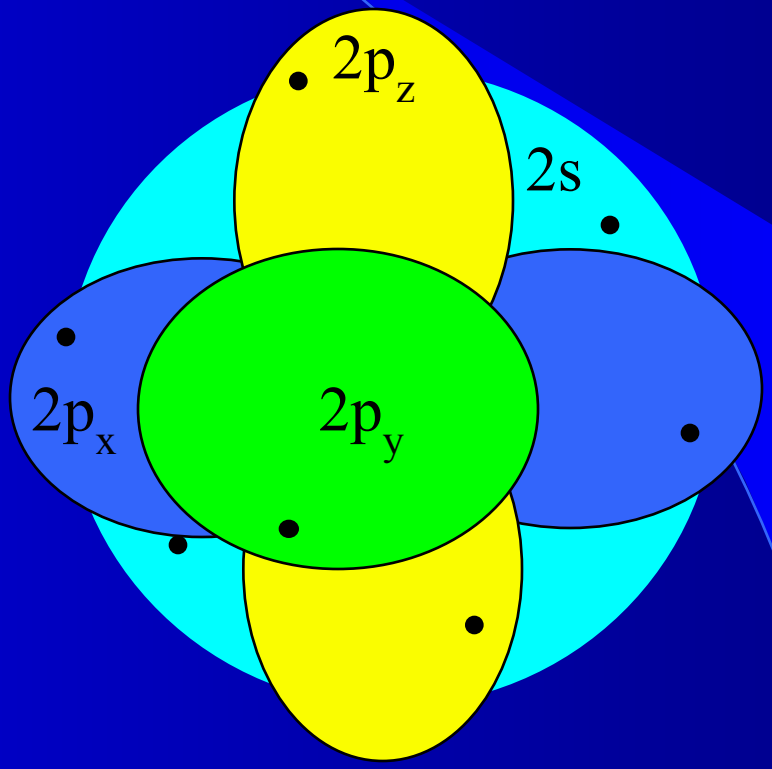
Inside a sodium atom

- Each 2p orbital has the nucleus centered between the two lobes



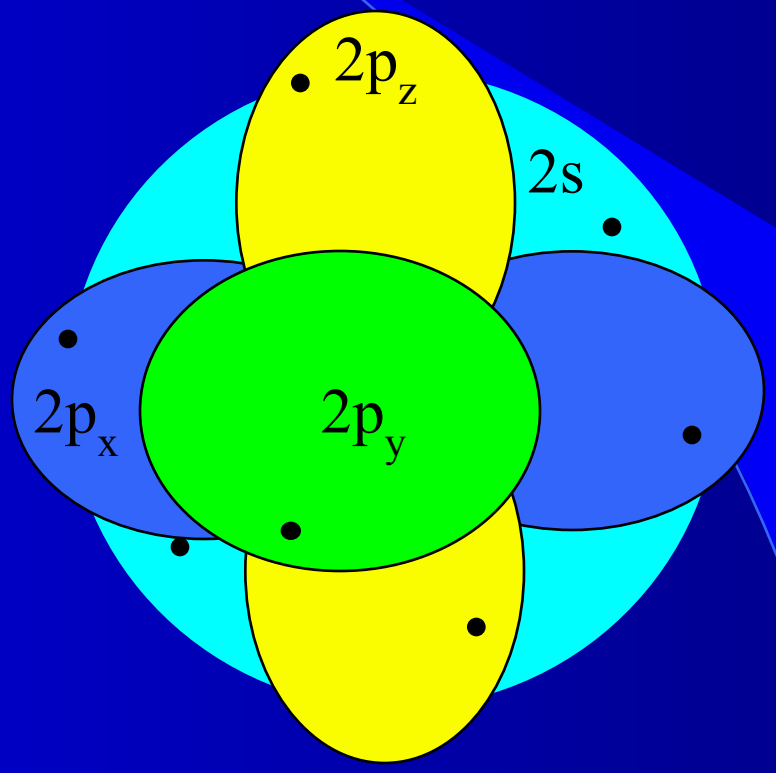
Inside a sodium atom

- Each 2p orbital has the nucleus centered between the two lobes



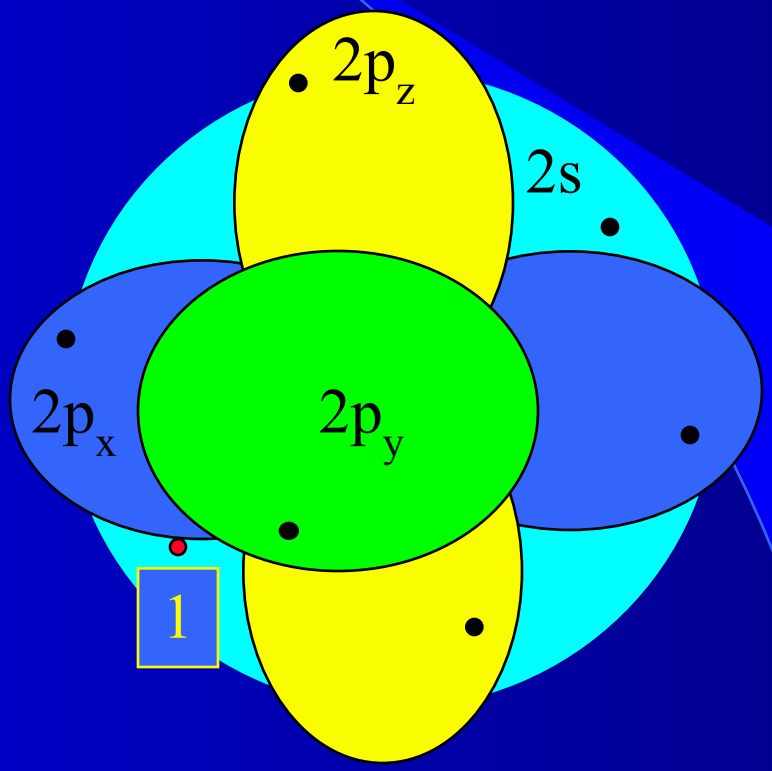
Inside a sodium atom

- The n = 2 shell is now complete; it has an octet of electrons…



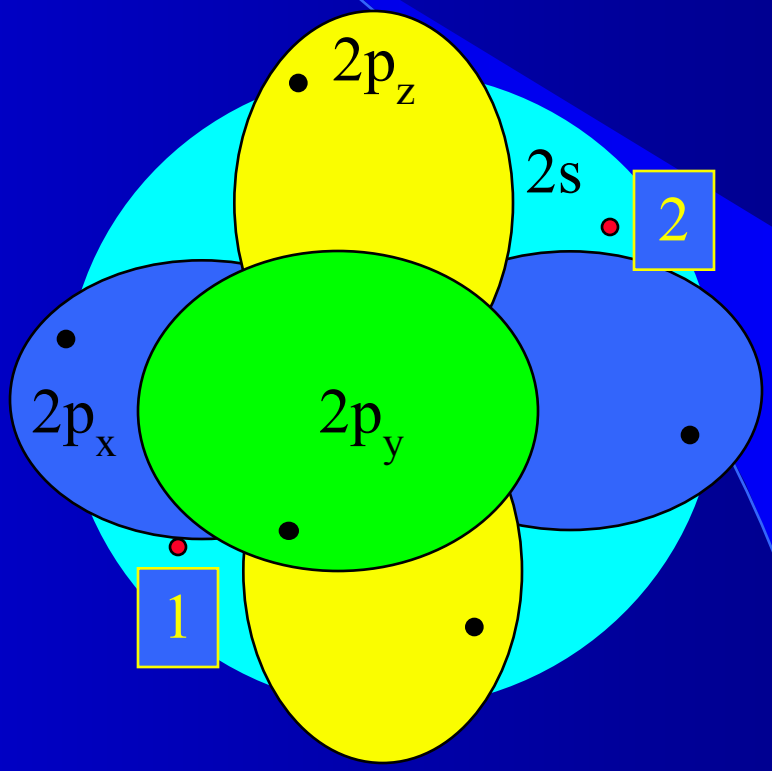
Inside a sodium atom

- The n = 2 shell is now complete; it has an octet of electrons…



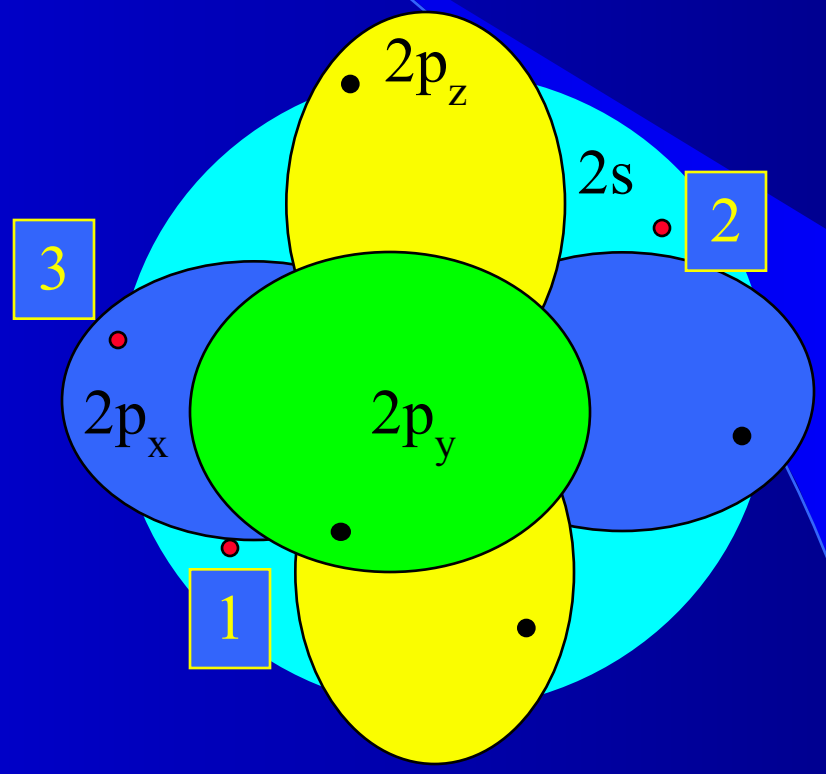
Inside a sodium atom

- The n = 2 shell is now complete; it has an octet of electrons…



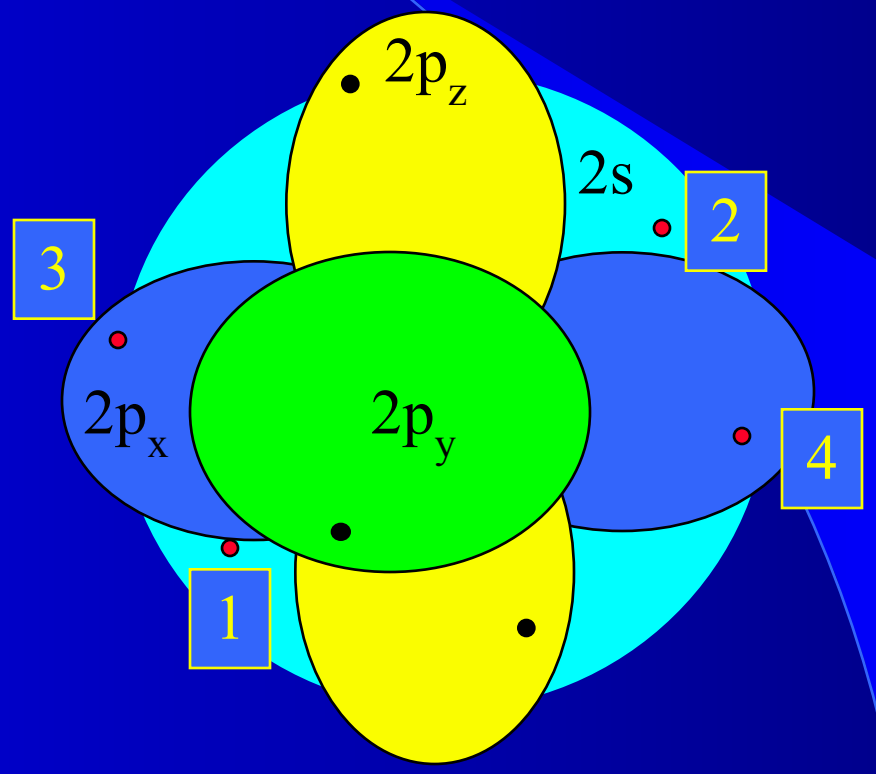
Inside a sodium atom

- The n = 2 shell is now complete; it has an octet of electrons…



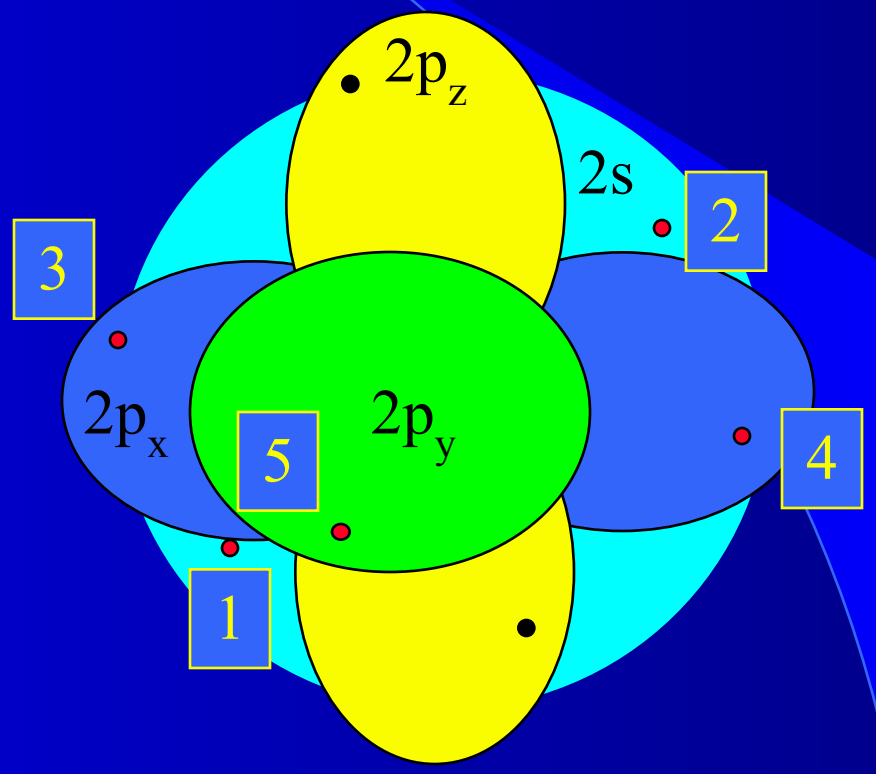
Inside a sodium atom

- The n = 2 shell is now complete; it has an octet of electrons…



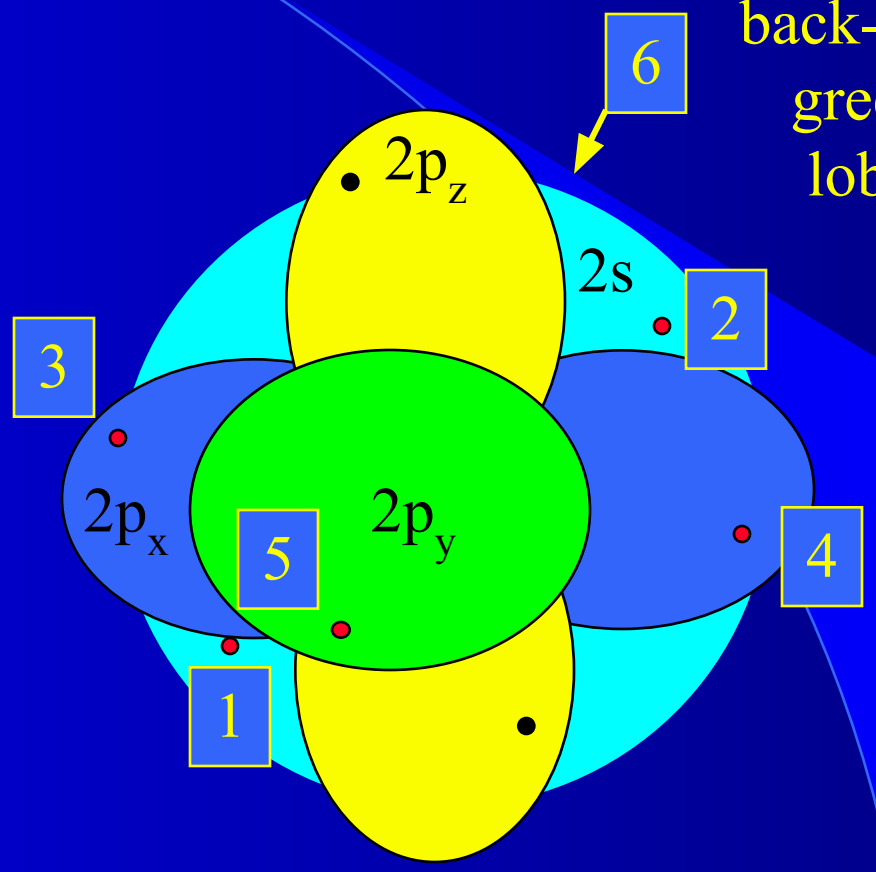
Inside a sodium atom

- The n = 2 shell is now complete; it has an octet of electrons…



Inside a sodium atom

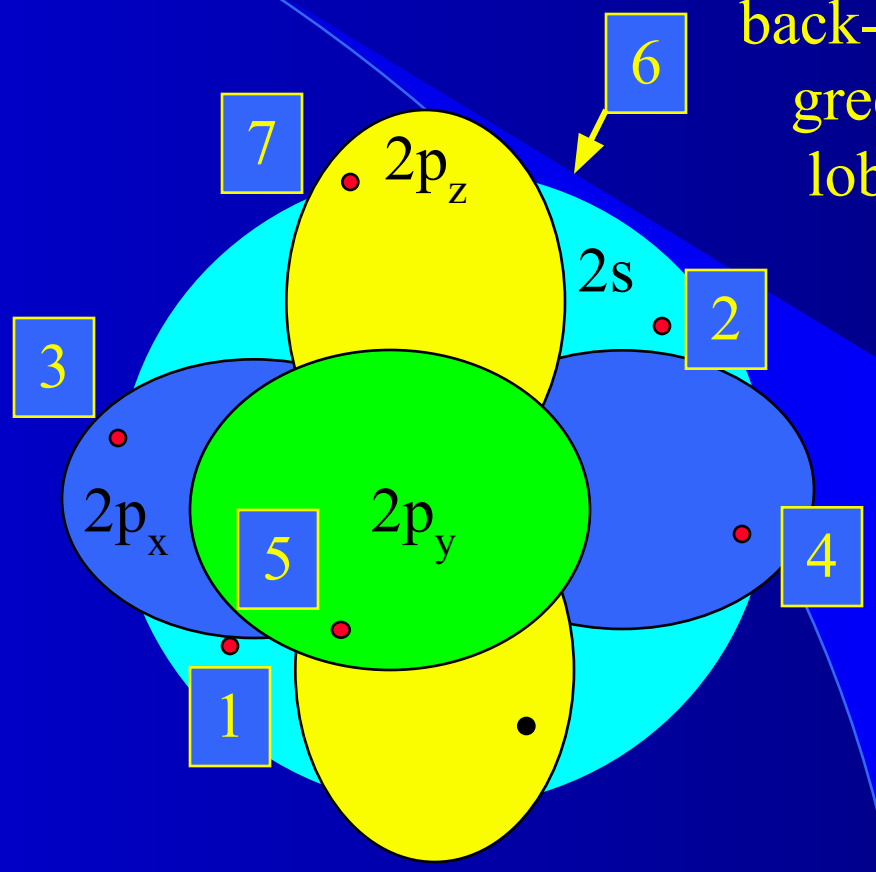
- The n = 2 shell is now complete; it has an octet of electrons…



Hiding on the back-side green lobe

Inside a sodium atom

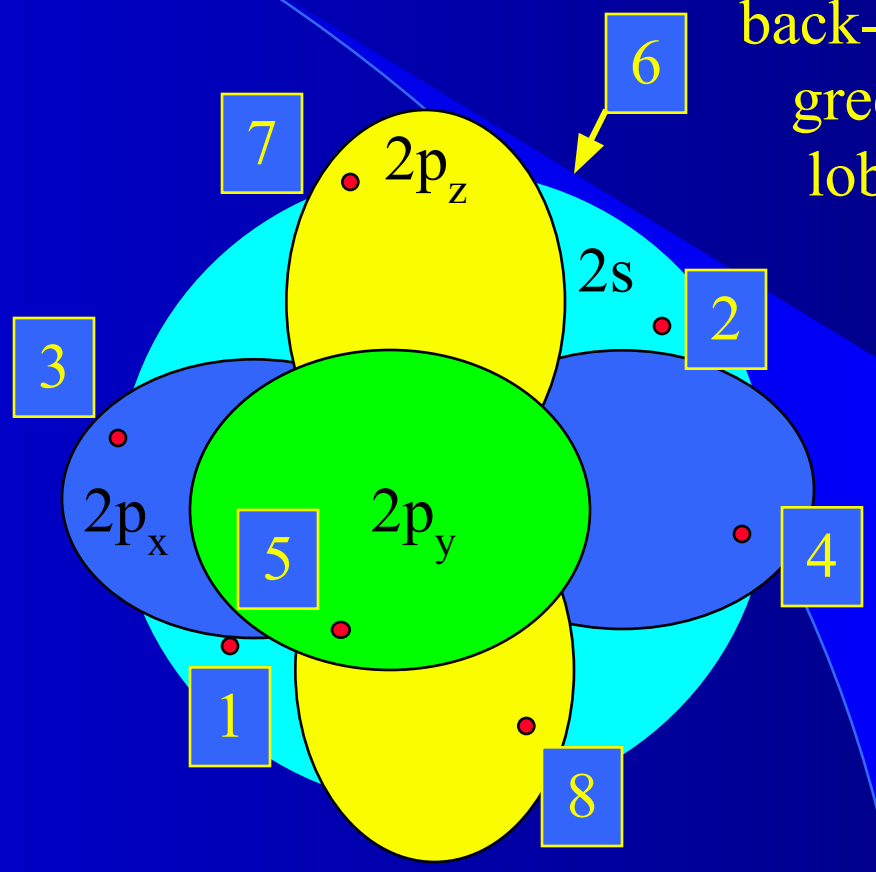
- The n = 2 shell is now complete; it has an octet of electrons…



Hiding on the back-side green lobe

Inside a sodium atom

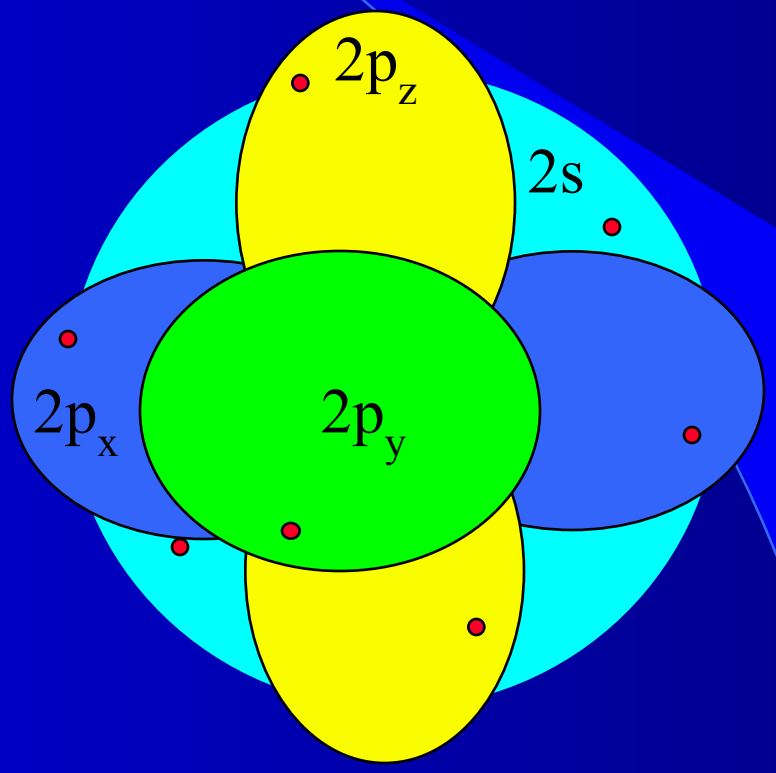
- The n = 2 shell is now complete; it has an octet of electrons…



Hiding on the back-side green lobe

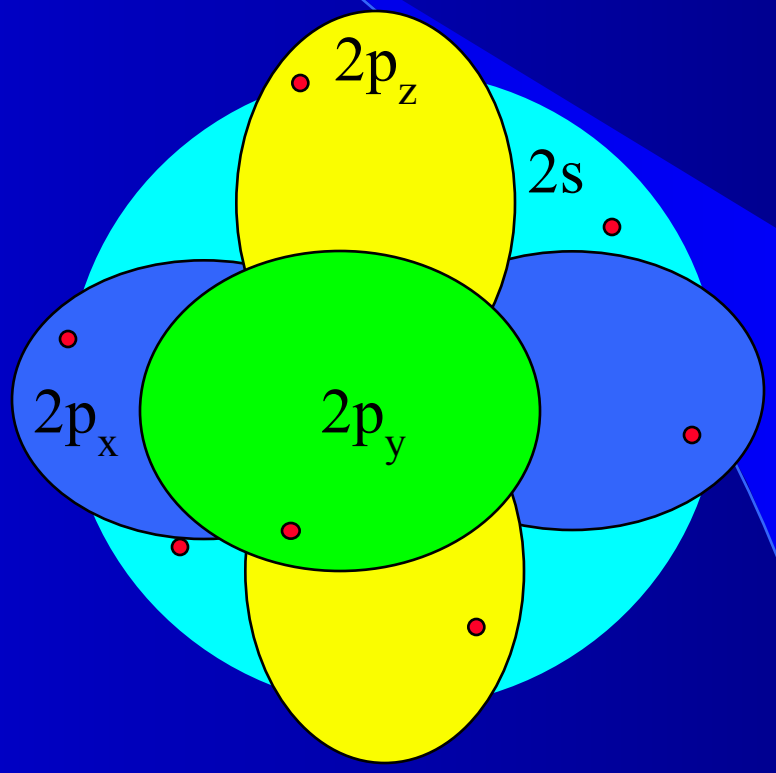
Inside a sodium atom

- The n = 2 shell is now complete; it has an octet of electrons…



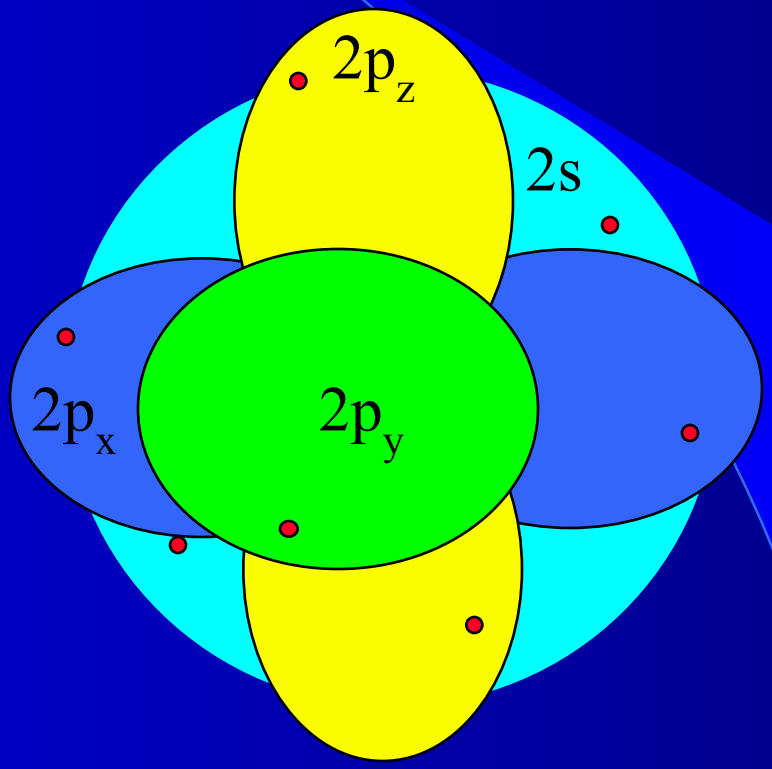
Inside a sodium atom

- Finally, the n=3 shell has a single electron in it...



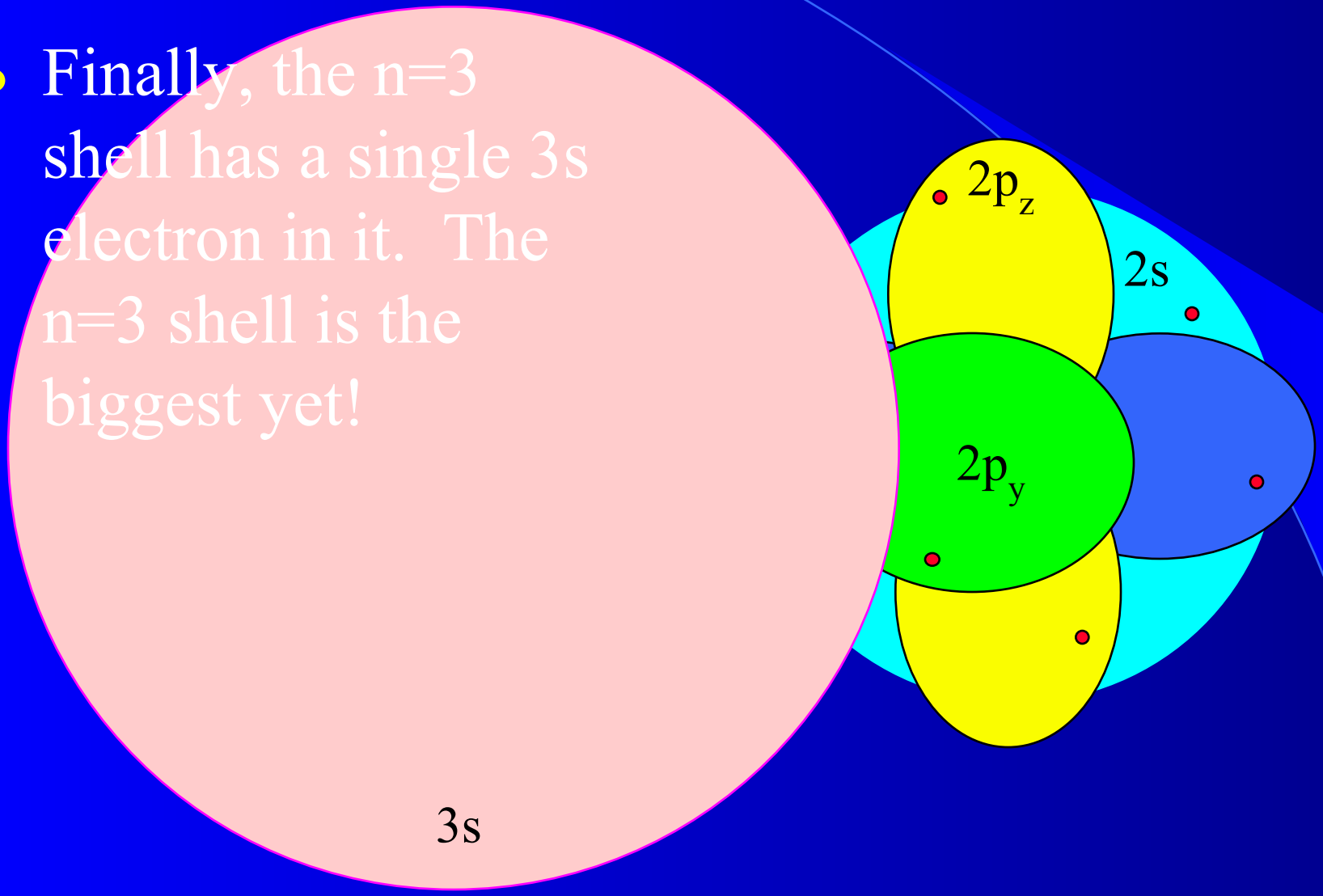
Inside a sodium atom

- Finally, the n=3 shell has a single electron in it. The n=3 shell is the biggest yet!



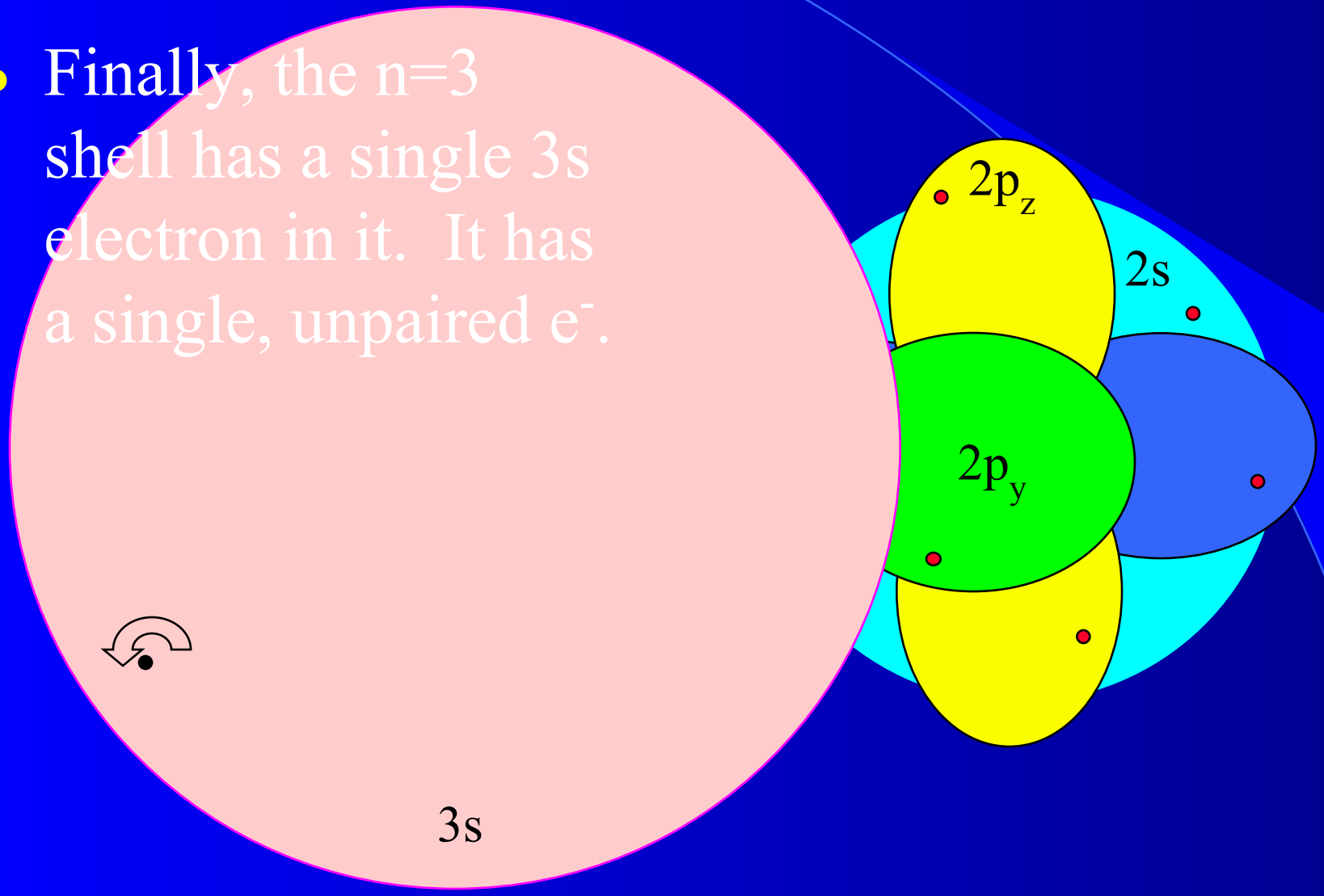
Inside a sodium atom

- Finally, the n=3 shell has a single 3s electron in it. The n=3 shell is the biggest yet!



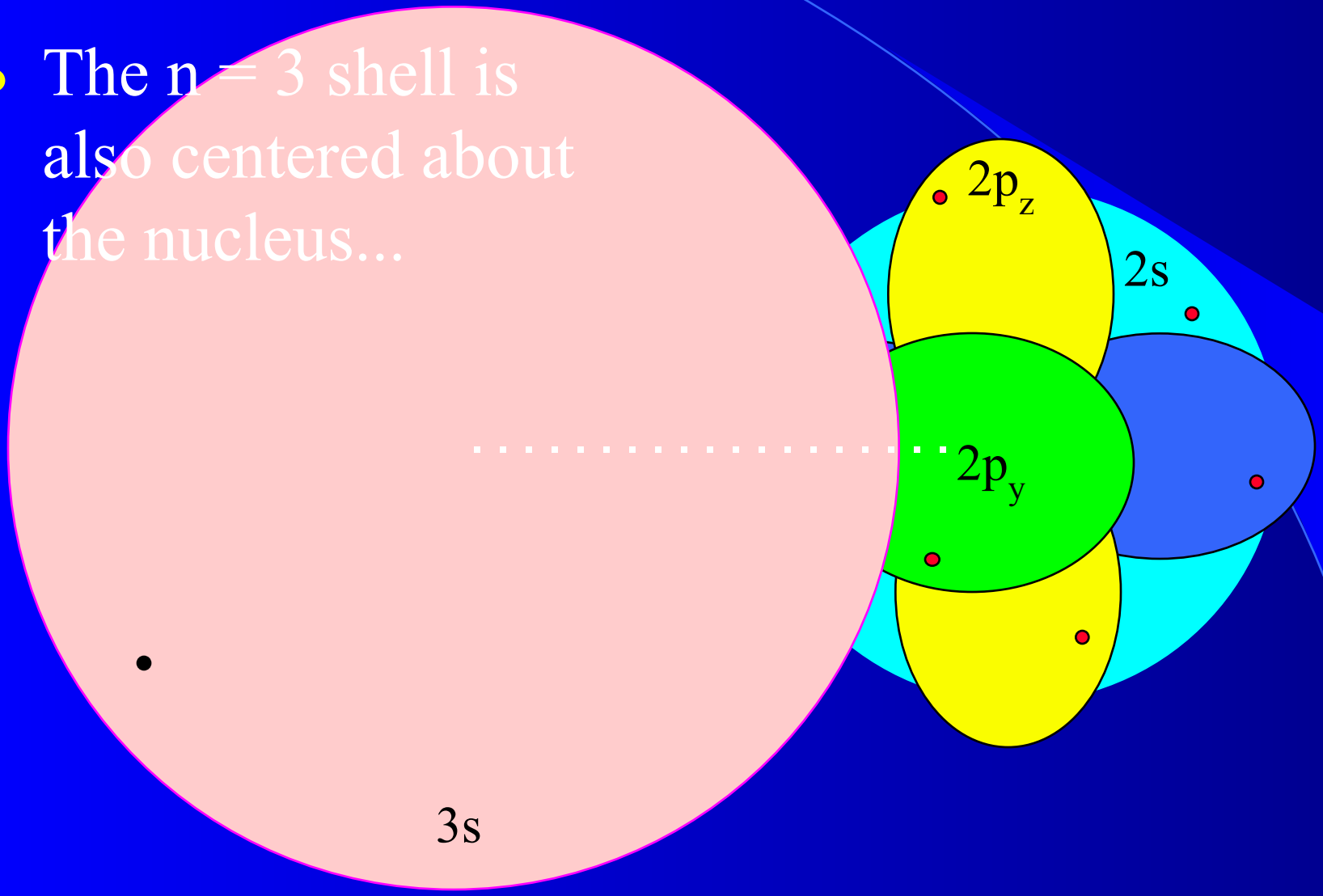
Inside a sodium atom

- Finally, the n=3 shell has a single 3s electron in it. It has a single, unpaired e^-.



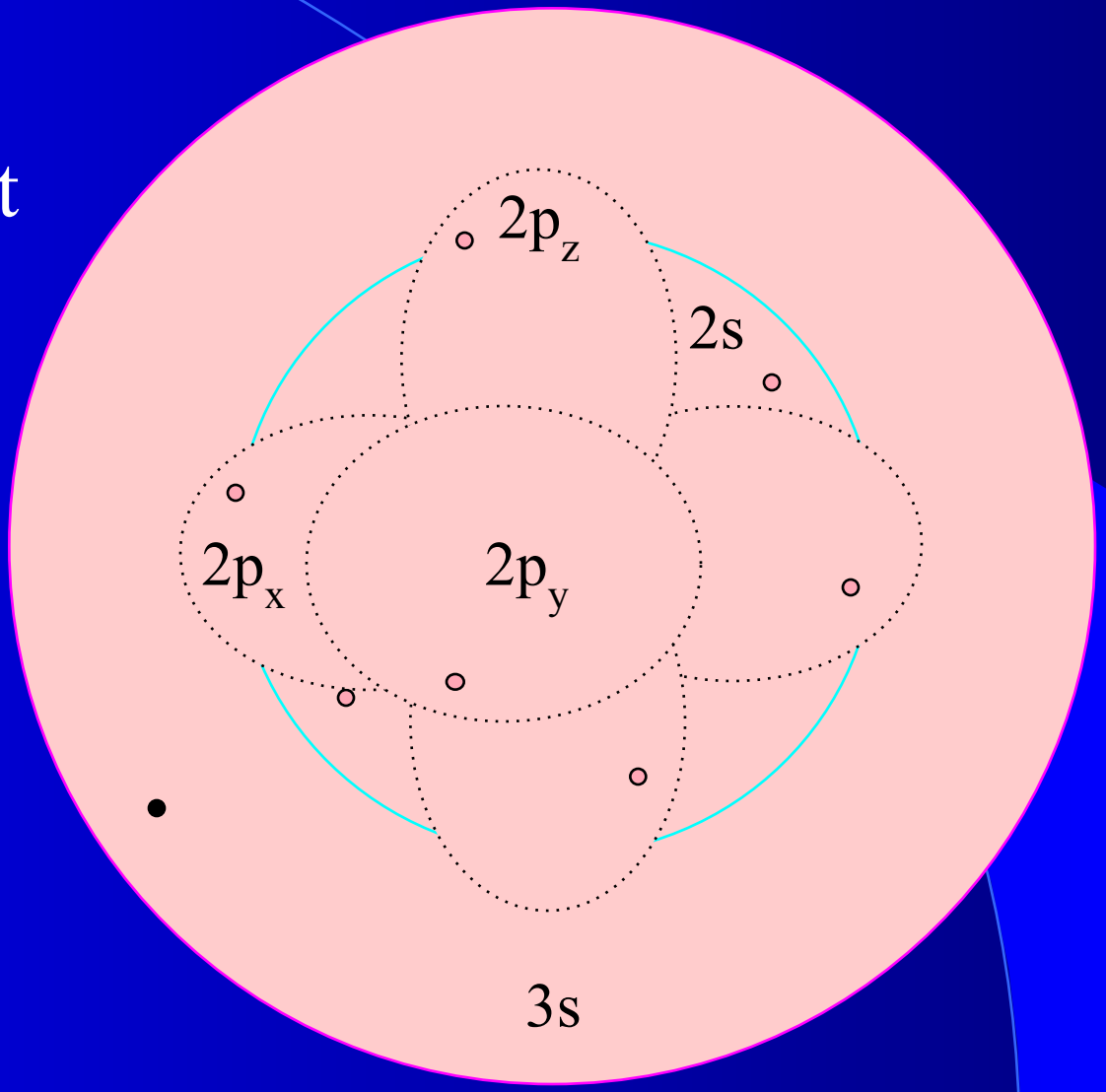
Inside a sodium atom

- The n = 3 shell is also centered about the nucleus...



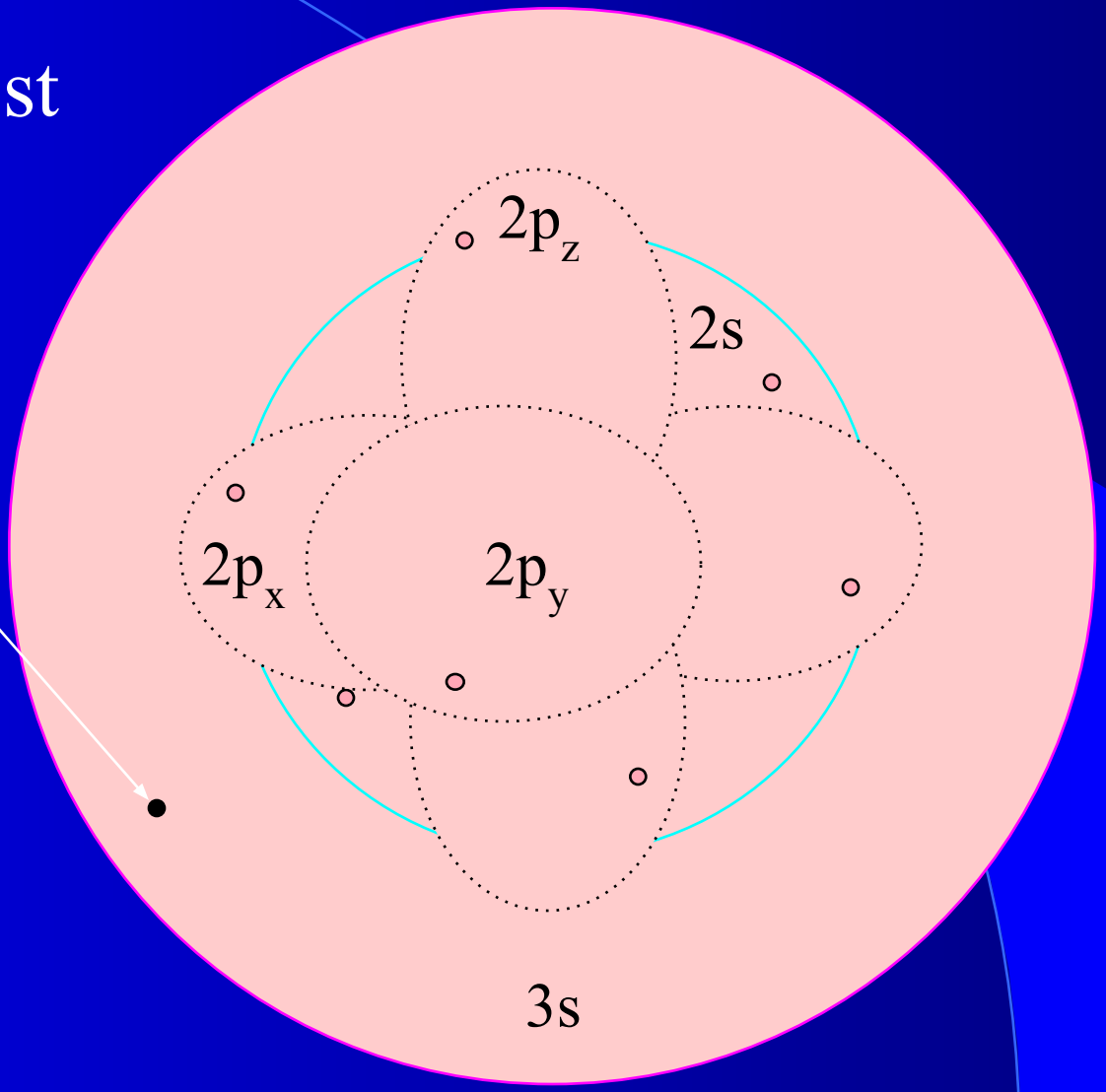
Inside a sodium atom

- The n = 3 shell is also centered about the nucleus...



Inside a sodium atom

- The 3s e^- is the most accessible e^- for interacting with another atom

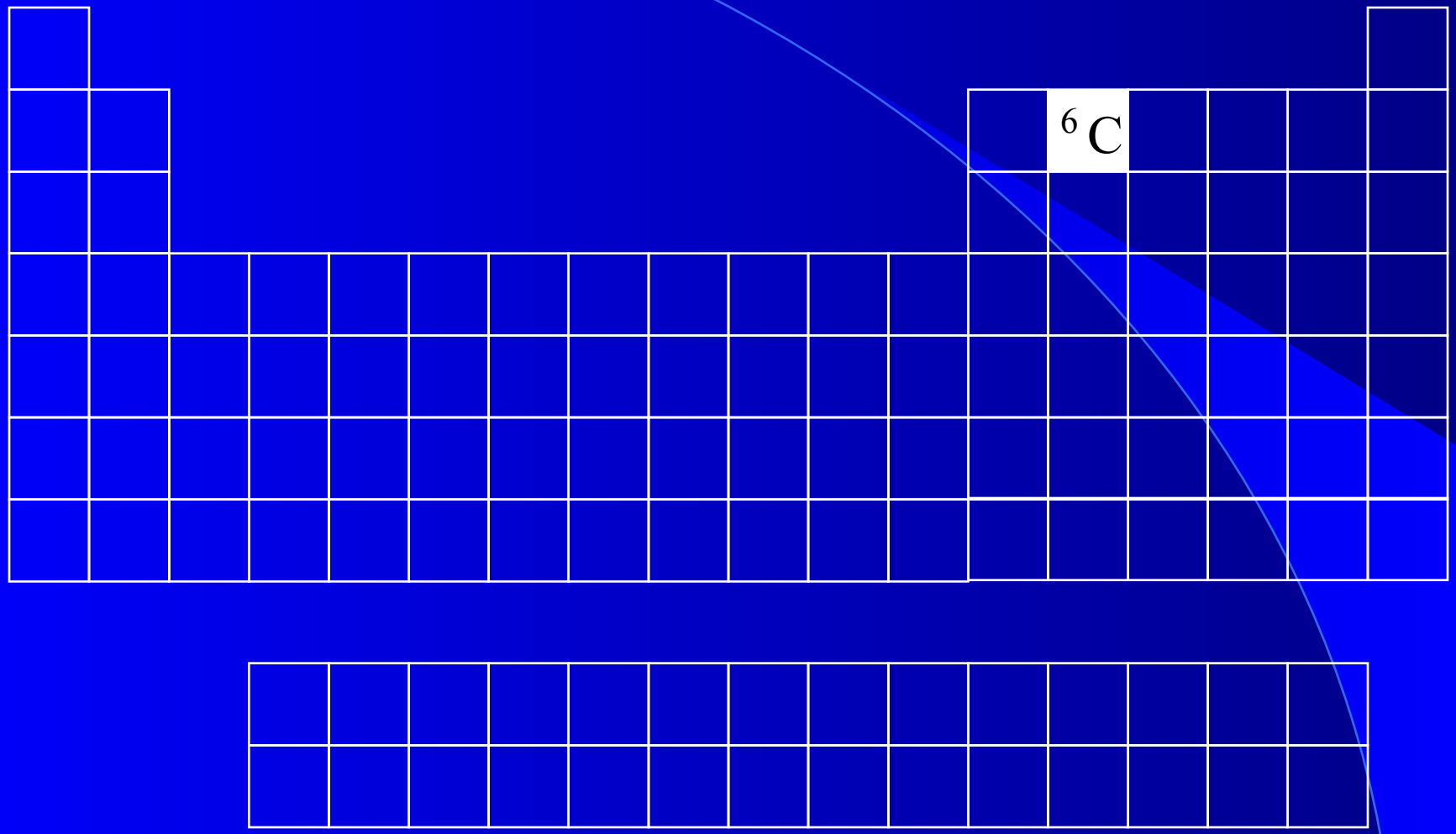


Electron Configurations

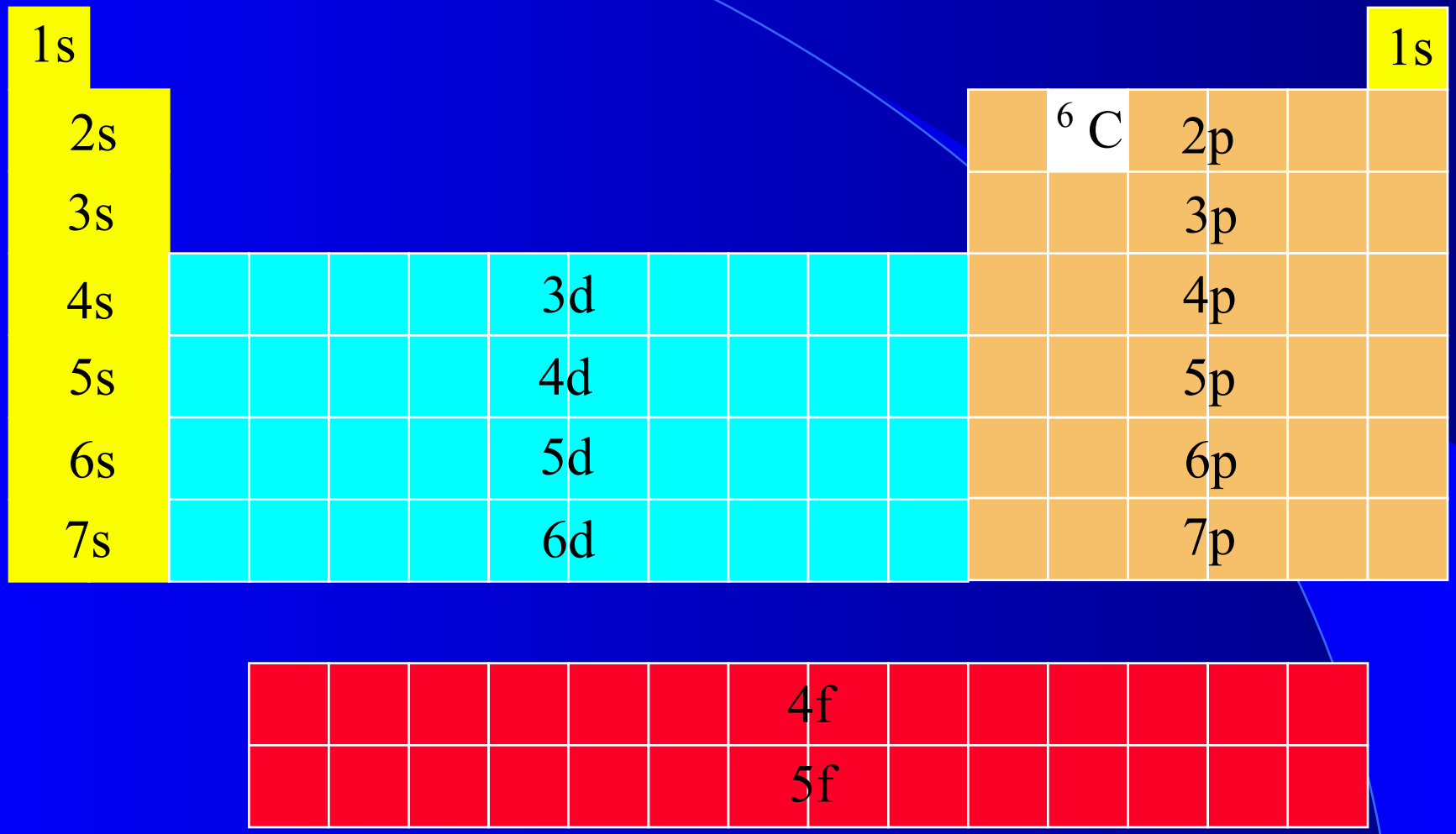
Electron Configurations

- Notational shorthand to show exact distribution of electrons in a given element
- Assume atom is in its lowest energy state, the ground state
- That is, no vacancies from bottom up
- Just count and list the number of each type of square you cross in arriving at the element of interest

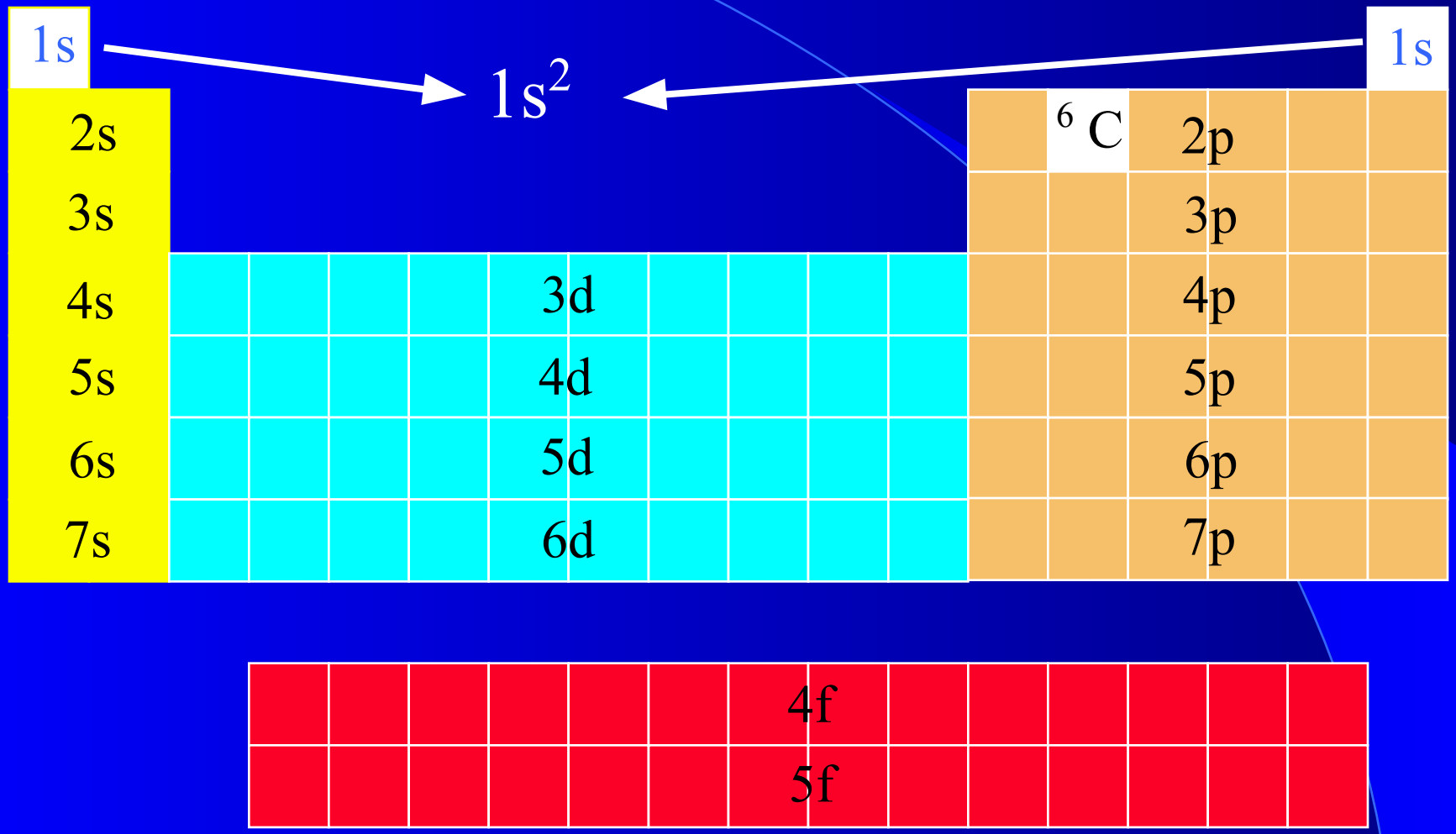
Example 1: Carbon



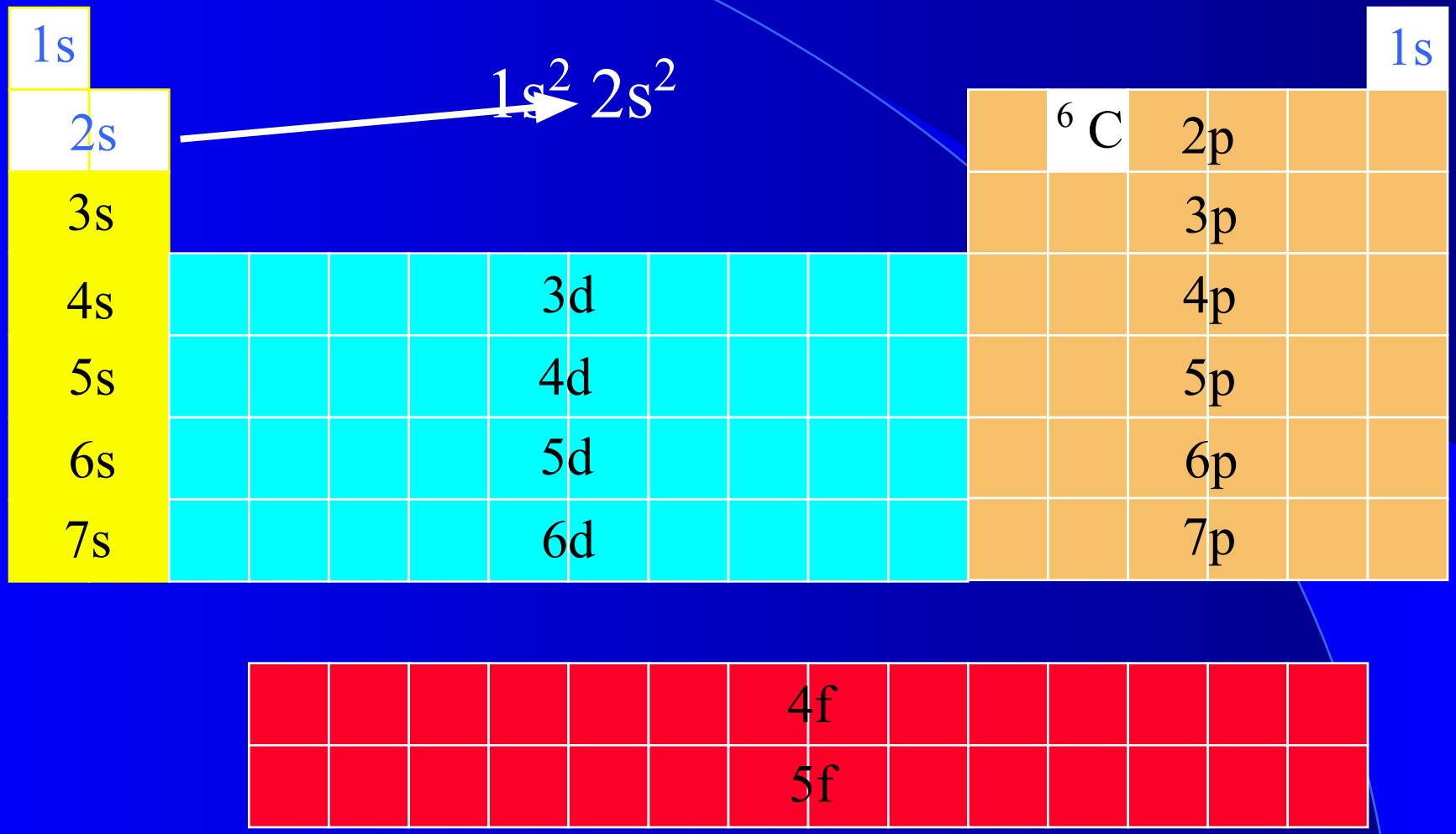
Carbon



Carbon

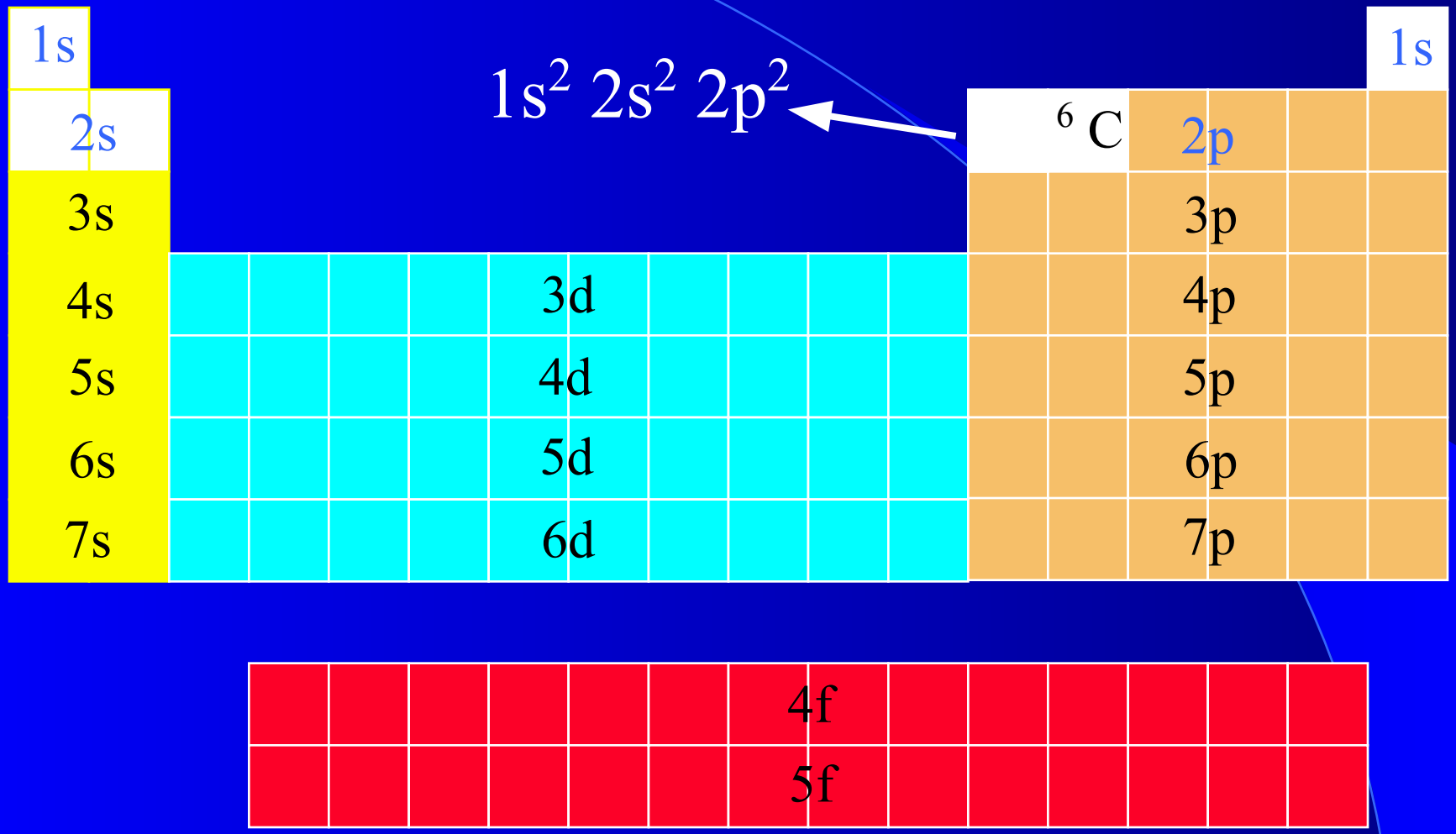


Carbon



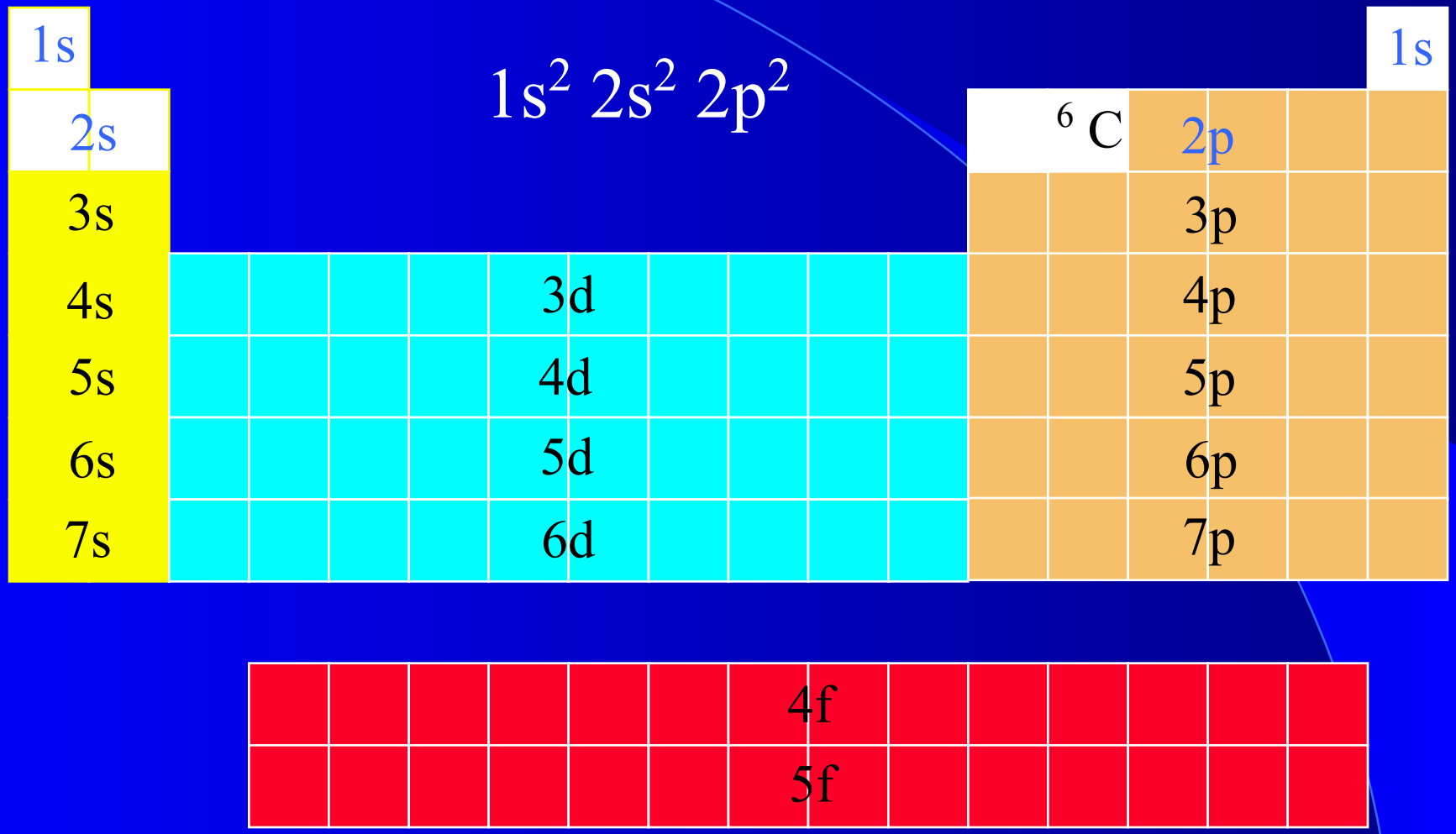
Carbon

$1s^2\ 2s^2\ 2p^2$



Carbon

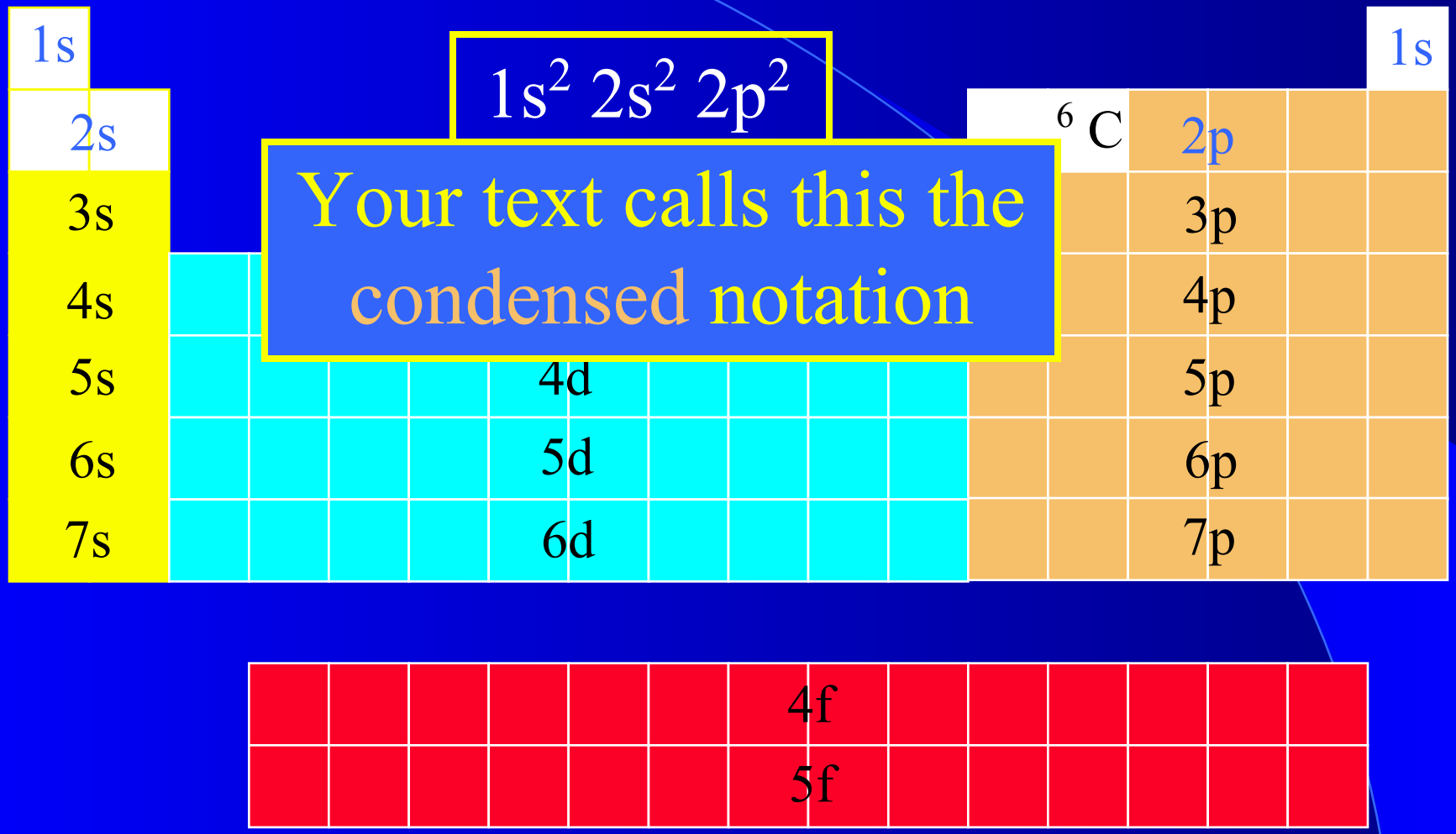
$1s^2\ 2s^2\ 2p^2$



Carbon

$1s^2\ 2s^2\ 2p^2$

Your text calls this the condensed notation



Electron Energy Levels

Electron Configuration Rules

- Begin at 1s and work up (aufbau principle)
- Each orbital has up to two electrons if opposite spins (Pauli exclusion principle)
- One e^- in each orbital of same type before adding second with opposite spin (Hund's rule)

Electron Energy Levels

1s __

Electron Energy Levels

2s __

1s __

Electron Energy Levels

2p __ __ __

2s __

1s __

Electron Energy Levels

3s __

2p __ __ __

2s __

1s __

Electron Energy Levels

3p __ __ __

3s __

2p __ __ __

2s __

1s __

Electron Energy Levels

4 s __

3p __ __ __

3s __

2p __ __ __

2s __

1s __

Electron Energy Levels

3d __ __ __ __ __

4 s __

3p __ __ __

3s __

2p __ __ __

2s __

1s __

Electron Energy Levels

4p __ __ __

3d __ __ __ __ __

4 s __

3p __ __ __

3s __

2p __ __ __

2s __

1s __

Template for e^- Configurations

Template for e^- Configurations

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

Template for e^- Configurations

- ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

Each dash represents an orbital

Template for e^- Configurations

- ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

Your text uses boxes, not dashes

Template for e^- Configurations

- ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

Works through Kr (no. 36)

Carbon Example

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

Carbon Example

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

6 electrons needed

Carbon Example

- ↑ ___ ___ ___ ___ ___ ___ ___ ___
- 1s 2s 2p 3s 3p

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- 4s 3d 4p

6 electrons needed

1 electron added

$1s^1$ H

Carbon Example

- ↑↓ ___ ___ ___ ___ ___ ___ ___ ___
- 1s 2s 2p 3s 3p

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- 4s 3d 4p

6 electrons needed

2 electrons added

$1s^2$ He

Carbon Example

- ↑↓ ___ ___ ___ ___ ___ ___ ___ ___
- 1s 2s 2p 3s 3p

First subshell filled before moving to next one

- ___ ___ ___ ___ ___ ___ ___
- 4s 3d 4p

6 electrons needed

2 electrons added

$1s^2$ He

Carbon Example

- ↑↓ ↑ ___ ___ ___ ___ ___ ___ ___
- 1s 2s 2p 3s 3p

- ___ ___ ___ ___ ___ ___ ___ ___
- 4s 3d 4p

6 electrons needed

3 electrons added

$1s^2 2s^1$ Li

Carbon Example

- ↑↓ ↑↓ ___ ___ ___ ___ ___ ___ ___
- 1s 2s 2p 3s 3p

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- 4s 3d 4p

6 electrons needed

4 electrons added

$1s^2 2s^2$ Be

Carbon Example

- ↑↓ ↑↓ ↑ ___ ___ ___ ___ ___ ___
- 1s 2s 2p 3s 3p

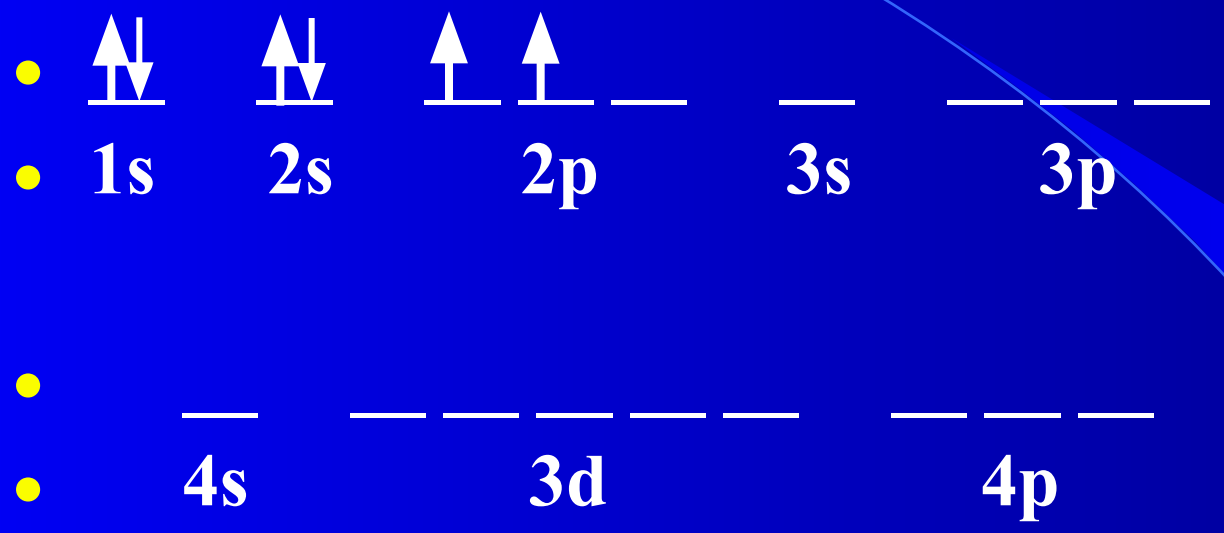
- ___ ___ ___ ___ ___ ___ ___ ___ ___
- 4s 3d 4p

6 electrons needed

5 electrons added

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

Carbon Example



6 electrons needed

6 electrons added

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

Carbon Example

- ↑↓ ↑↓ ↑ ↑ ___ ___ ___ ___ ___
- 1s 2s 2p 3s 3p
- ___ ___ ___ ___
- 4s 4p

One e^- in each orbital of a subshell before any of opposite spins added

6 electrons needed

6 electrons added

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

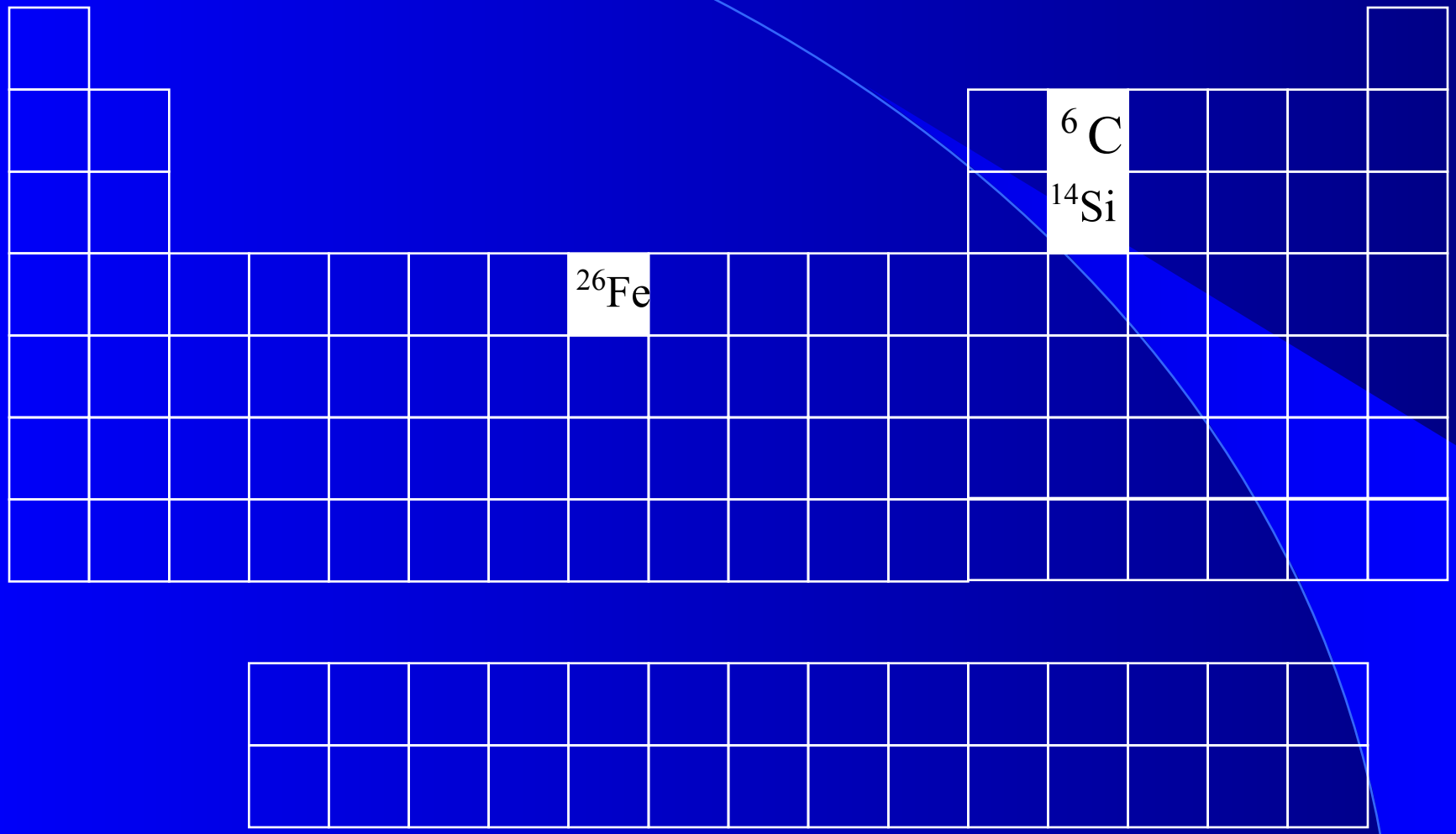
Outermost shells...

- Note that carbon and silicon have similar outer shells

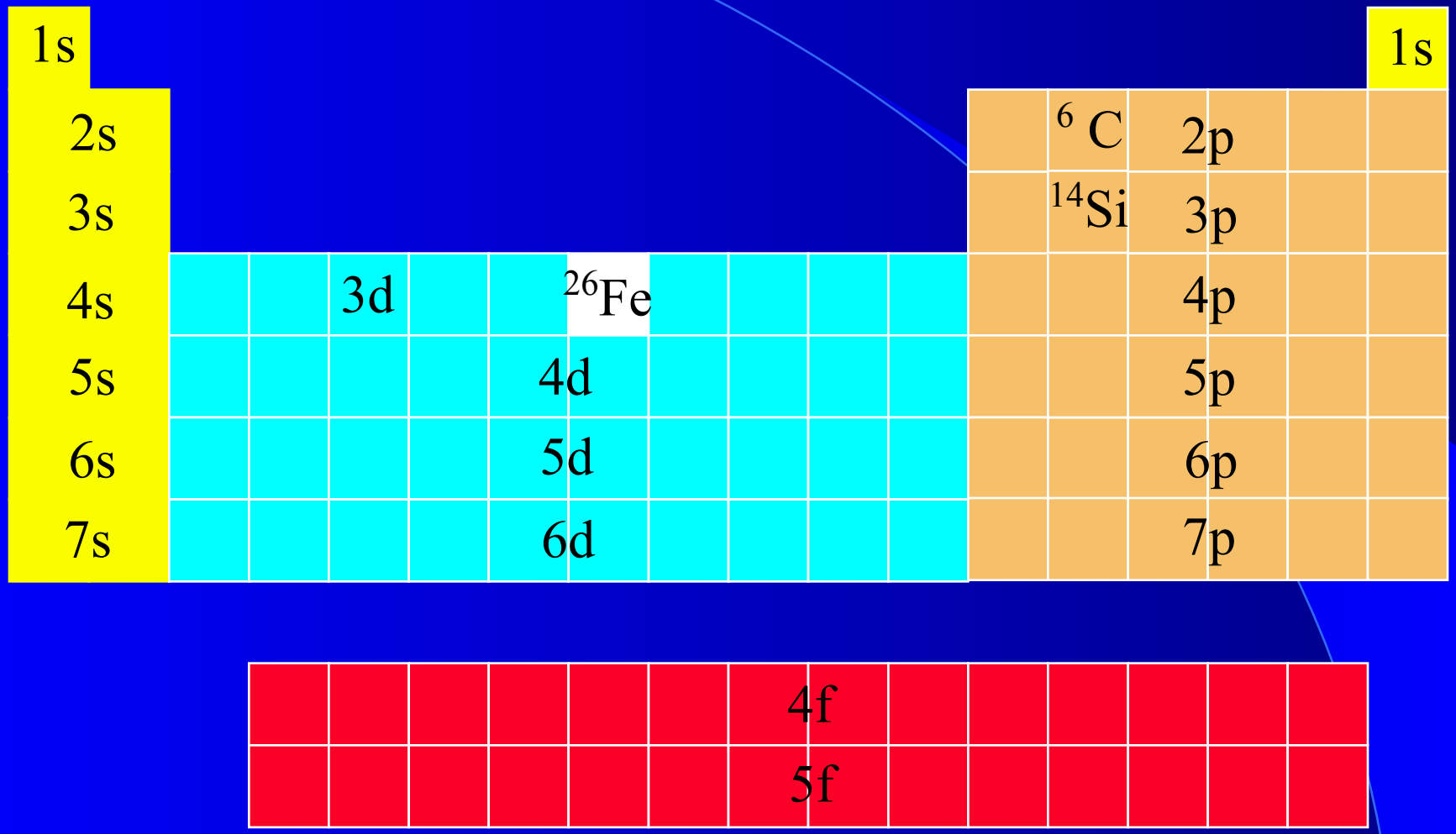
$1s^2 2s^2 2p^2$
carbon

$1s^2 2s^2 2p^6 3s^2 3p^2$
silicon

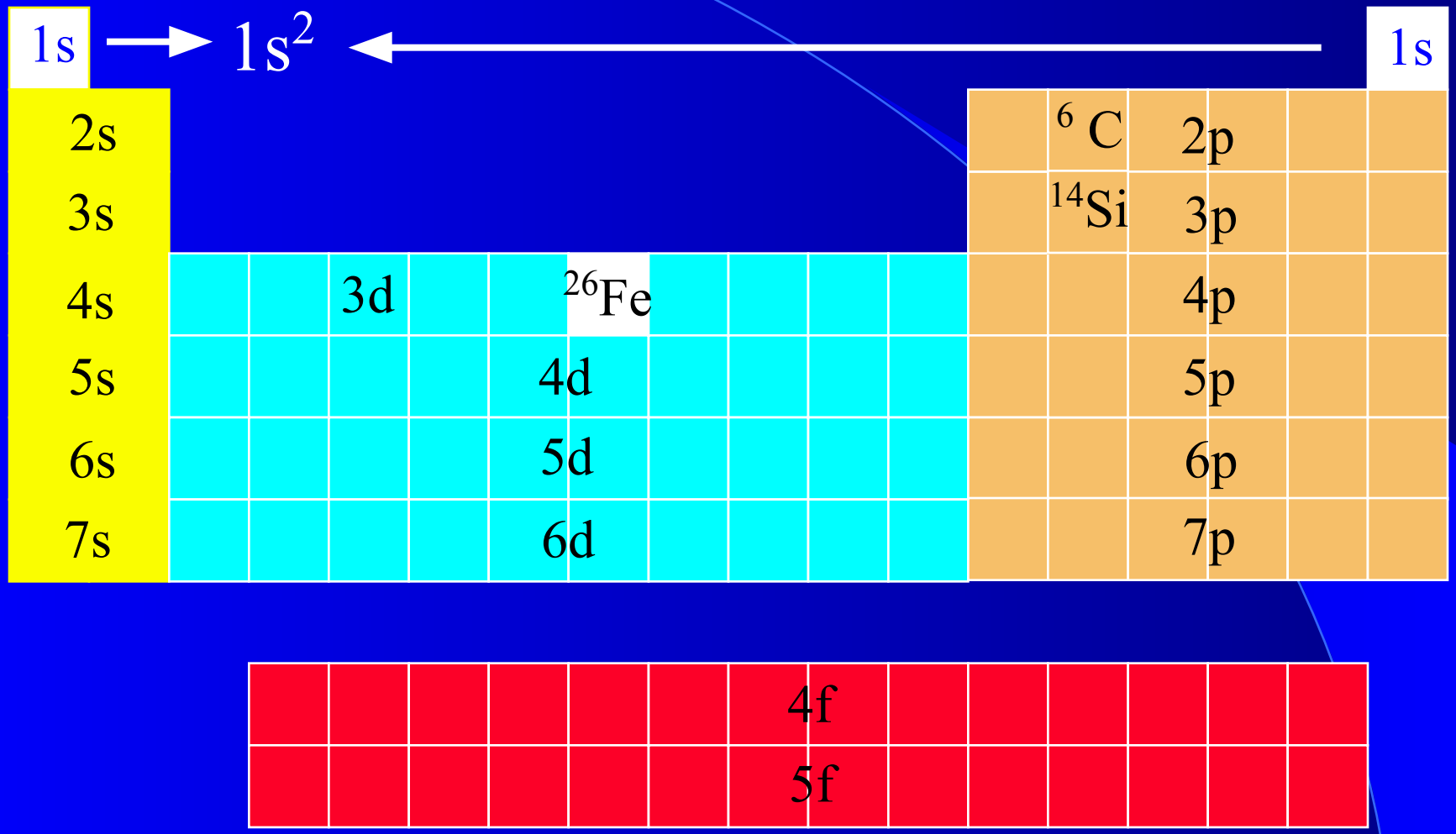
Example 2: Iron



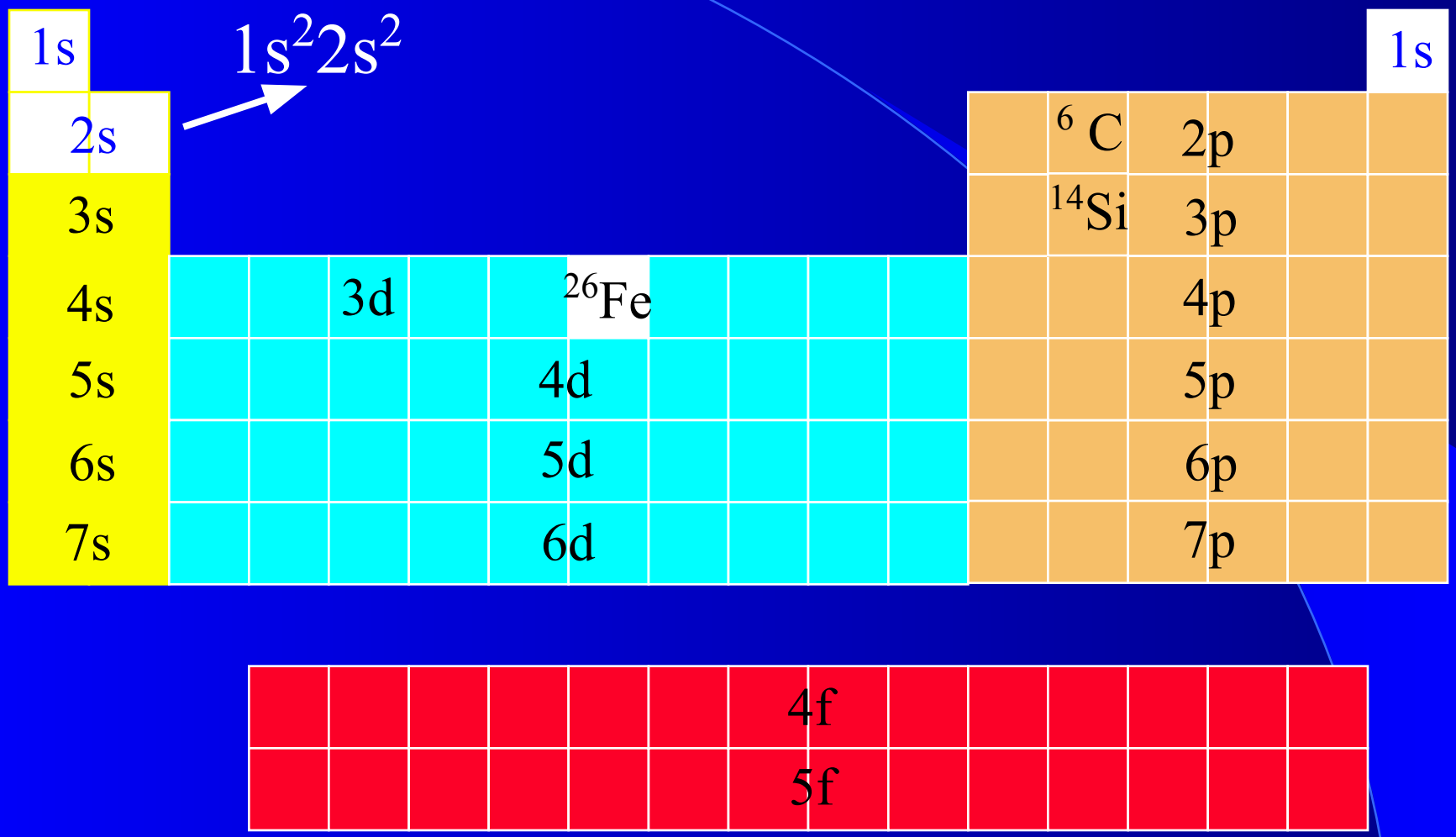
Iron


1s
1s
2s
3s
4s
5s
6s
7s
3d
^{26}Fe
4d
5d
6d
^{6}C
^{14}Si
2p
3p
4p
5p
6p
7p
4f
5f

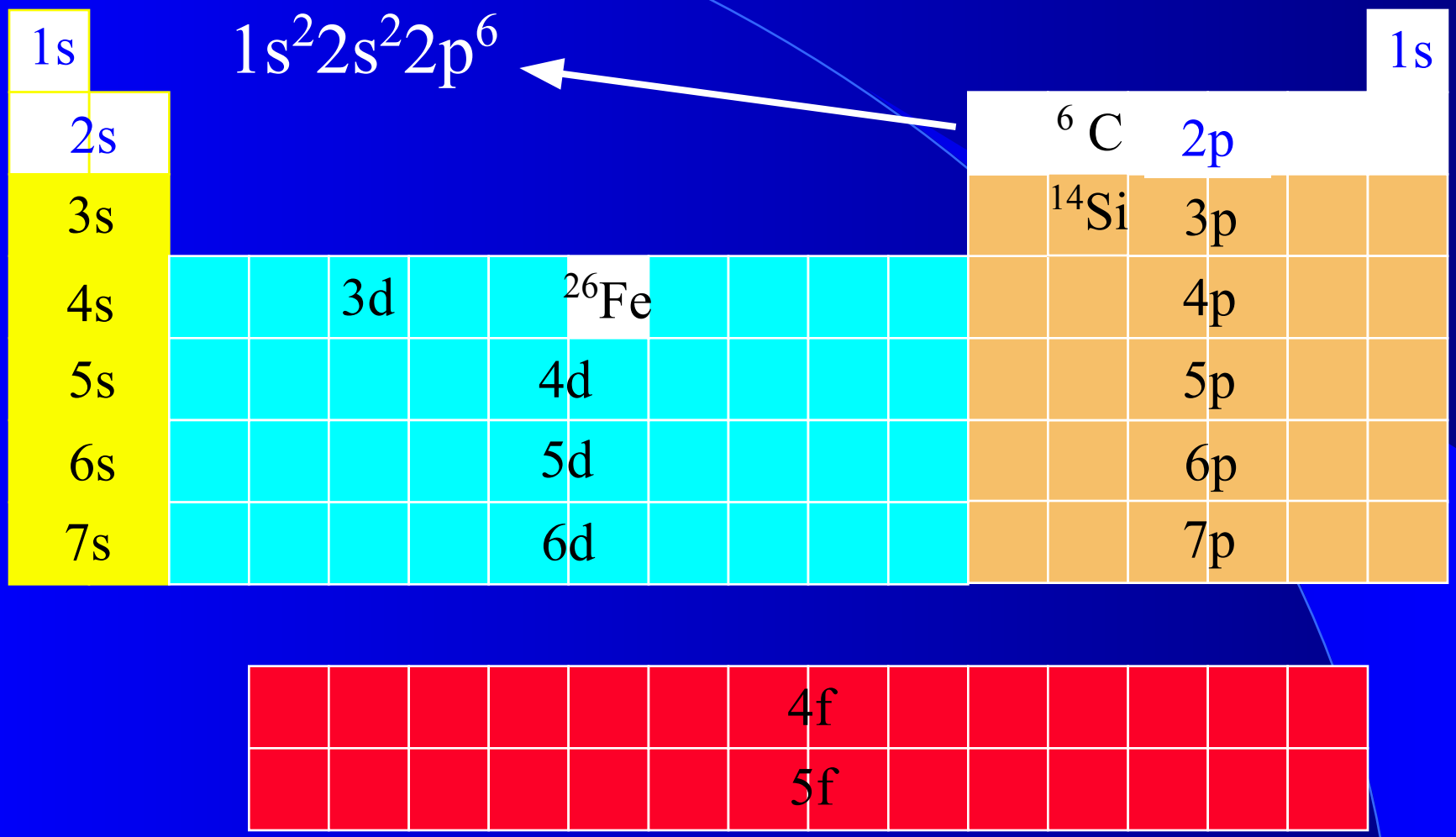
Iron


1s
1s²
1s
2s
3s
4s
5s
6s
7s
3d
26Fe
4d
5d
6d
6 C
14Si
2p
3p
4p
5p
6p
7p
4f
5f

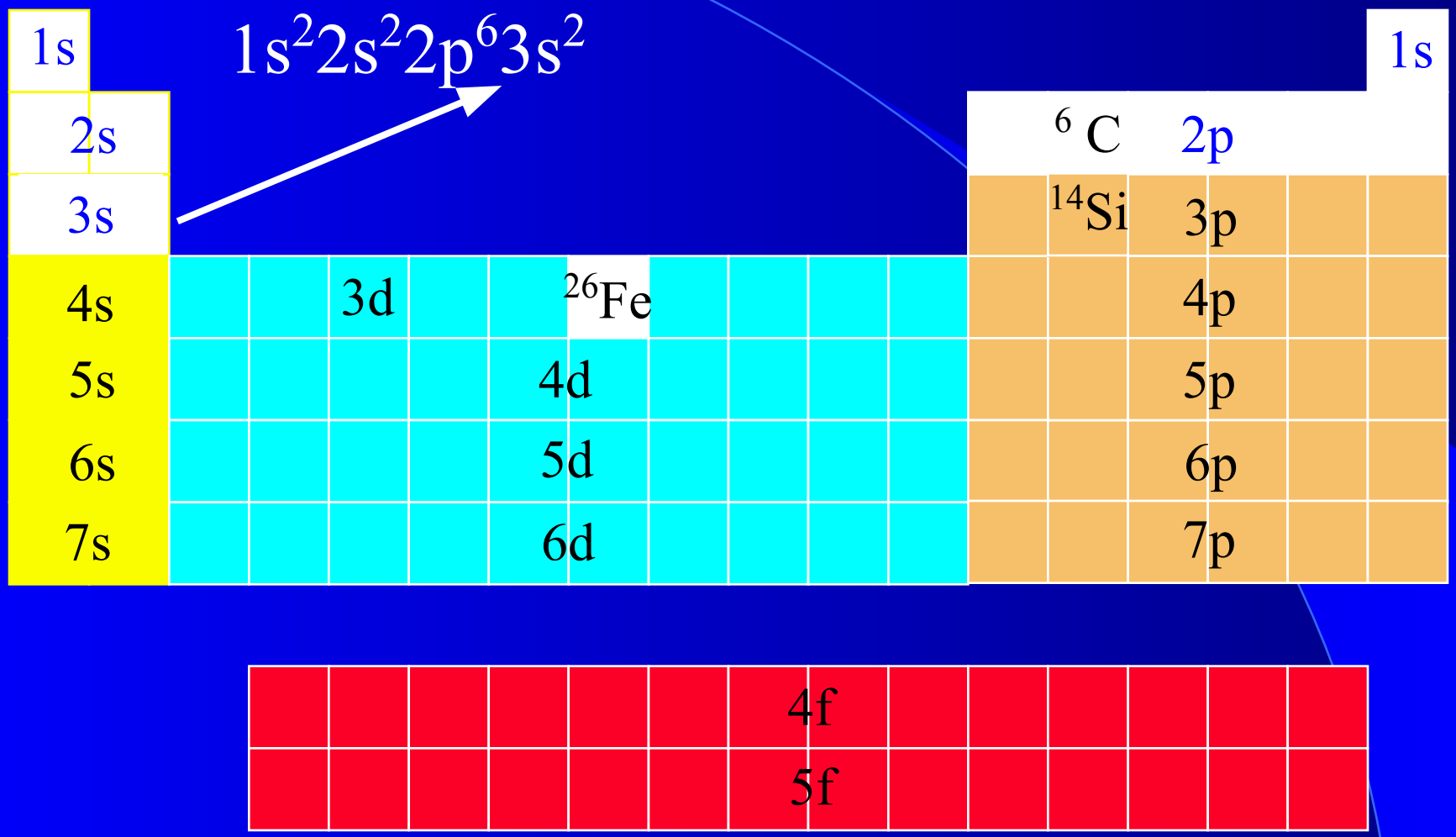
Iron


1s
$1s^2 2s^2$
2s
3s
4s
5s
6s
7s
3d
^{26}Fe
4d
5d
6d
1s
^{6}C
2p
^{14}Si
3p
4p
5p
6p
7p
4f
5f

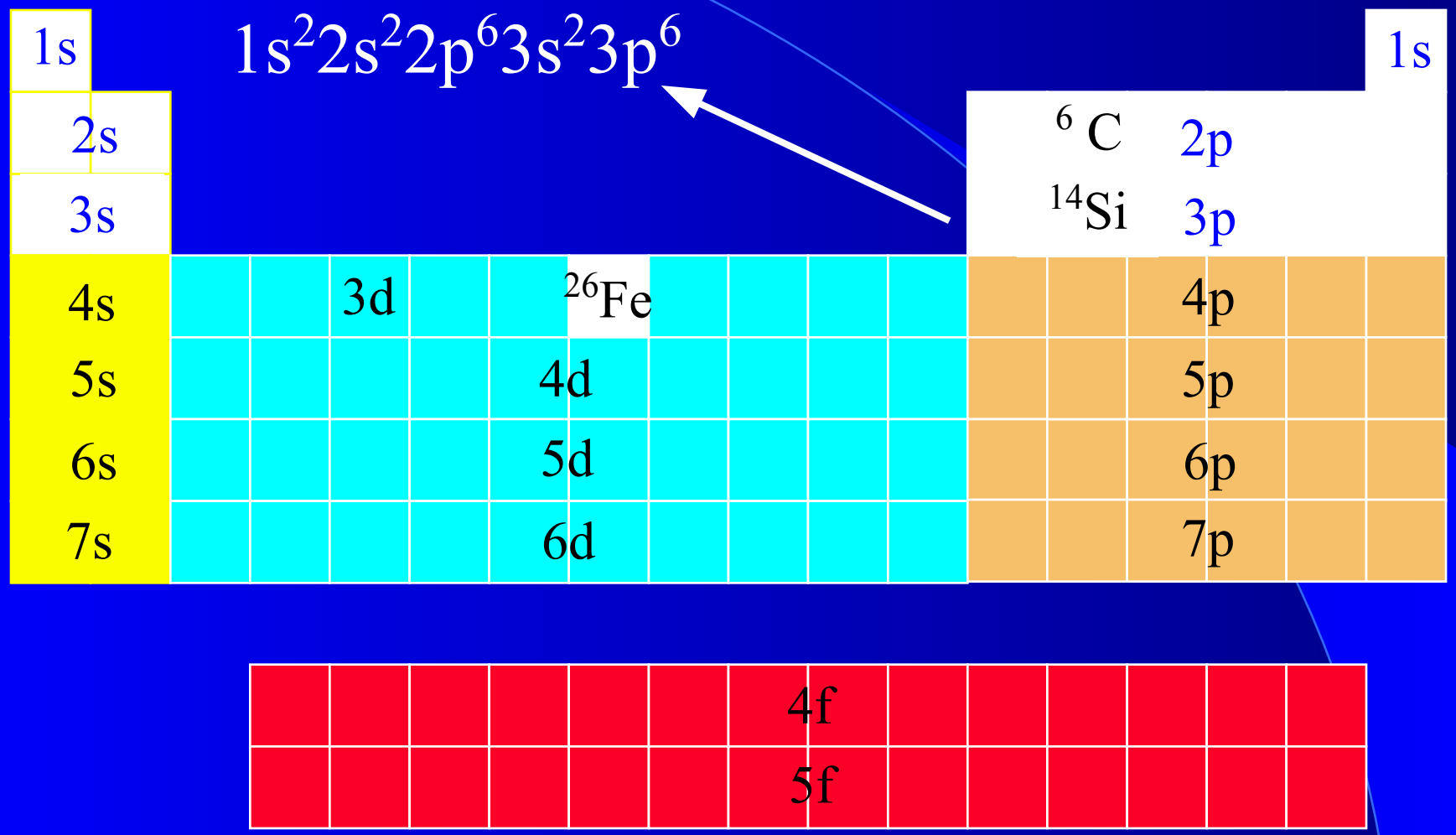
Iron


1s
$1s^2 2s^2 2p^6$
1s
2s
^{6}C
2p
3s
^{14}Si
3p
4s
3d
^{26}Fe
4p
5s
4d
5p
6s
5d
6p
7s
6d
7p
4f
5f

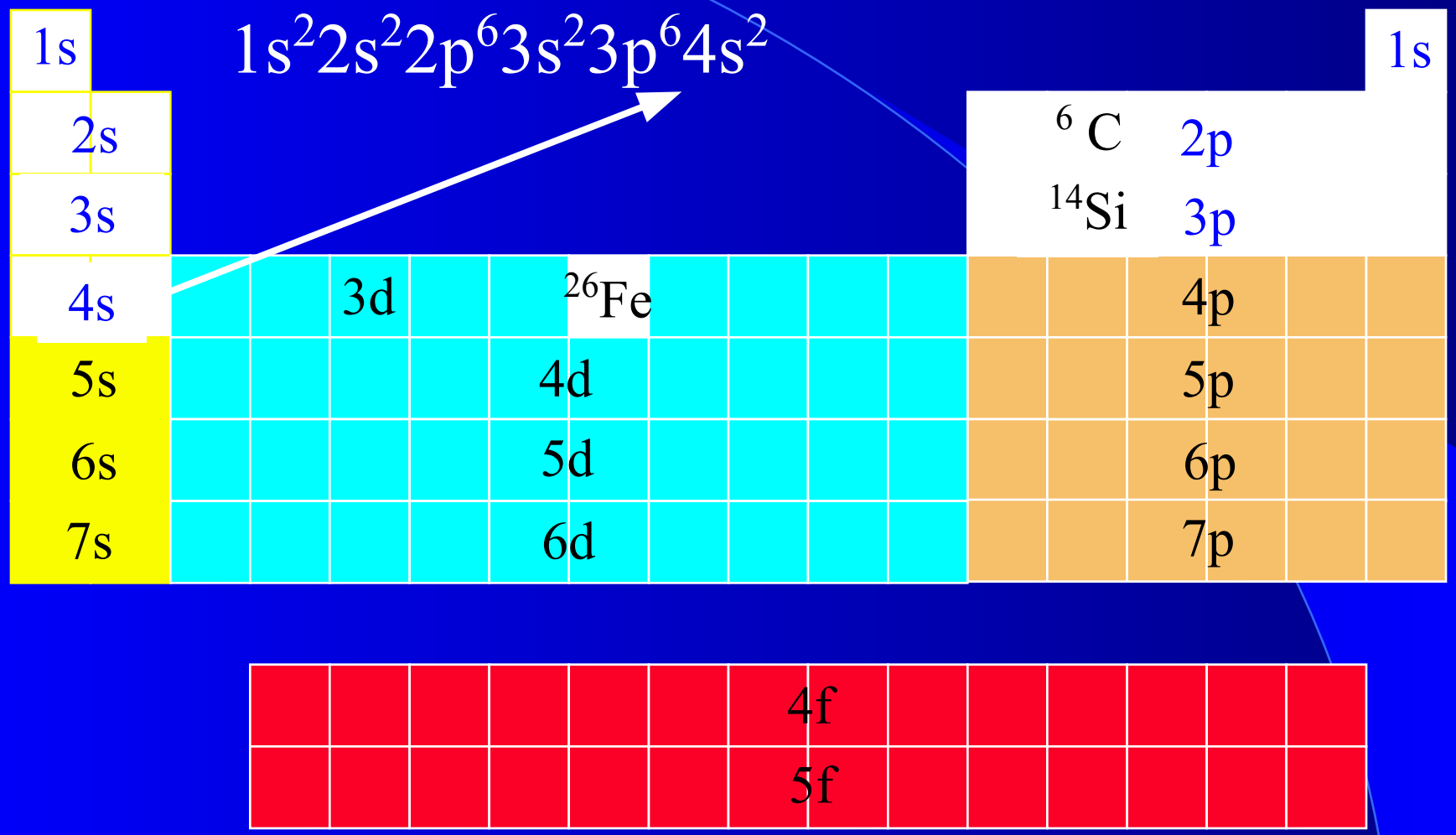
Iron


1s
2s
3s
4s
5s
6s
7s
$1s^2 2s^2 2p^6 3s^2$
3d
^{26}Fe
4d
5d
6d
1s
^{6}C
2p
^{14}Si
3p
4p
5p
6p
7p
4f
5f

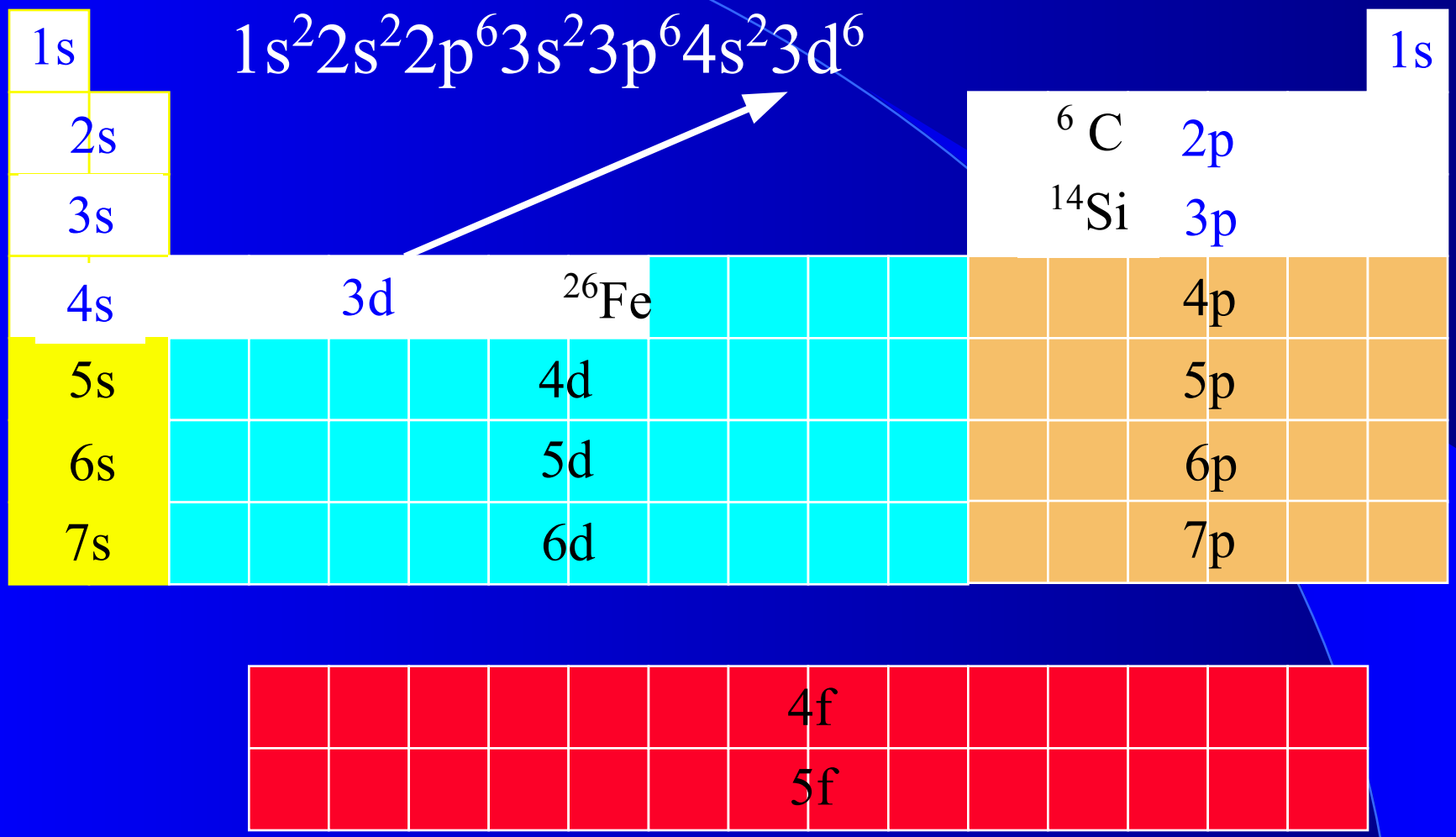
Iron


1s
$1s^2 2s^2 2p^6 3s^2 3p^6$
1s
2s
3s
^{6}C
2p
^{14}Si
3p
4s
3d
^{26}Fe
4p
5s
4d
5p
6s
5d
6p
7s
6d
7p
4f
5f

Iron

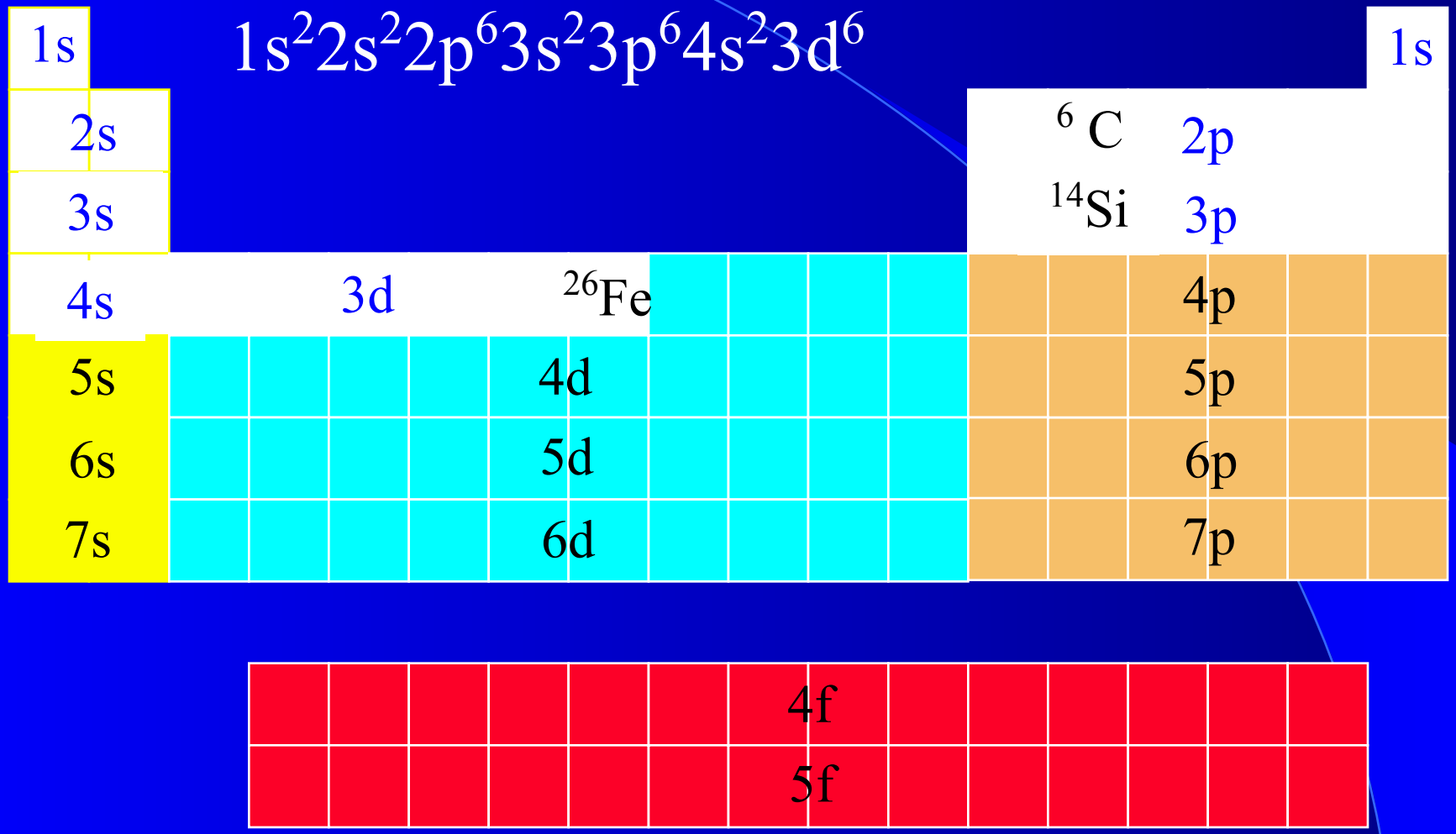

1s
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
1s
2s
3s
4s
3d
^{26}Fe
^{6}C
2p
^{14}Si
3p
4p
5s
4d
5p
6s
5d
6p
7s
6d
7p
4f
5f

Iron


1s
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
1s
2s
3s
^{6}C
2p
^{14}Si
3p
4s
3d
^{26}Fe
4p
5s
4d
5p
6s
5d
6p
7s
6d
7p
4f
5f

Iron

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$



Iron Example

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

Iron Example

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **1s 2s 2p 3s 3p**

- ___ ___ ___ ___ ___ ___ ___ ___ ___
- **4s 3d 4p**

26 electrons needed

Iron Example

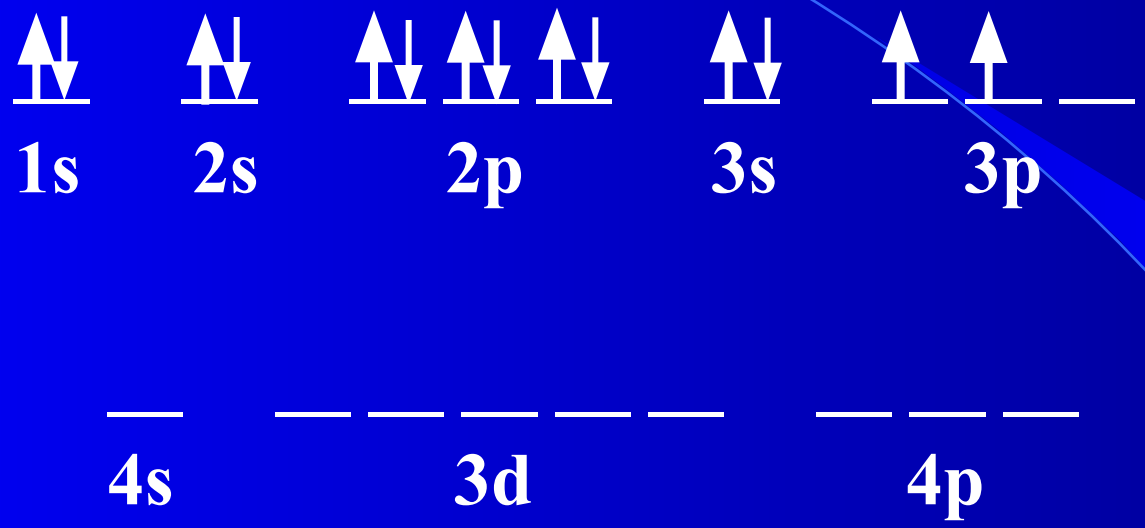
- __ __ __ __ __ __ __ __ __
- **1s 2s 2p 3s 3p**

- __ __ __ __ __ __ __ __ __
- **4s 3d 4p**

26 electrons needed

Start where we left off last time...

Iron Example



26 electrons needed

14 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^2$

Si

Iron Example

- ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑ ↑ ↑
- **1s 2s 2p 3s 3p**

- — — — — — — — — — —
- **4s 3d 4p**

26 electrons needed

15 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^3$

P

Iron Example

- ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑ ↑
- **1s 2s 2p 3s 3p**

- — — — — — — — — — —
- **4s 3d 4p**

26 electrons needed

16 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^4$

S

Iron Example

- ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑
- 1s 2s 2p 3s 3p

- — — — — — — — — —
- 4s 3d 4p

26 electrons needed

17 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^5$

Cl

Iron Example

- ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓ ↑↓
- **1s 2s 2p 3s 3p**

- — — — — — — — — — —
- **4s 3d 4p**

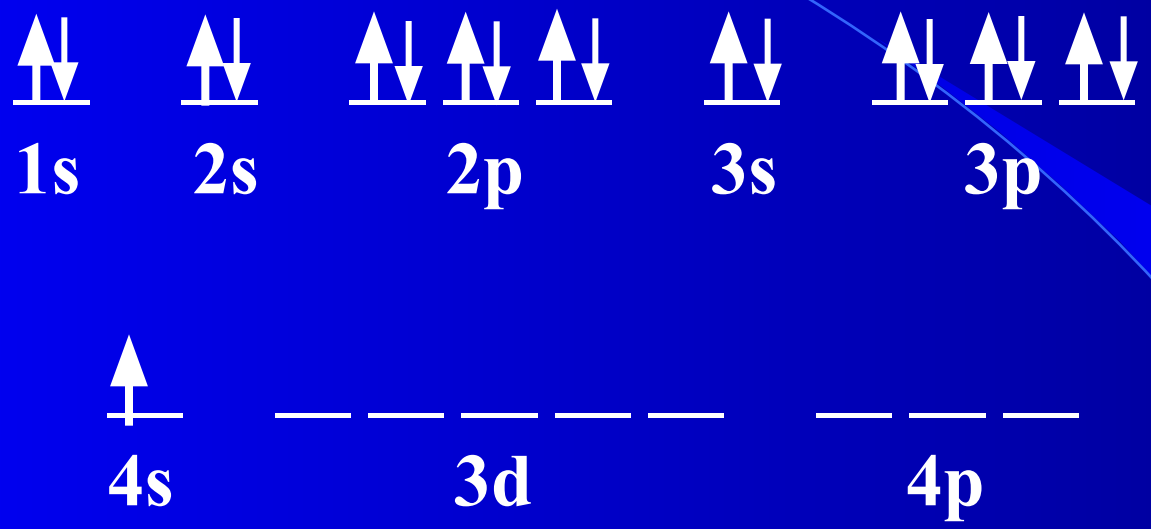
26 electrons needed

18 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^6$

Ar

Iron Example



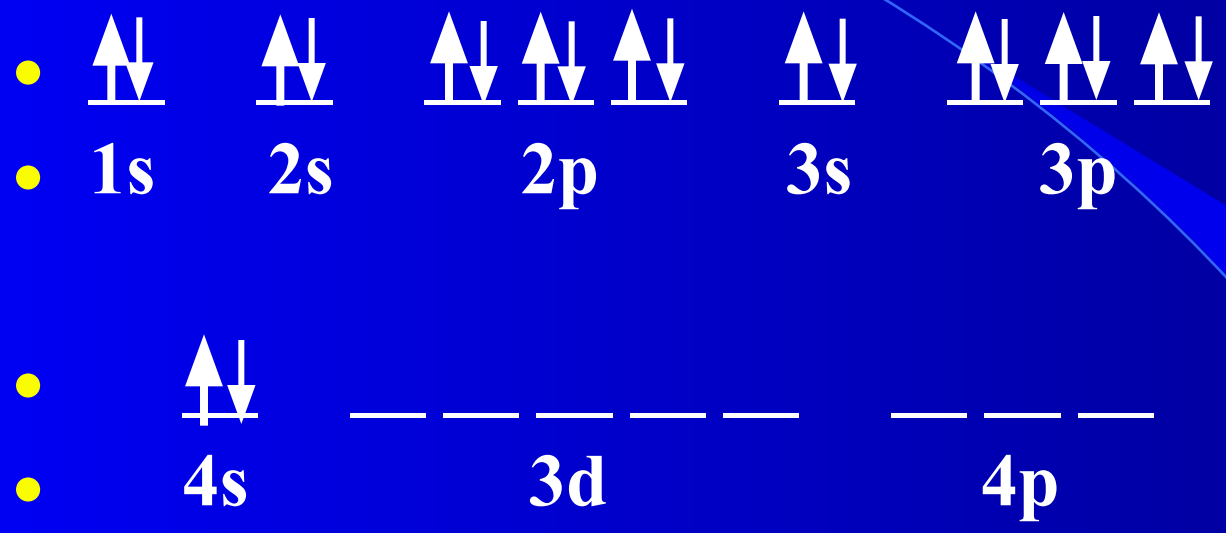
26 electrons needed

19 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$

K

Iron Example



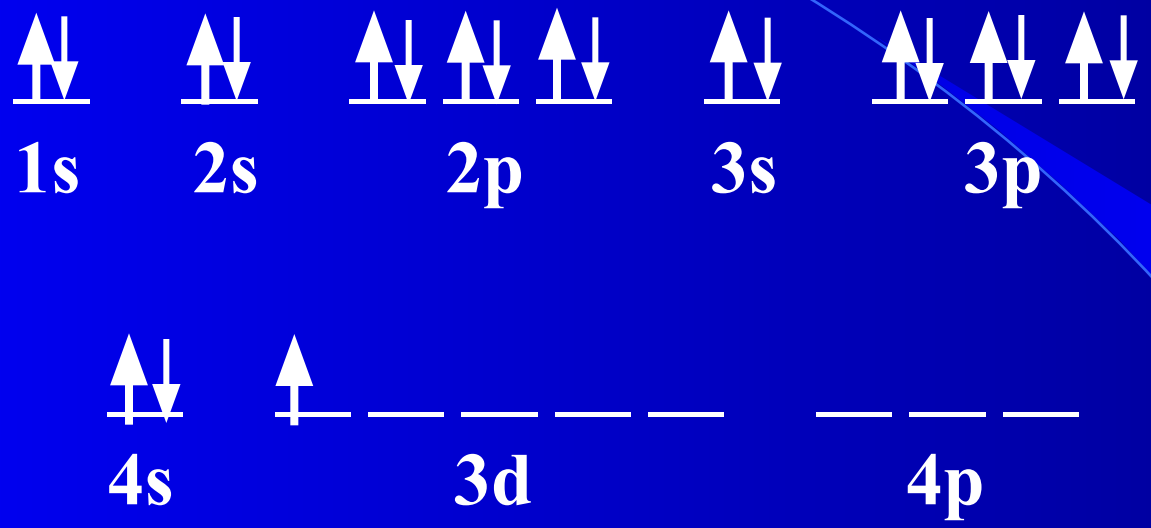
26 electrons needed

20 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

Ca

Iron Example



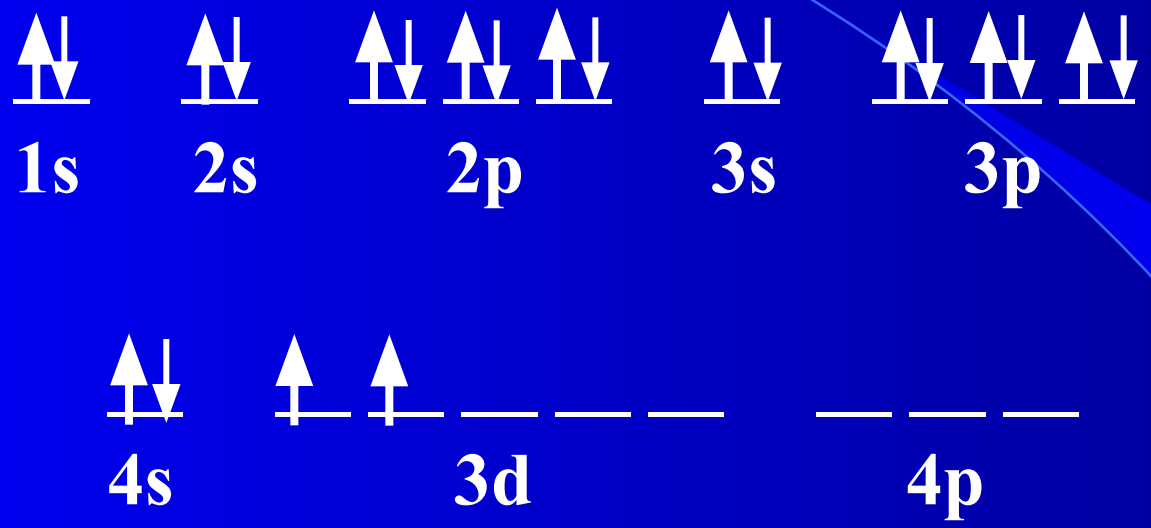
26 electrons needed

21 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^1$

Sc

Iron Example



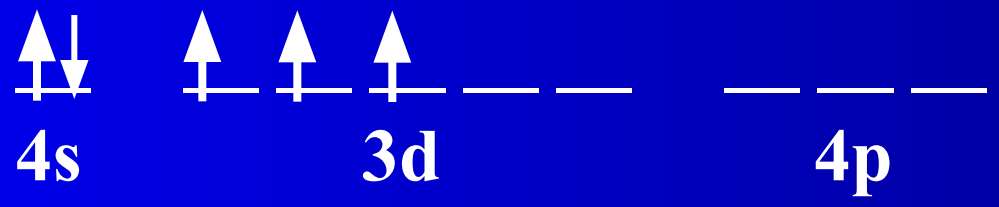
26 electrons needed

22 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$

Ti

Iron Example



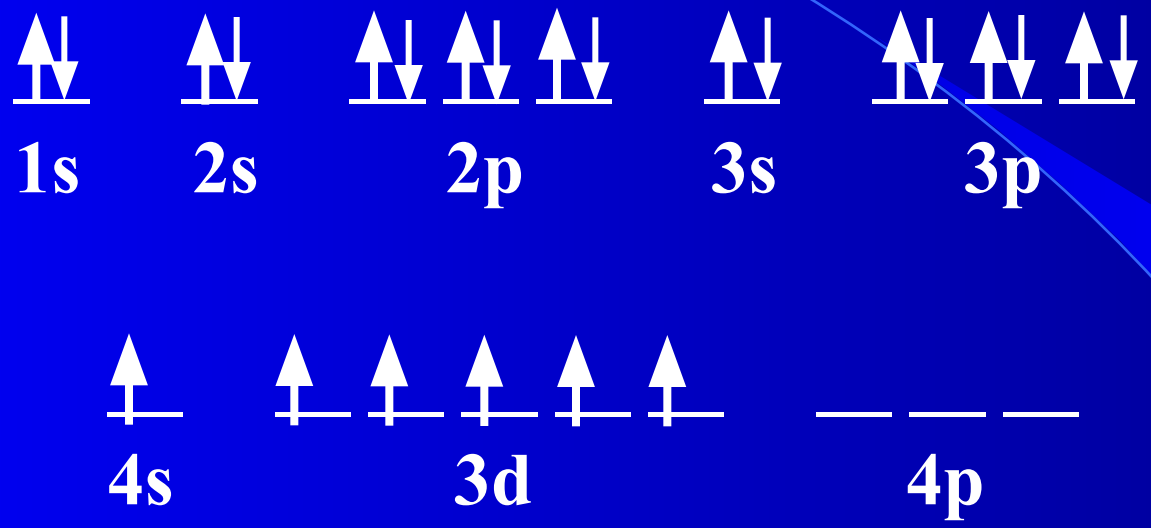
26 electrons needed

23 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$

V

Iron Example



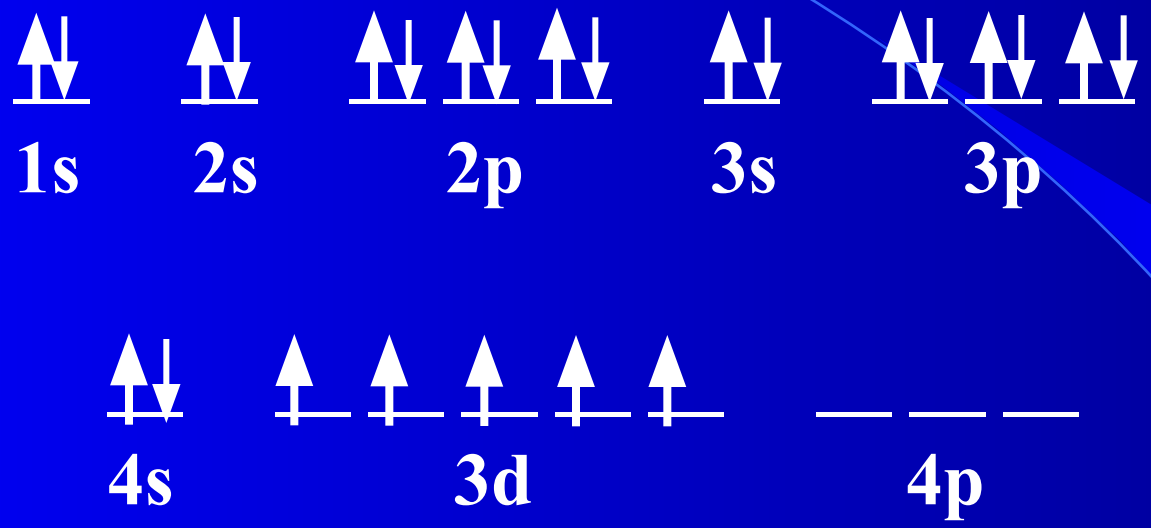
26 electrons needed

24 electrons added

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^5$

Cr (exception)

Iron Example



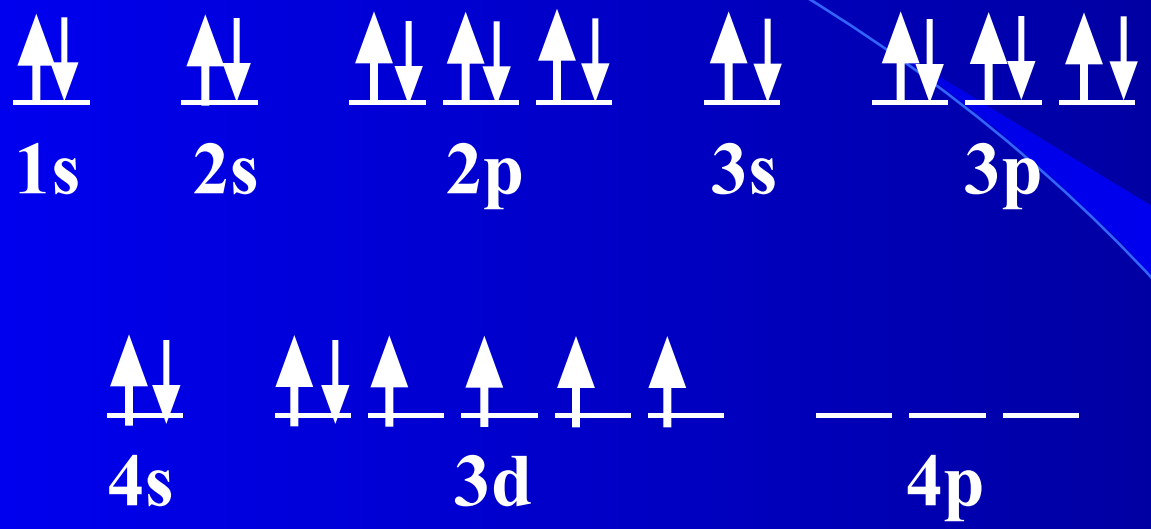
26 electrons needed

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$

25 electrons added

Mn

Iron Example



26 electrons needed

26 electrons added

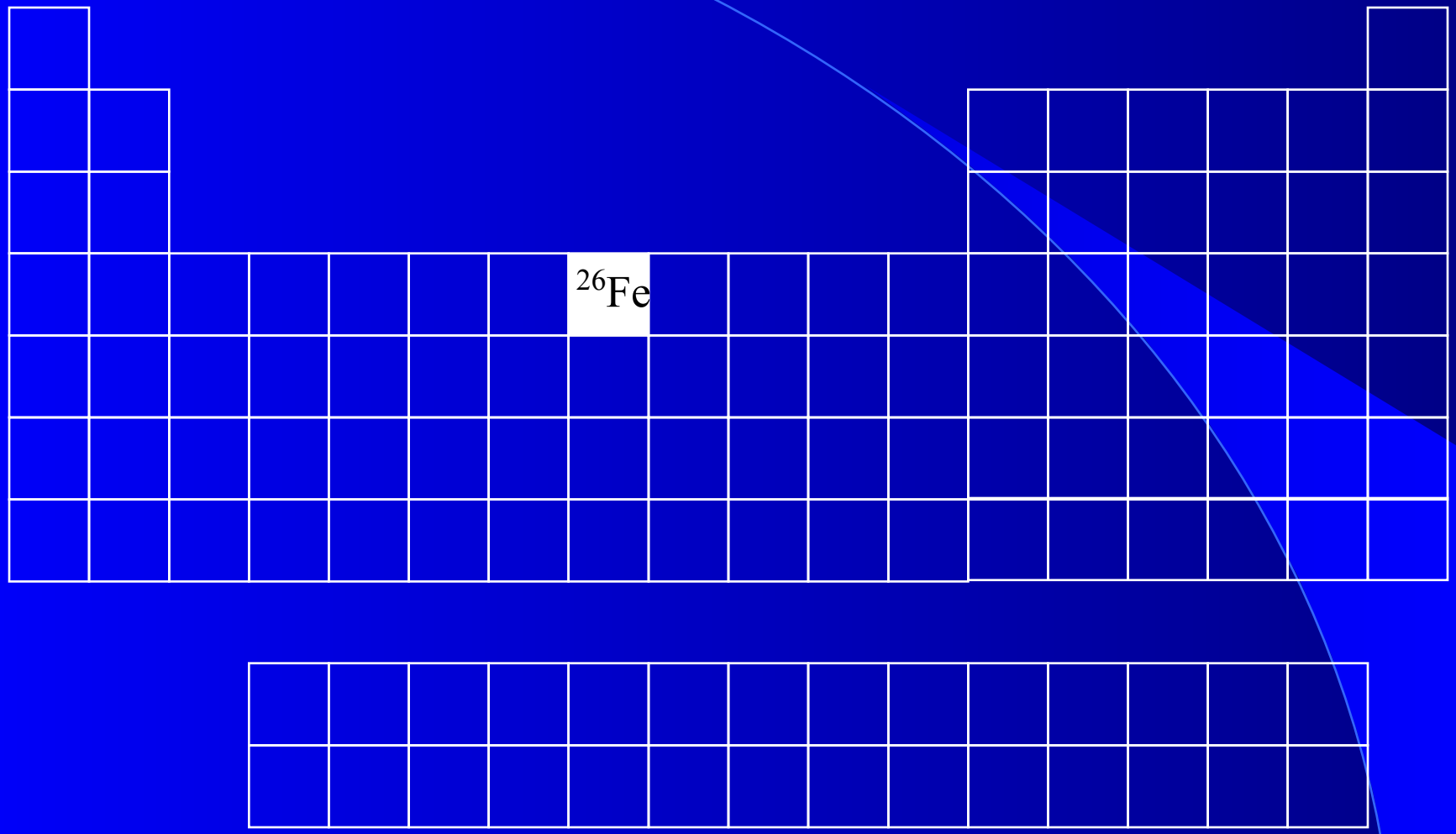
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$

Fe

Noble gas notation

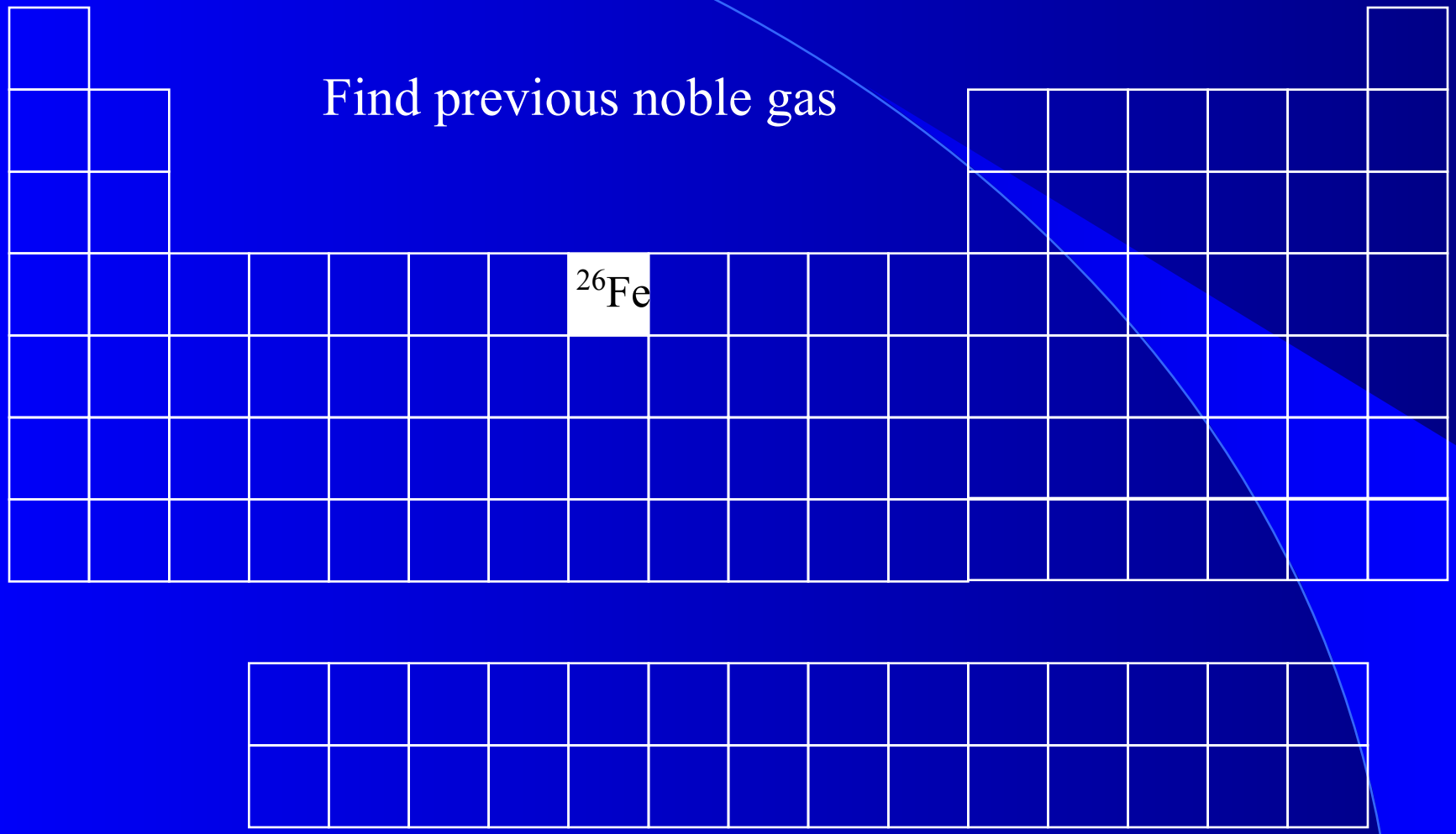
- Eventually, electron configurations get too long!
- Noble gas notation shortens it by using a noble gas core
- Fe $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$

Noble gas notation

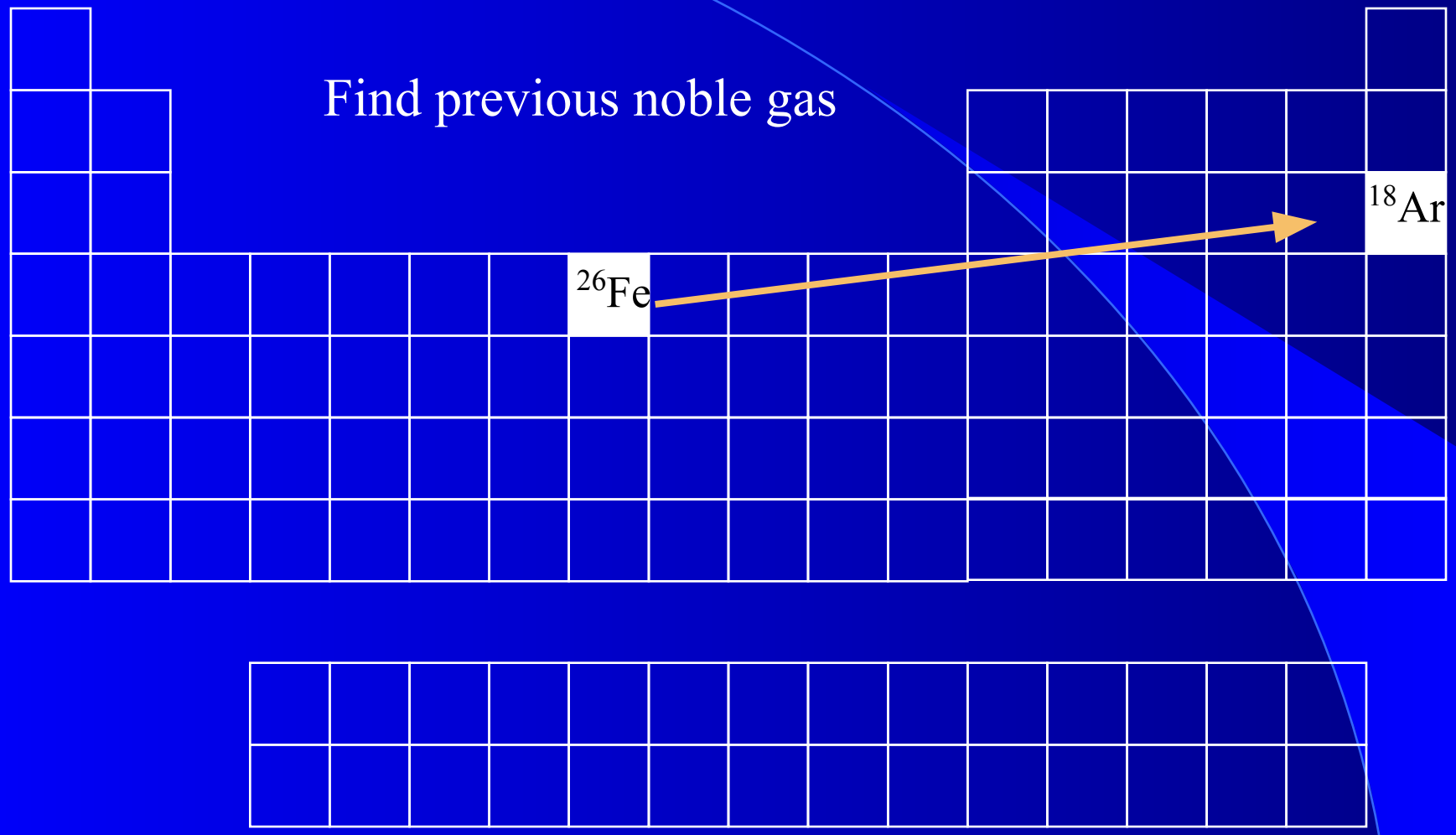


Noble gas notation

Find previous noble gas



Noble gas notation



Noble gas notation

- Eventually, electron configurations get too long!
- Noble gas notation shortens it by using a noble gas core
- Fe $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$

Noble gas notation

- Eventually, electron configurations get too long!
- Noble gas notation shortens it by using a noble gas core
- Fe $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$

Noble gas notation

- Eventually, electron configurations get too long!
- Noble gas notation shortens it by using a noble gas core
- Fe $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- Fe $[Ar]4s^2 3d^6$

Noble gas notation

- Eventually, electron configurations get too long!
- Noble gas notation shortens it by using a noble gas core
- Fe $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- Fe $[Ar]4s^2 3d^6$

- Often called kernel notation

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$
3. $[Ar] 4s^2 3d^{10} 4p^5$
4. $[Ar]\ 3d^{10} 4s^2 4p^5$

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$
3. $[Ar] 4s^2 3d^{10} 4p^5$
4. $[Ar]\ 3d^{10} 4s^2 4p^5$

They're ALL correct
just different variations!

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$
3. $[Ar] 4s^2 3d^{10} 4p^5$
4. $[Ar]\ 3d^{10} 4s^2 4p^5$

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$
3. $[Ar] 4s^2 3d^{10} 4p^5$
4. $[Ar]\ 3d^{10} 4s^2 4p^5$

They're ALL correct
just different variations!

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$ (handout order)
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$
3. $[Ar] 4s^2 3d^{10} 4p^5$
4. $[Ar]\ 3d^{10} 4s^2 4p^5$

They're ALL correct
just different variations!

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$ (handout order)
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$ (layer order)
3. $[Ar] 4s^2 3d^{10} 4p^5$
4. $[Ar]\ 3d^{10} 4s^2 4p^5$

They're ALL correct
just different variations!

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$ (handout order)
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$ (layer order)
3. $[Ar] 4s^2 3d^{10} 4p^5$ (noble gas + handout order)
4. $[Ar]\ 3d^{10} 4s^2 4p^5$

They're ALL correct
just different variations!

What's the electron configuration for a neutral bromine atom?

1. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$ (handout order)
2. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^5$ (layer order)
3. $[Ar] 4s^2 3d^{10} 4p^5$ (noble gas + handout order)
4. $[Ar]\ 3d^{10} 4s^2 4p^5$ (noble gas + layer order)

They're ALL correct
just different variations!

Electron Removal Order

- When forming cations, you remove electrons from the outermost layer first
- Sometimes requires you to regroup notation in layer order

Forming Fe^{2+} cation

- Fe neutral atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$

Forming Fe^{2+} cation

- Fe neutral atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- regrouped: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$

Forming Fe^{2+} cation

- Fe neutral atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- regrouped: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$

Forming Fe^{2+} cation

- Addition order: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- (handout order)
- Removal order: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$
- (layer order)

Forming Fe^{2+} cation

- Fe neutral atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- regrouped: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$
- Fe^{2+} cation: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$

Forming Fe^{2+} cation

- Fe neutral atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- regrouped: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$
- Fe^{2+} cation: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$
  - (2 outermost e^-'s removed)

Forming Fe^{2+} cation

- Fe neutral atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$
- regrouped: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$
- Fe^{2+} cation: $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$
  - (2 outermost e^-'s removed)

What is the electron configuration for a Zn^{2+} cation?

1. $[Ar]4s^2 3d^{10}$
2. $[Ar]3d^{10}$
3. $[Ar]4s^2 3d^8$
4. $[Ar]4s^2 3d^{10} 4p^2$

What is the electron configuration for a Zn^{2+} cation?

1. $[Ar]4s^2 3d^{10}$ nope, neutral Zn atom
2. $[Ar]3d^{10}$
3. $[Ar]4s^2 3d^8$
4. $[Ar]4s^2 3d^{10} 4p^2$

What is the electron configuration for a Zn^{2+} cation?

1. $[Ar]4s^2 3d^{10}$ nope, neutral Zn atom
2. $[Ar]3d^{10}$
3. $[Ar]4s^2 3d^8$
4. $[Ar]4s^2 3d^{10} 4p^2$ nope, it GAINED 2 e^-'s!

What is the electron configuration for a Zn^{2+} cation?

1. $[Ar]4s^2 3d^{10}$ nope, neutral Zn atom
2. $[Ar]3d^{10}$
3. $[Ar]4s^2 3d^8$ nope, lost inner 3d e^-'s
4. $[Ar]4s^2 3d^{10} 4p^2$ nope, it GAINED 2 e^-'s!

What is the electron configuration for a Zn^{2+} cation?

1. $[Ar]4s^2 3d^{10}$ nope, neutral Zn atom
2. $[Ar]3d^{10}$ yep, lost highest n-level e^-'s
3. $[Ar]4s^2 3d^8$ nope, lost inner 3d e^-'s
4. $[Ar]4s^2 3d^{10} 4p^2$ nope, it GAINED 2 e^-'s!

Electron Removal Order

- When forming cations, you remove electrons from the outermost layer first
- Sometimes requires you to regroup notation in layer order

What is the electron configuration for a Co^{3+} cation?

1. $[Ar]4s^2 3d^7$
2. $[Ar]4s^2 3d^{10}$
3. $[Ar]4s^2 3d^4$
4. $[Ar]3d^6$

What is the electron configuration for a Co^{3+} cation?

1. $[Ar]4s^2 3d^7$ nope, neutral Co atom
2. $[Ar]4s^2 3d^{10}$
3. $[Ar]4s^2 3d^4$
4. $[Ar]3d^6$

What is the electron configuration for a Co^{3+} cation?

1. $[Ar]4s^2 3d^7$ nope, neutral Co atom
2. $[Ar]4s^2 3d^{10}$ nope, it gained 3 e^-'s
3. $[Ar]4s^2 3d^4$
4. $[Ar]3d^6$

What is the electron configuration for a Co^{3+} cation?

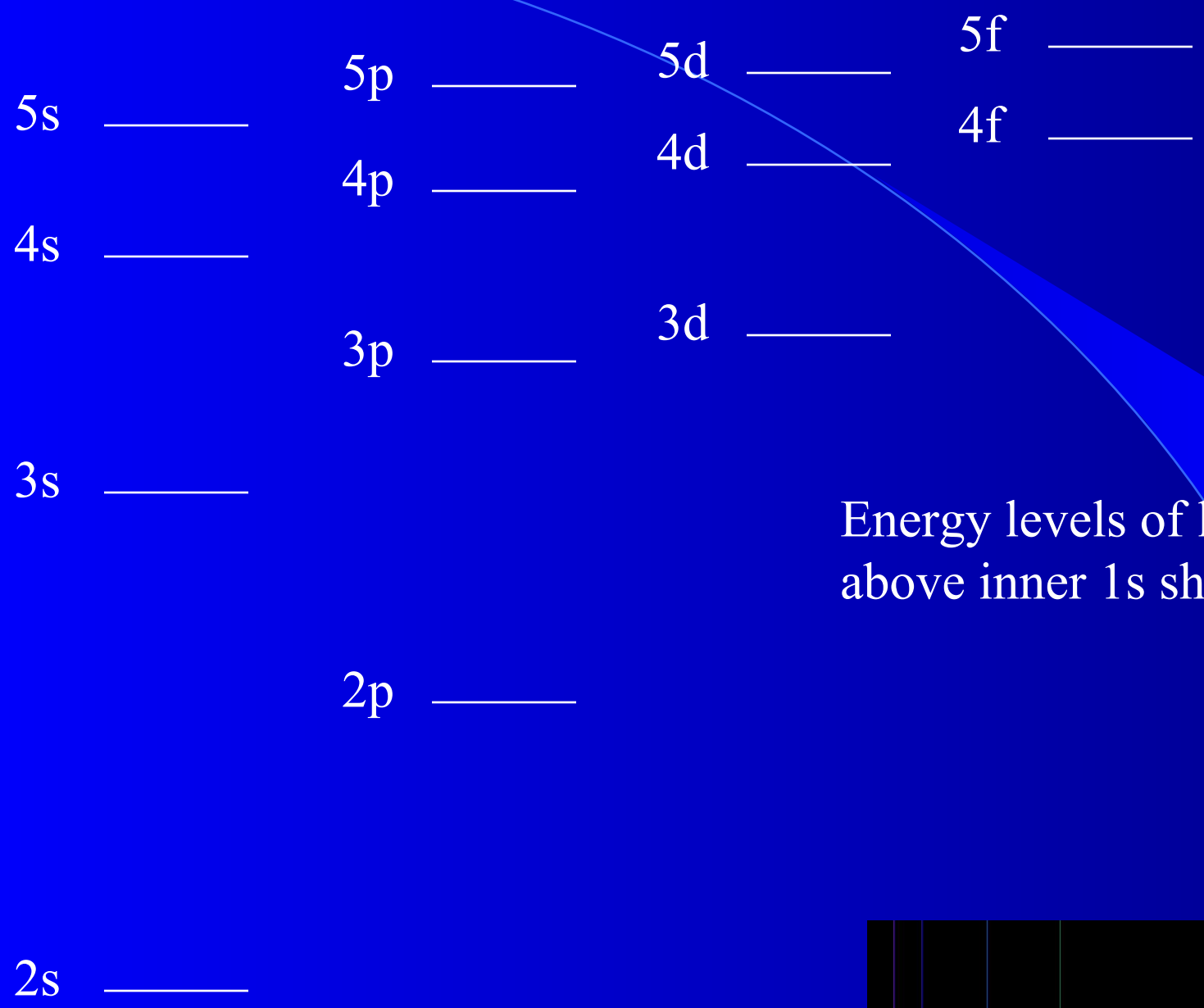
1. $[Ar]4s^2 3d^7$ nope, neutral Co atom
2. $[Ar]4s^2 3d^{10}$ nope, it gained 3 e^-'s
3. $[Ar]4s^2 3d^4$ nope, it lost inner e^-'s
4. $[Ar]3d^6$

What is the electron configuration for a Co^{3+} cation?

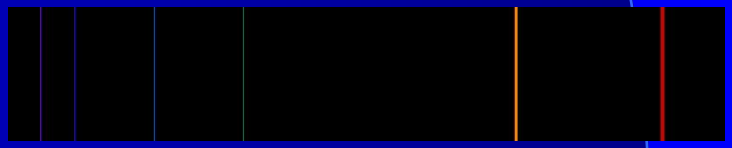
1. $[Ar]4s^2 3d^7$ nope, neutral Co atom
2. $[Ar]4s^2 3d^{10}$ nope, it gained 3 e^-'s
3. $[Ar]4s^2 3d^4$ nope, it lost inner e^-'s
4. $[Ar]3d^6$ yep, it lost $4s^2$ first

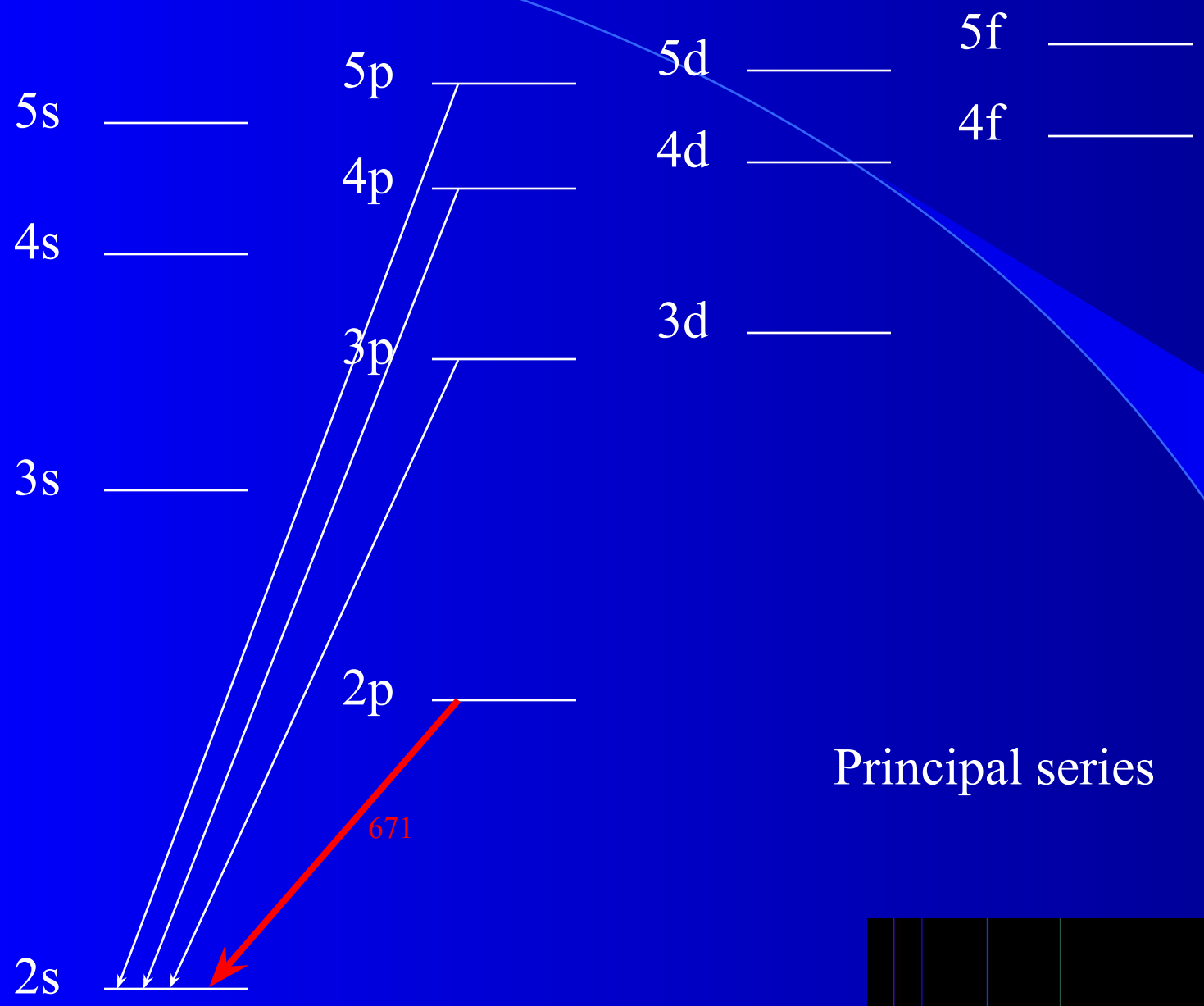
Lithium Flame Colors Revisited

- Now that you're familiar with electron energy level designations, we can see a more complete description of the fuchsia colored flame that the lithium oxalate salt produced in the Cauldron of Fire
- Recall that Li's electron configuration is $1s^2 2s^1$
- The easiest electron to remove is the $2s^1$

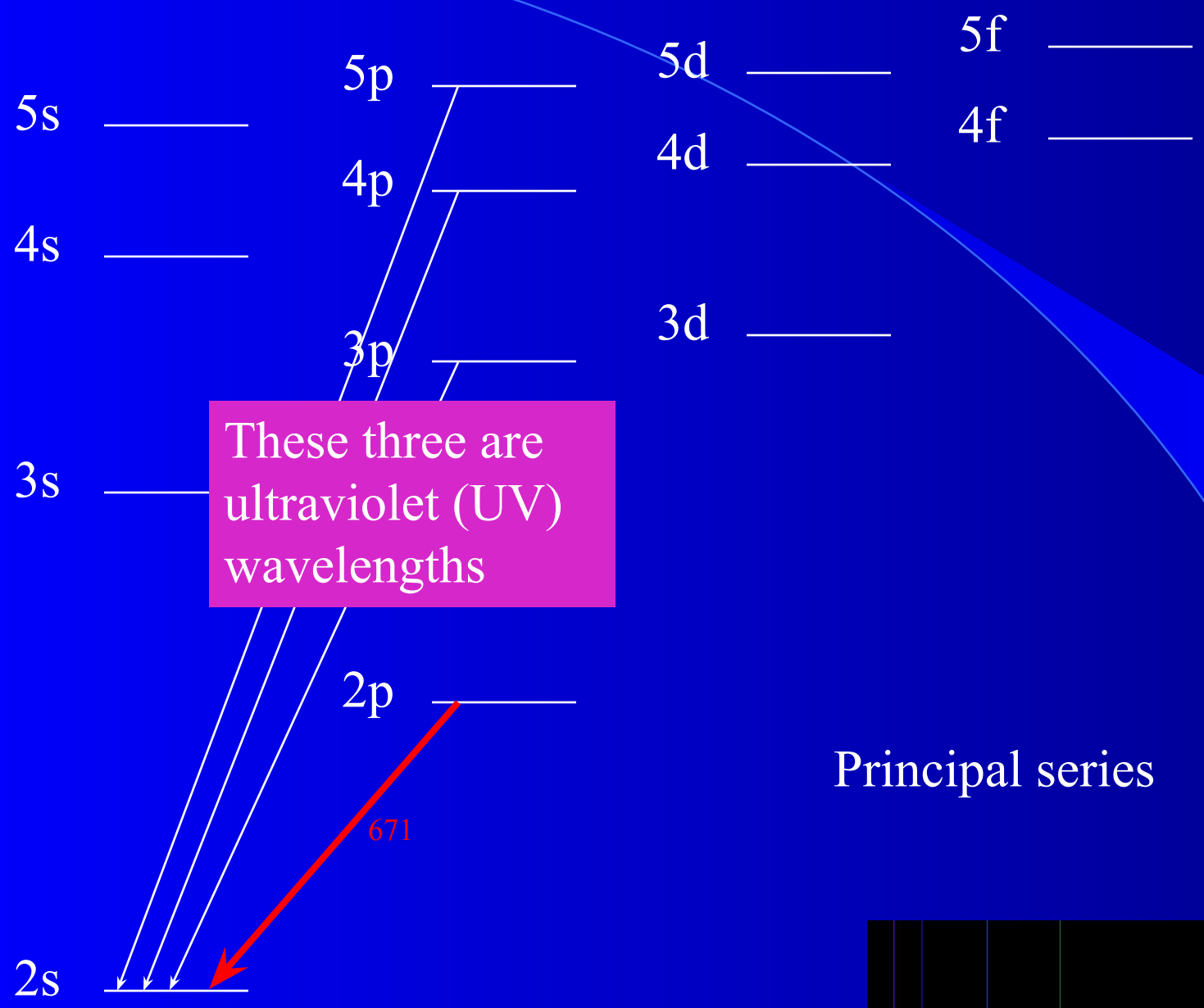


Energy levels of lithium above inner 1s shell

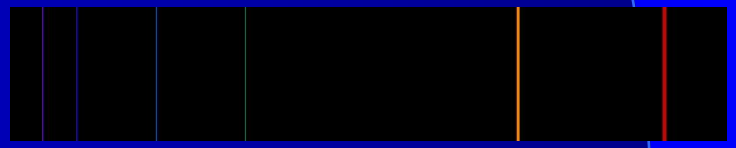


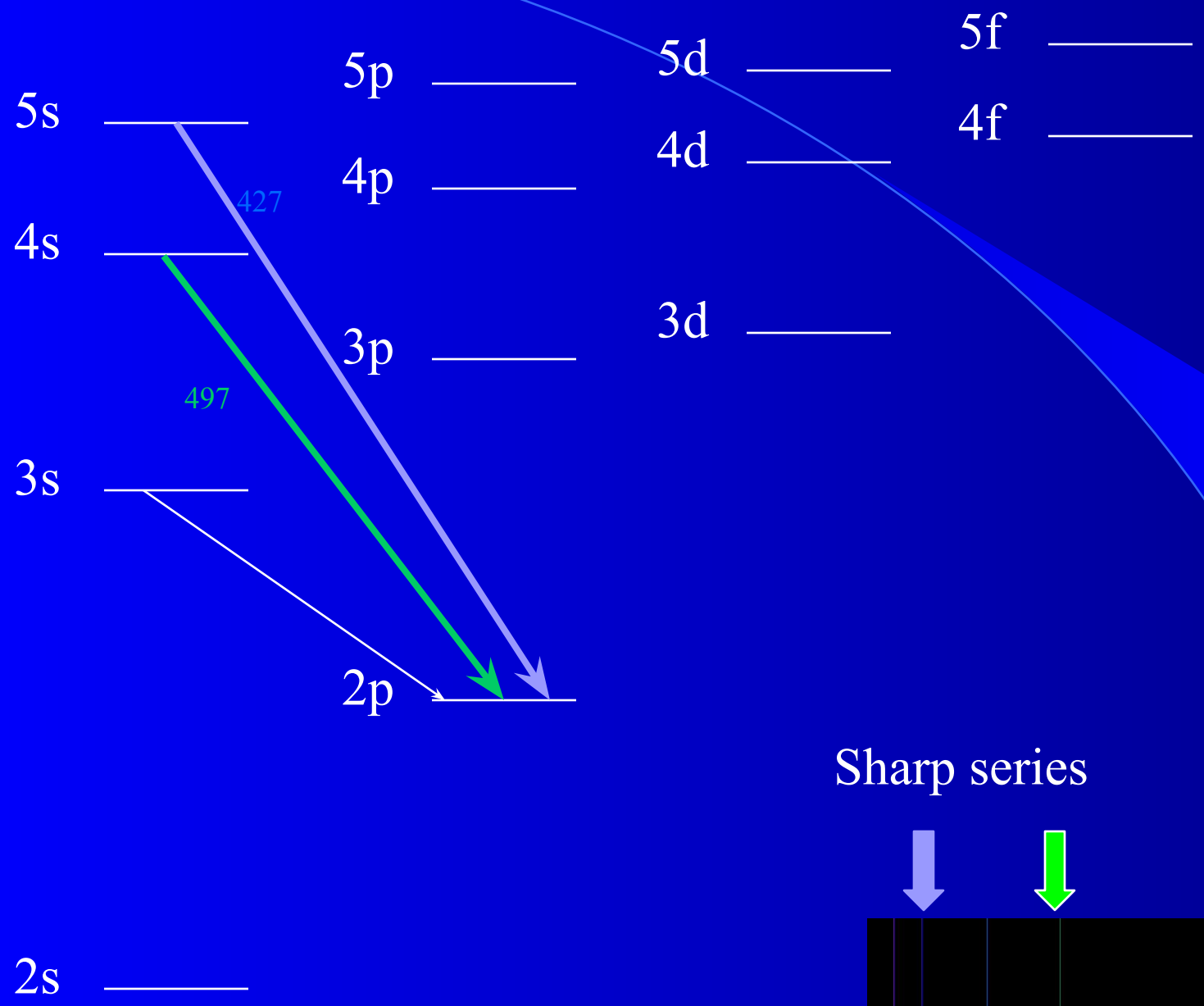


Principal series

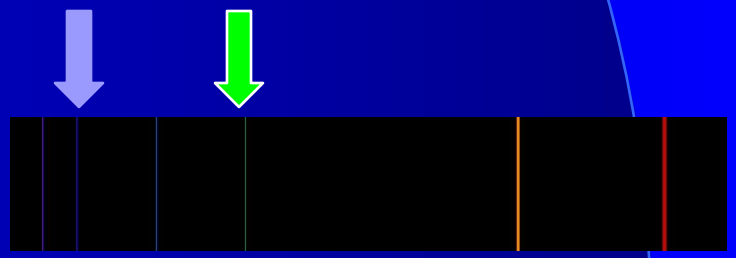


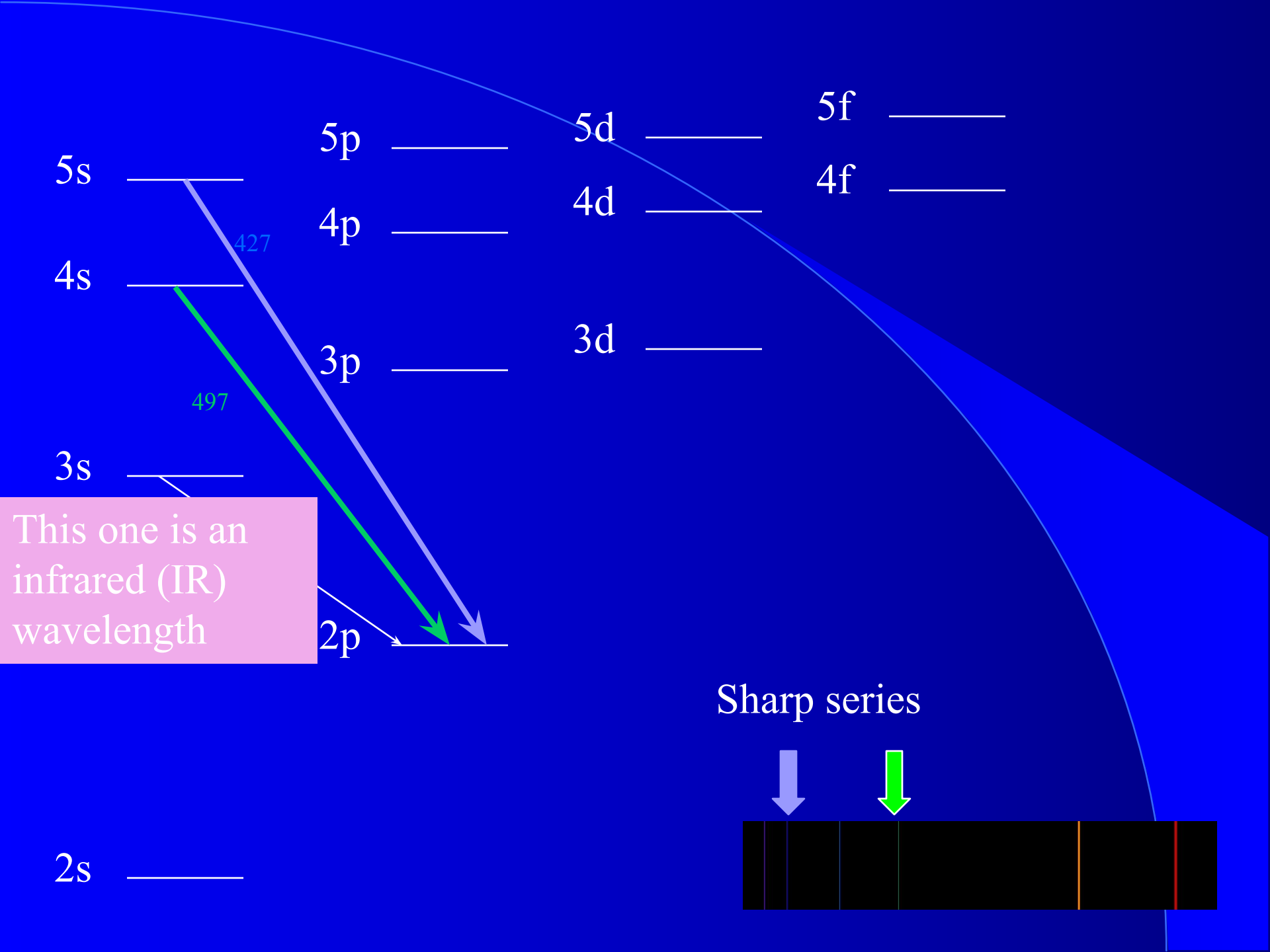
Principal series

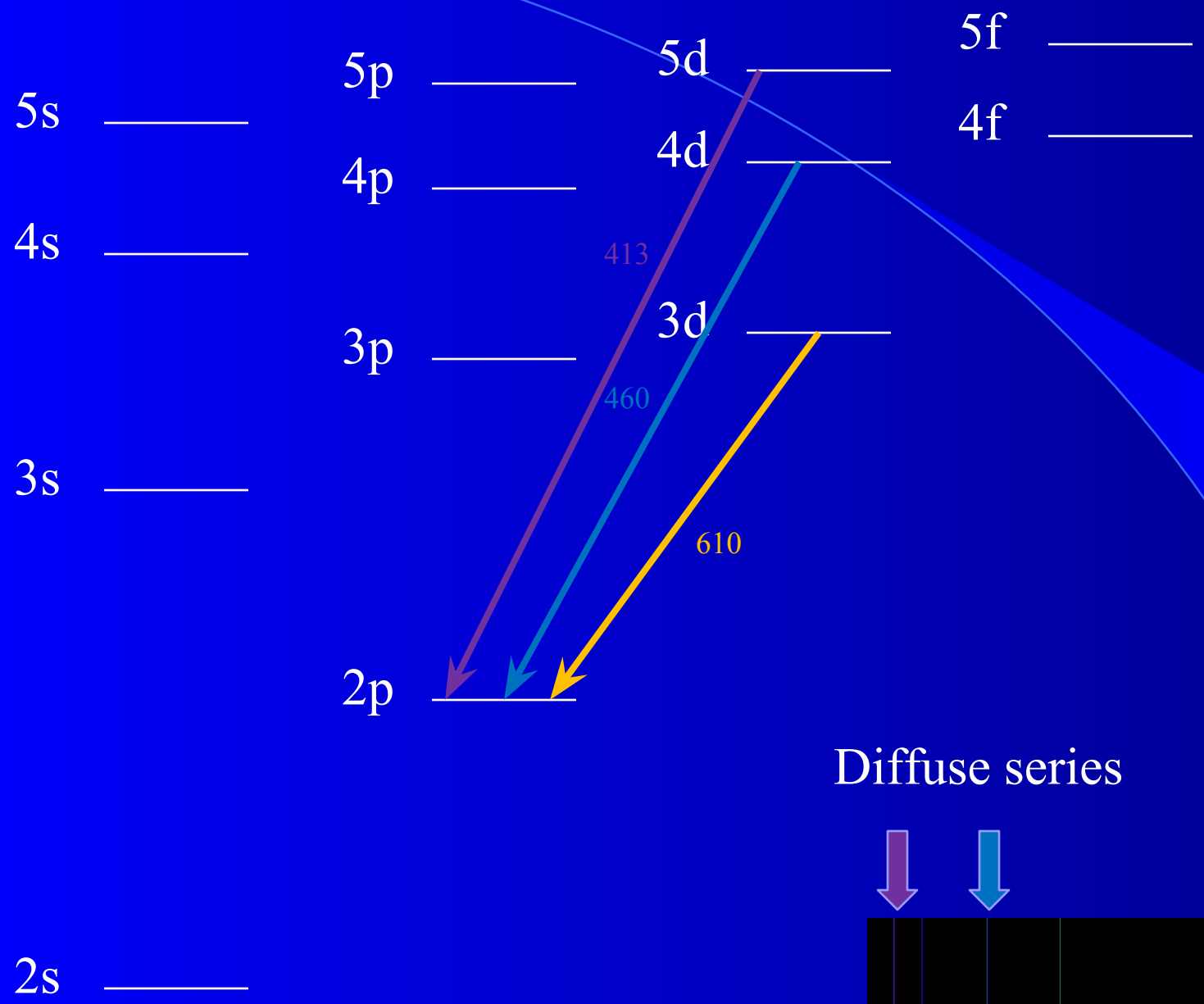




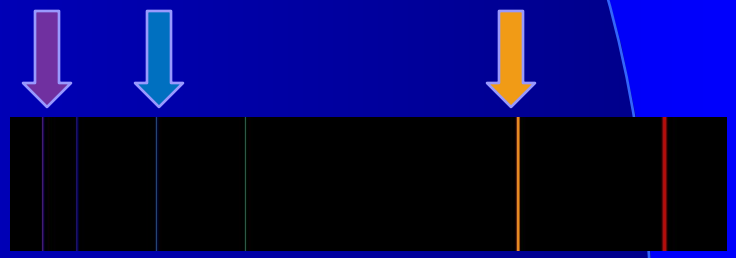
Sharp series

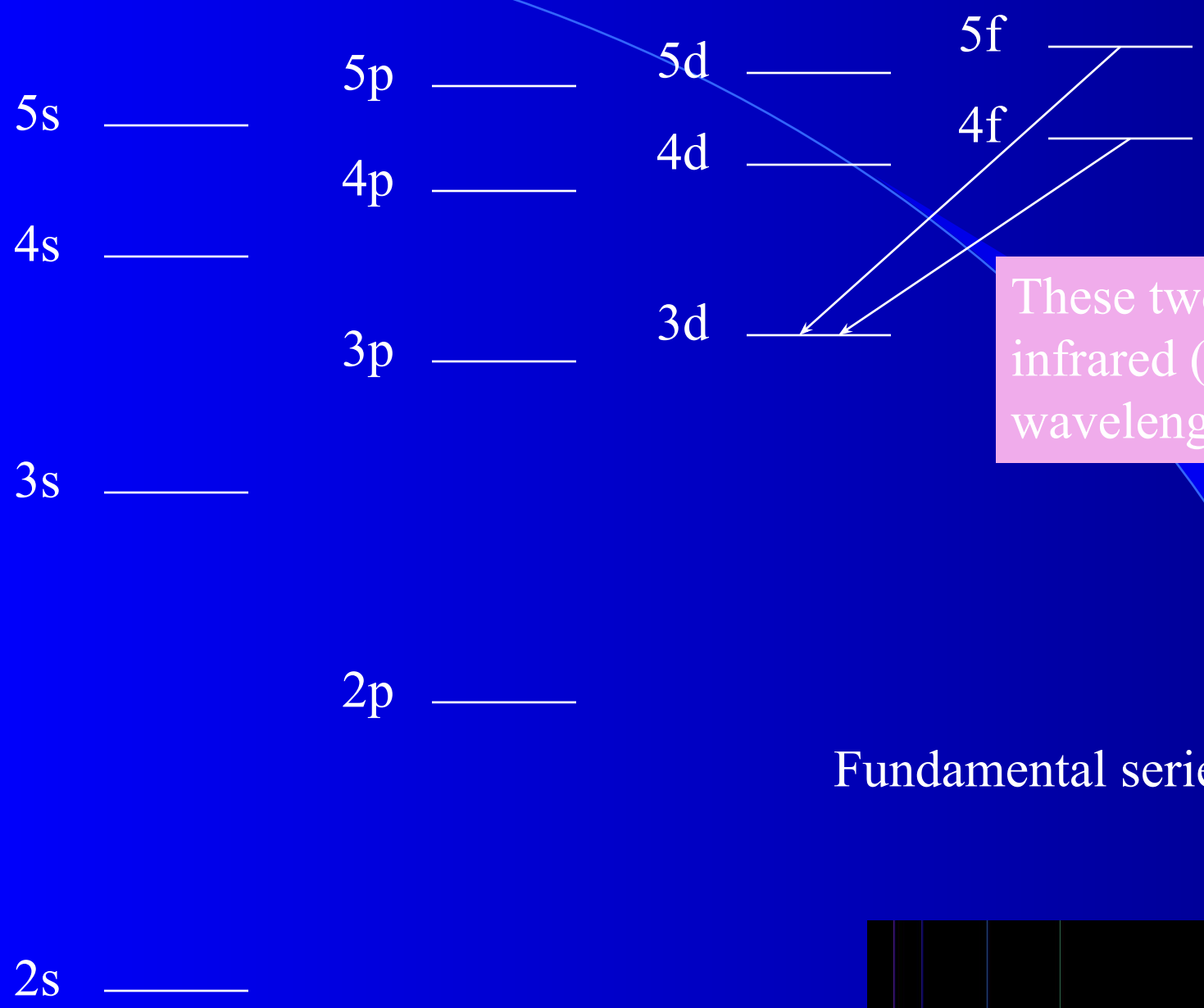



5s
4s
3s
2s
5p
4p
3p
2p
5d
4d
3d
5f
4f
427
497
This one is an infrared (IR) wavelength
Sharp series



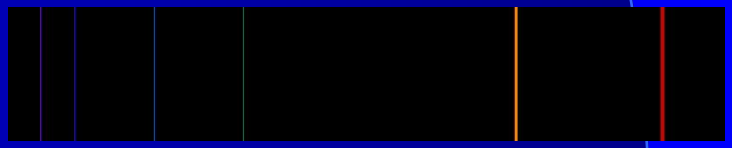
Diffuse series

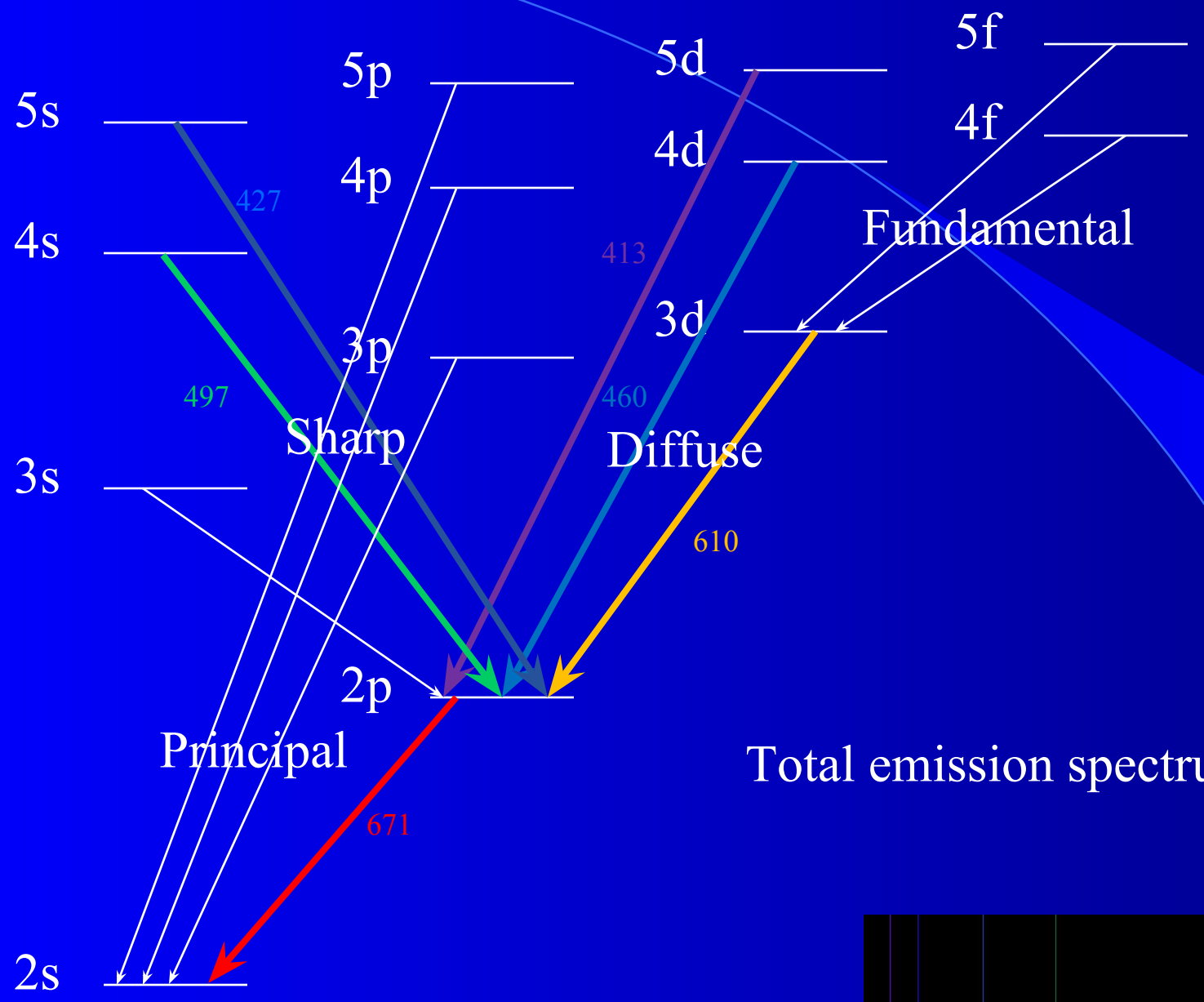




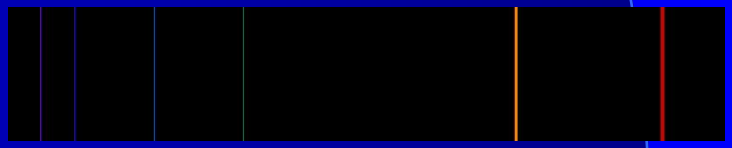
These two are infrared (IR) wavelengths

Fundamental series





Total emission spectrum



Periodic Trends

- Many periodic properties of atoms are due to their electron configurations
- Members of the same group have similar valence shells
- Li [He]$2s^1$
- Na [Ne]$3s^1$
- K [Ar]$4s^1$
- Rb [Kr]$5s^1$
- Cs [Xe]$6s^1$

Periodic Trends

- Many periodic properties of atoms are due to their electron configurations
- Members of the same group have similar valence shells
- Li [He]$2s^1$
- Na [Ne]$3s^1$
- K [Ar]$4s^1$
- Rb [Kr]$5s^1$
- Cs [Xe]$6s^1$

Alkali metals all have a valence shell holding one s-electron

Lewis Structures of Atoms

Lewis Structures of Atoms

Atomic symbols represent the nucleus plus inner shell e^-'s

Lewis Structures of Atoms

Atomic symbols represent the nucleus plus inner shell e^-'s

1A	2A	3A	4A	5A	6A	7A	8A
H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar

Lewis Structures of Atoms

Atomic symbols represent the nucleus plus inner shell e^-'s
Dots are added to indicate valence shell electrons

1A	2A	3A	4A	5A	6A	7A	8A
H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar

Lewis Structures of Atoms

Atomic symbols represent the nucleus plus inner shell e^-'s
Dots are added to indicate valence shell electrons

1A	2A	3A	4A	5A	6A	7A	8A
• H							• He •
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar

Lewis Structures of Atoms

Atomic symbols represent the nucleus plus inner shell e^-'s
Dots are added to indicate valence shell electrons

1A	2A	3A	4A	5A	6A	7A	8A
H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar

Lewis Structures of Atoms

Atomic symbols represent the nucleus plus inner shell e^-'s
Dots are added to indicate valence shell electrons

1A	2A	3A	4A	5A	6A	7A	8A
H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar

Lewis Structures of Atoms

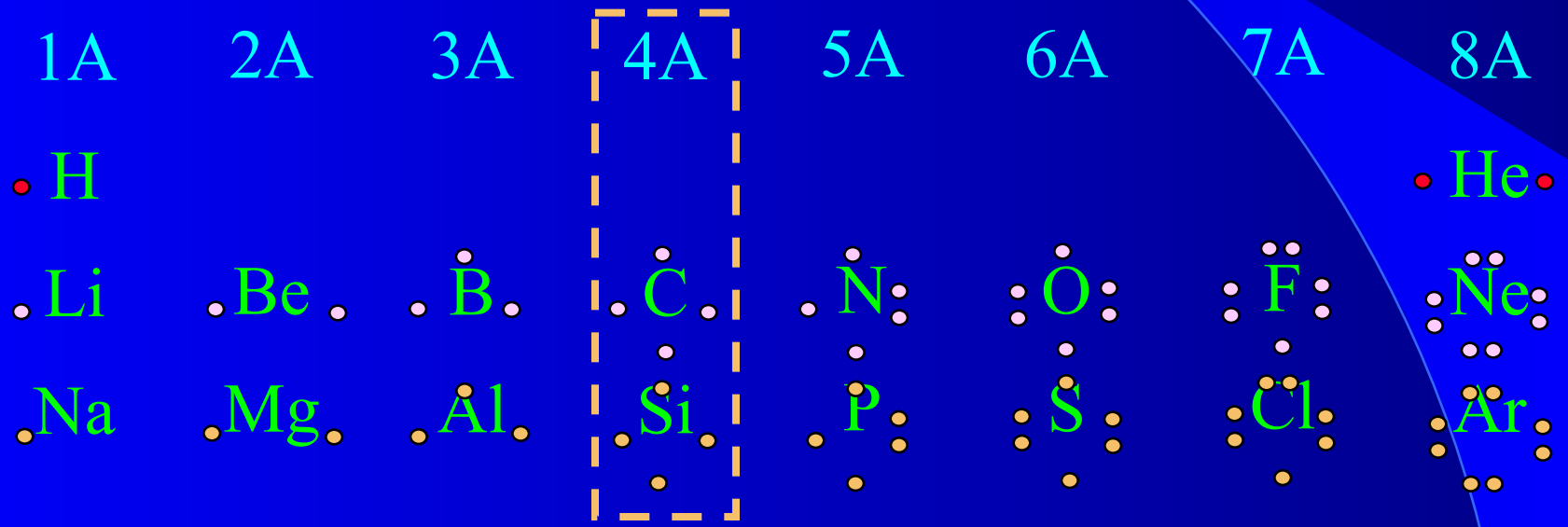
Atomic symbols represent the nucleus plus inner shell e^-'s
Dots are added to indicate valence shell electrons

1A	2A	3A	4A	5A	6A	7A	8A
H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar

Note that the number of valence electrons is equal to the element's group number for main group elements

Lewis Structures of Atoms

Atomic symbols represent the nucleus plus inner shell e^-'s
Dots are added to indicate valence shell electrons



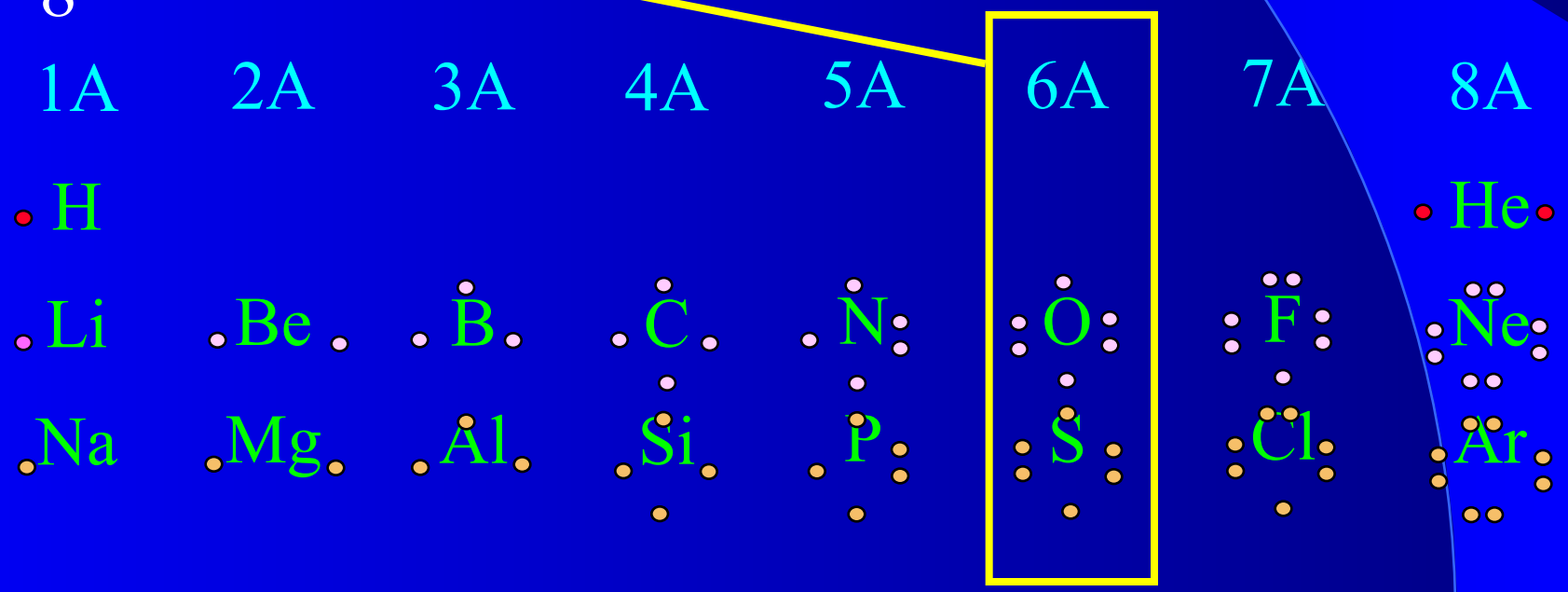
Members of Group 4A each have four valence electrons!

How many valence electrons does oxygen have?

1. 1
2. 2
3. 6
4. 8

How many valence electrons does oxygen have?

1. 1
2. 2
3. 6
4. 8



Periodic Trends

Many periodic properties of atoms are due to their electron configurations

Metallic Character

- Ionization energy
  - energy to remove an electron
- Electronegativity
  - tendency to attract an electron
- Effective nuclear Charge
- Atomic radius

Trends in Metallic Character

Hydrogen ($1s^1$)

- No suitable position for hydrogen in the periodic table, it really could be a class by itself
- Like alkali metals, has a single *s* electron and forms H^+ ion, which is hydrated in solution (H_3O^+)
- Also forms hydride ion H^- in ionic compounds, NaH, CaH_2
- Hydrides reacts with water:

$$2NaH(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$$

$$CaH_2(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + 2H_2(g)$$

- Most important compound of hydrogen is water,

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

Trends in Metallic Character

Metallic character decreases

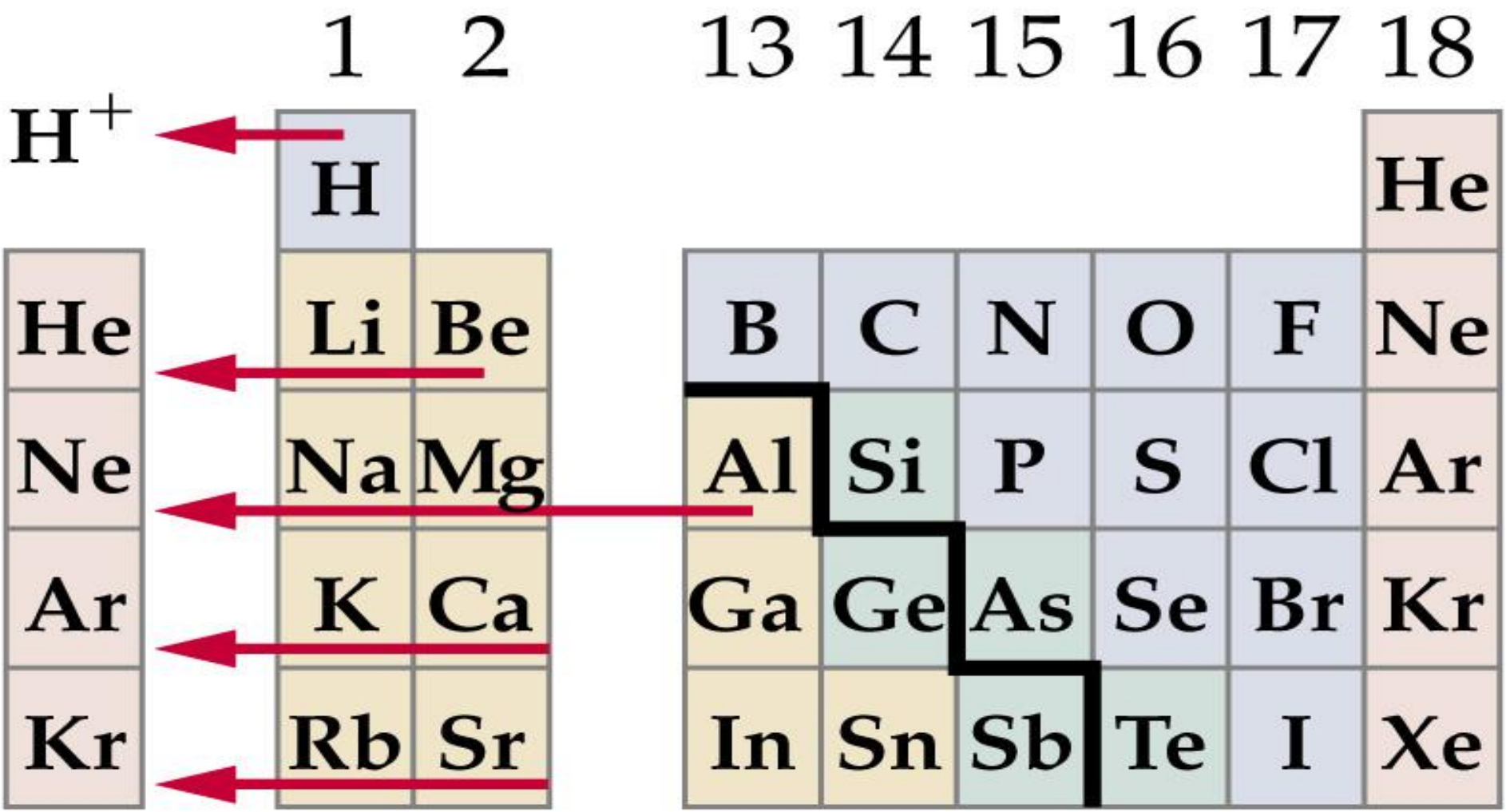
Metals
Metalloids
Nonmetals

Metallic character increases

Periods	1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110	111	112		114		116		

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

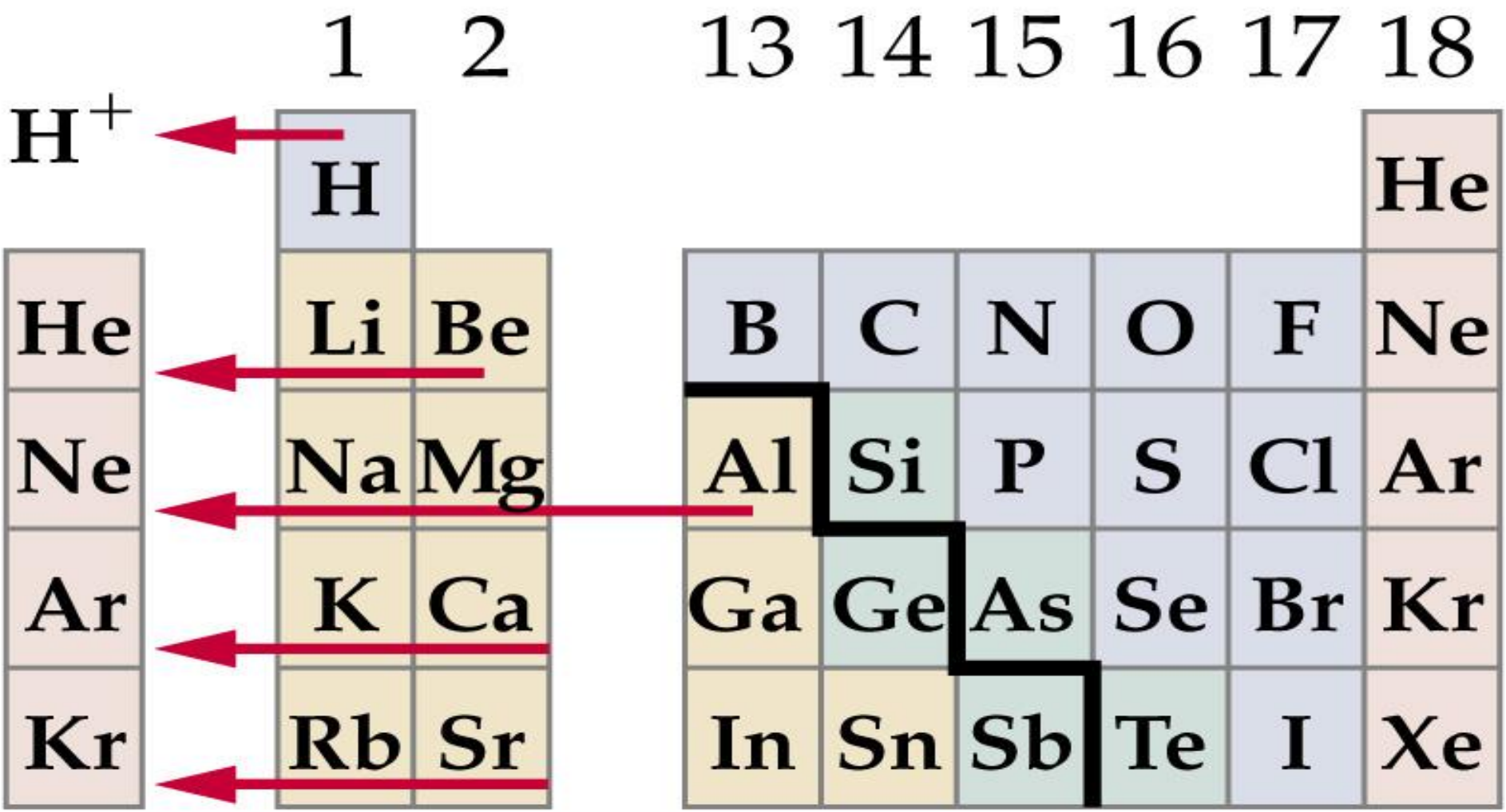
Metals Tend to Lose Electrons



Nonmetals Tend to Gain Electrons

1	2	13	14	15	16	17	18
H							He
Li	Be	B	C	N	O	F	Ne
Na	Mg	Al	Si	P	S	Cl	Ar
K	Ca	Ga	Ge	As	Se	Br	Kr
Rb	Sr	In	Sn	Sb	Te	I	Xe

Metals Tend to Lose Electrons

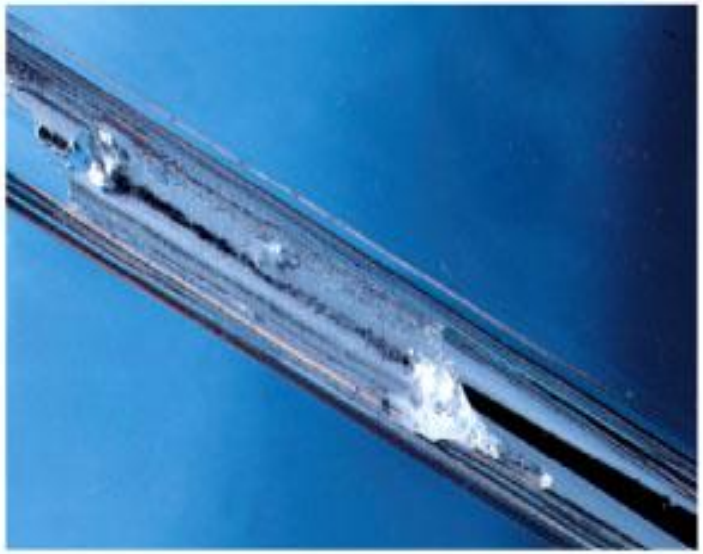


Group 1A Elements (ns^1, $n \geq 2$)

Lithium (Li)

Sodium (Na)

Potassium (K)



Rubidium (Rb)

Cesium (Cs)

Potassium metal

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$2\ K(s) + 2\ H_2O \rightarrow$$

Potassium metal

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$2\,K(s) + 2\,H_2O \Rightarrow 2\,K^+(aq) + 2\,OH^-(aq) + H_2(g)$$

Potassium metal

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$2\,K(s) + 2\,H_2O \Rightarrow 2\,K^+(aq) + 2\,OH^-(aq) + H_2(g)$$

A pair of ions is formed that can attract each other

Potassium metal

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$2\,K(s) + 2\,H_2O \Rightarrow 2\,K^+(aq) + 2\,OH^-(aq) + H_2(g)$$

KOH is soluble in water, hence the (aq), so we don't see any solid here. But if we let the water evaporate we'd get KOH(s).

Potassium metal

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$2\,K(s) + 2\,H_2O \Rightarrow 2\,K^+(aq) + 2\,OH^-(aq) + H_2(g)$$

KOH is soluble in water, hence the (aq), so we don't see any solid here. But if we let the water evaporate, we'd get KOH(s).

K^+ Stability

- Potassium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$

K^+ Stability

- Potassium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$

- Form the electron configuration for the K^+ ion by removing the outermost shell

K^+ Stability

- Potassium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
- K^+ ion: $1s^2 2s^2 2p^6 3s^2 3p^6$

K^+ Stability

- Potassium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
- K^+ ion: $1s^2 2s^2 2p^6 3s^2 3p^6$
- Notice anything "noble" about the ion's electron configuration?

K^+ Stability

- Potassium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
- K^+ ion: $1s^2 2s^2 2p^6 3s^2 3p^6$
- Ar atom: $1s^2 2s^2 2p^6 3s^2 3p^6$

K^+ and Ar are isoelectronic, that is, they have identical electron configurations

K^+ Stability

- Potassium atom: [Ar]$4s^1$
- K^+ ion: [Ar]
- Ar atom: [Ar]

K^+ is a stable chemical species because it has a noble gas configuration

Sodium metal

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$2\ Na(s) + 2\ H_2O \rightarrow 2\ Na^+(aq) + 2\ OH^-(aq) + H_2(g)$$

Na^+ Stability

- Sodium atom: [Ne]$3s^1$
- Na^+ ion: [Ne]
- Ne atom: [Ne]

Na^+ is a stable chemical species because it has a noble gas configuration

Group 1A Ions

- Hydrogen H^+
- Lithium Li^+
- Sodium Na^+
- Potassium K^+
- Rubidium Rb^+

- Notice any pattern?

Group 1A Ions

- Hydrogen H^+ no e's!
- Lithium Li^+ [He]
- Sodium Na^+ [Ne]
- Potassium K^+ [Ar]
- Rubidium Rb^+ [Kr]

- Notice any pattern?

Group 1A Ions

• H	$1s^1$	H^+	no e's!
• Li	[He]$2s^1$	Li^+	[He]
• Na	[Ne]$3s^1$	Na^+	[Ne]
• K	[Ar]$4s^1$	K^+	[Ar]
• Rb	[Kr]$5s^1$	Rb^+	[Kr]

Neutral atoms

Group 1A Ions

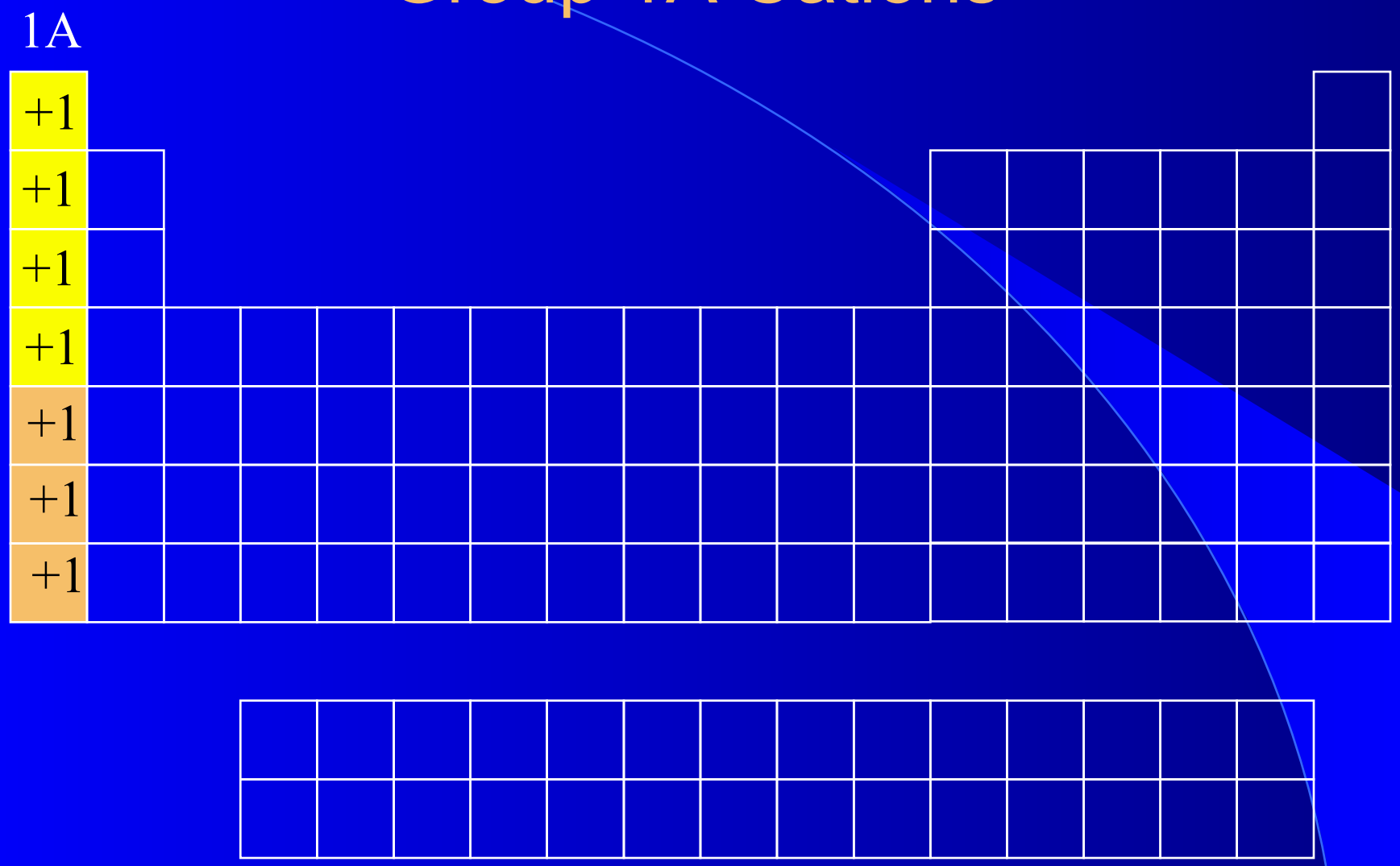
Neutral atoms			Stable ions
• H	$1s^1$	H^+	no e's!
• Li	[He]$2s^1$	Li^+	[He]
• Na	[Ne]$3s^1$	Na^+	[Ne]
• K	[Ar]$4s^1$	K^+	[Ar]
• Rb	[Kr]$5s^1$	Rb^+	[Kr]

All Group 1A elements lose an e^- to achieve a noble gas look

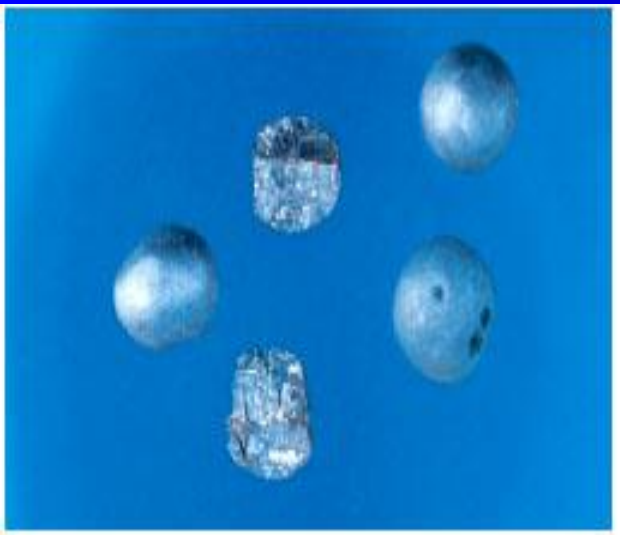
Group 1A Ions

- Group 1A elements lose their single s-electron to form +1 cations
- They form stable +1 ions that are isoelectronic with the preceding noble gas (except H)

Group 1A Cations

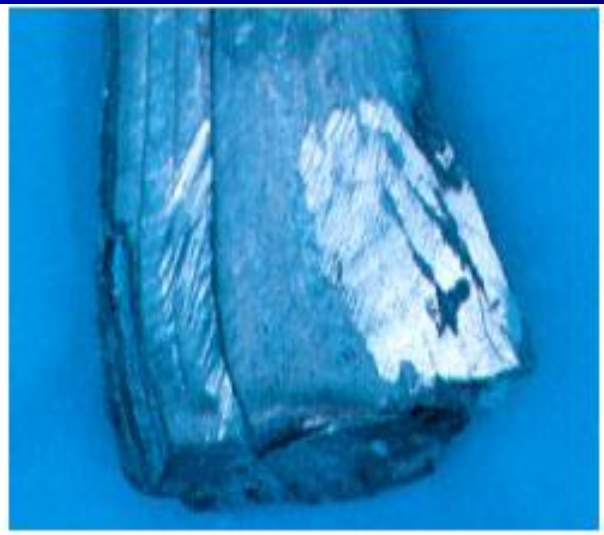


Group 2A Elements (ns^2, $n \geq 2$)

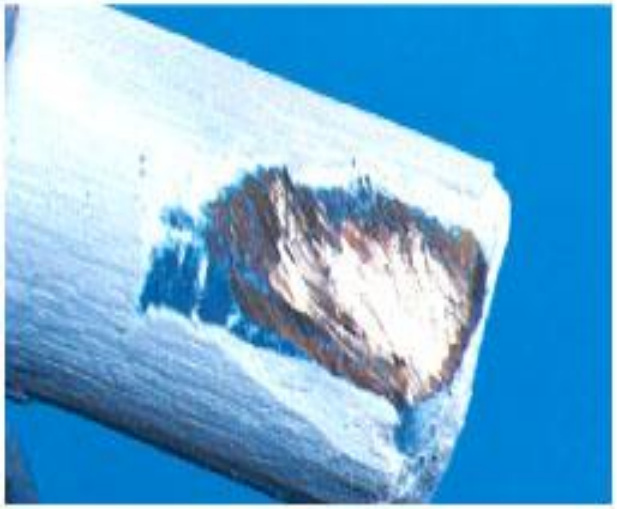


Beryllium (Be)

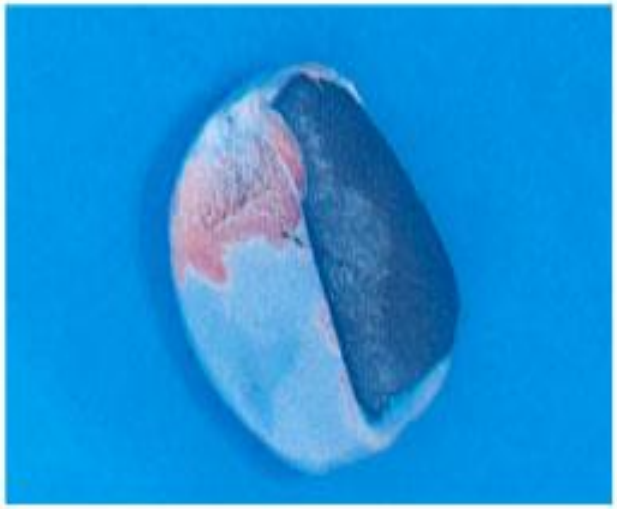
Magnesium (Mg)



Calcium (Ca)



Strontium (Sr)



Barium (Ba)

Radium (Ra)

Calcium metal demo

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

Calcium metal demo

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$Ca(s) + 2\,H_2O \rightarrow$

Calcium metal demo

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$Ca(s) + 2\,H_2O \rightarrow Ca^{2+} + H_2(g) + 2\,OH^-$$

Calcium metal demo

- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations ...

$$Ca(s) + 2\,H_2O \rightarrow Ca^{2+} + H_2(g) + 2\,OH^-$$

A pair of ions is formed that can attract each other

Calcium metal demo

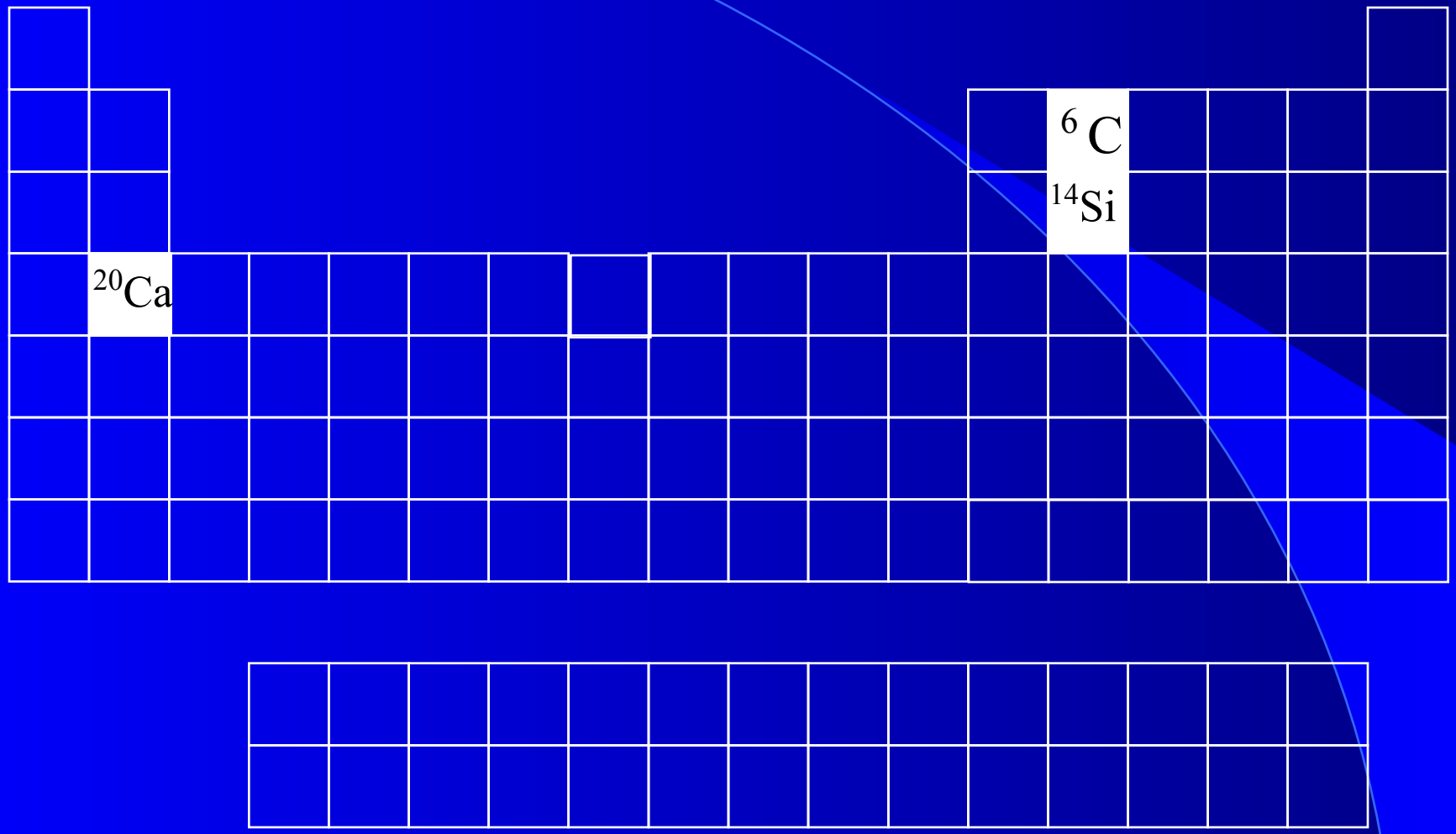
- Metals achieve noble gas configurations by losing loosely held outer electrons and becoming cations...

$$Ca(s) + 2\,H_2O \rightarrow Ca^{2+} + H_2(g) + 2\,OH^-$$

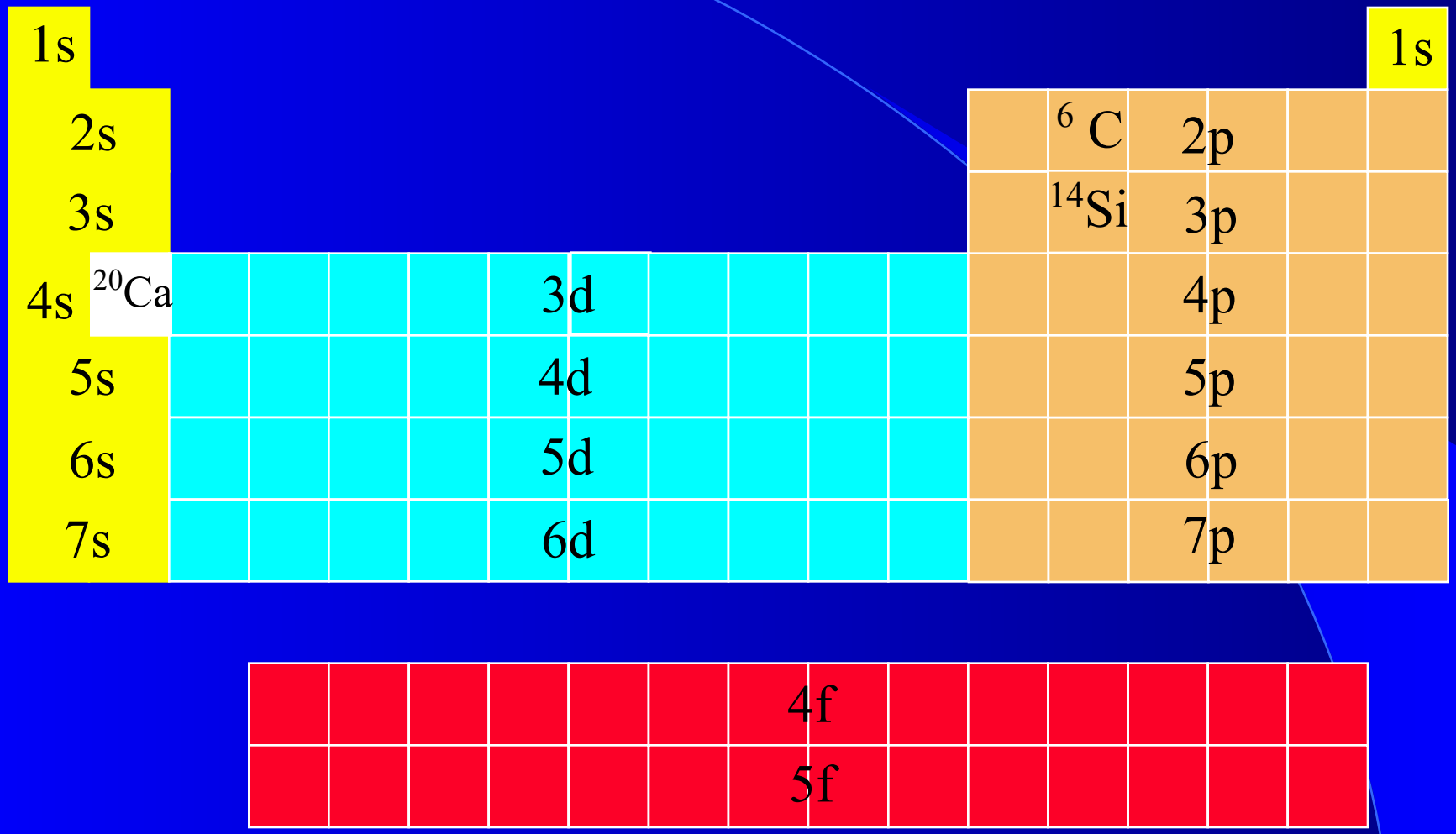
$$\rightarrow Ca(OH)_2(s) + H_2(g)$$

slaked lime

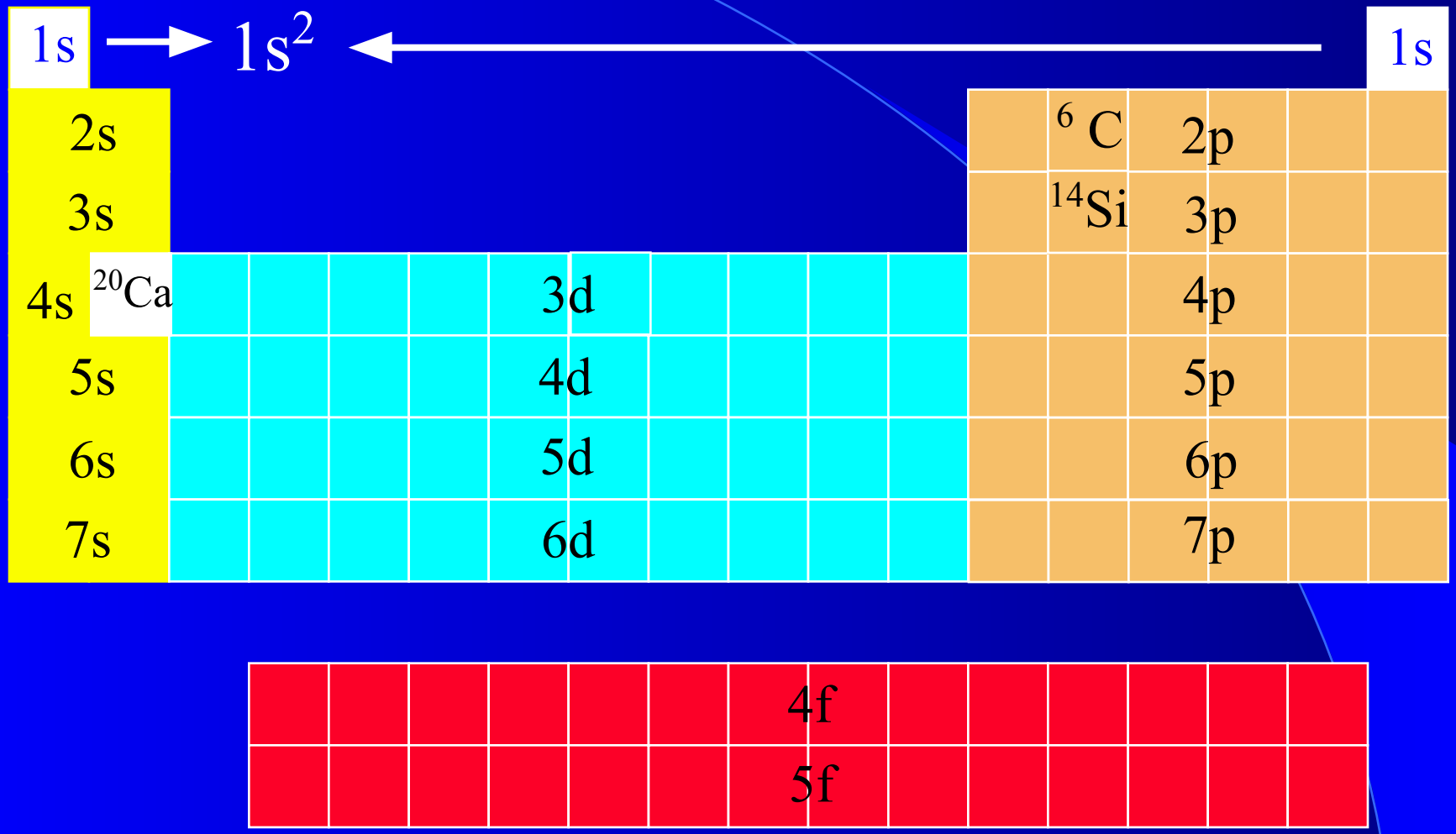
Calcium's Electron Configuration



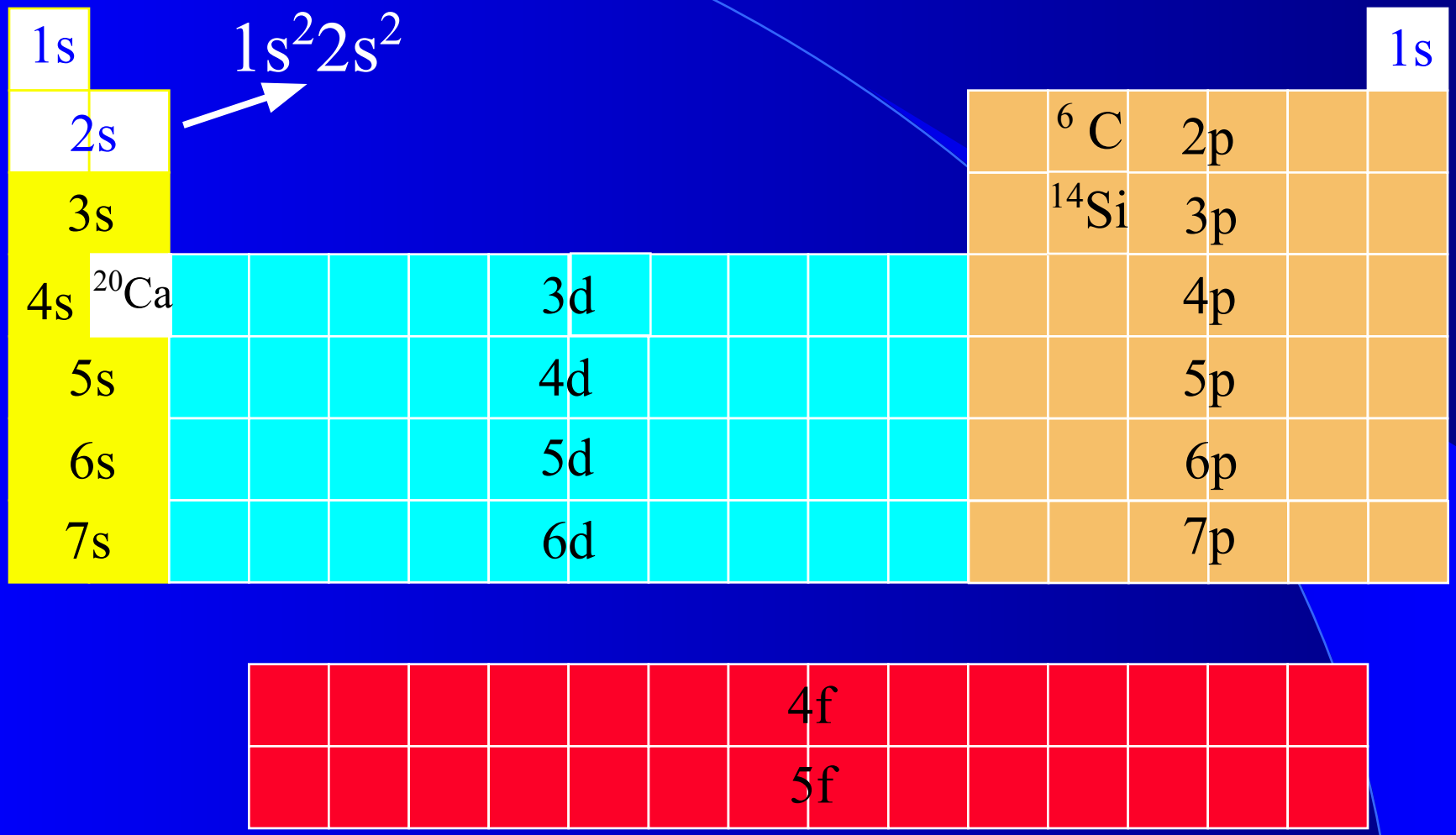
Calcium's Electron Configuration



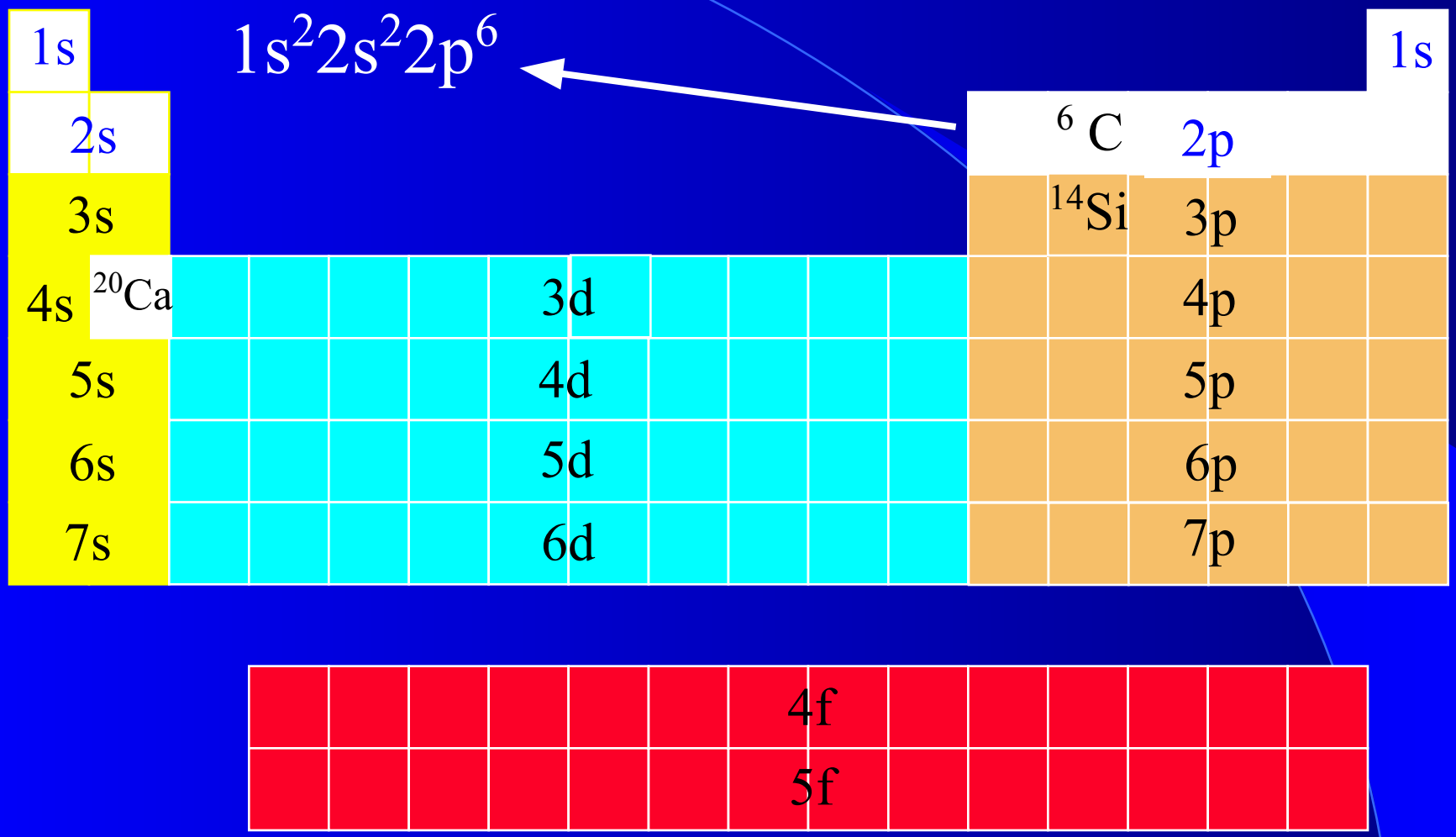
Calcium's Electron Configuration



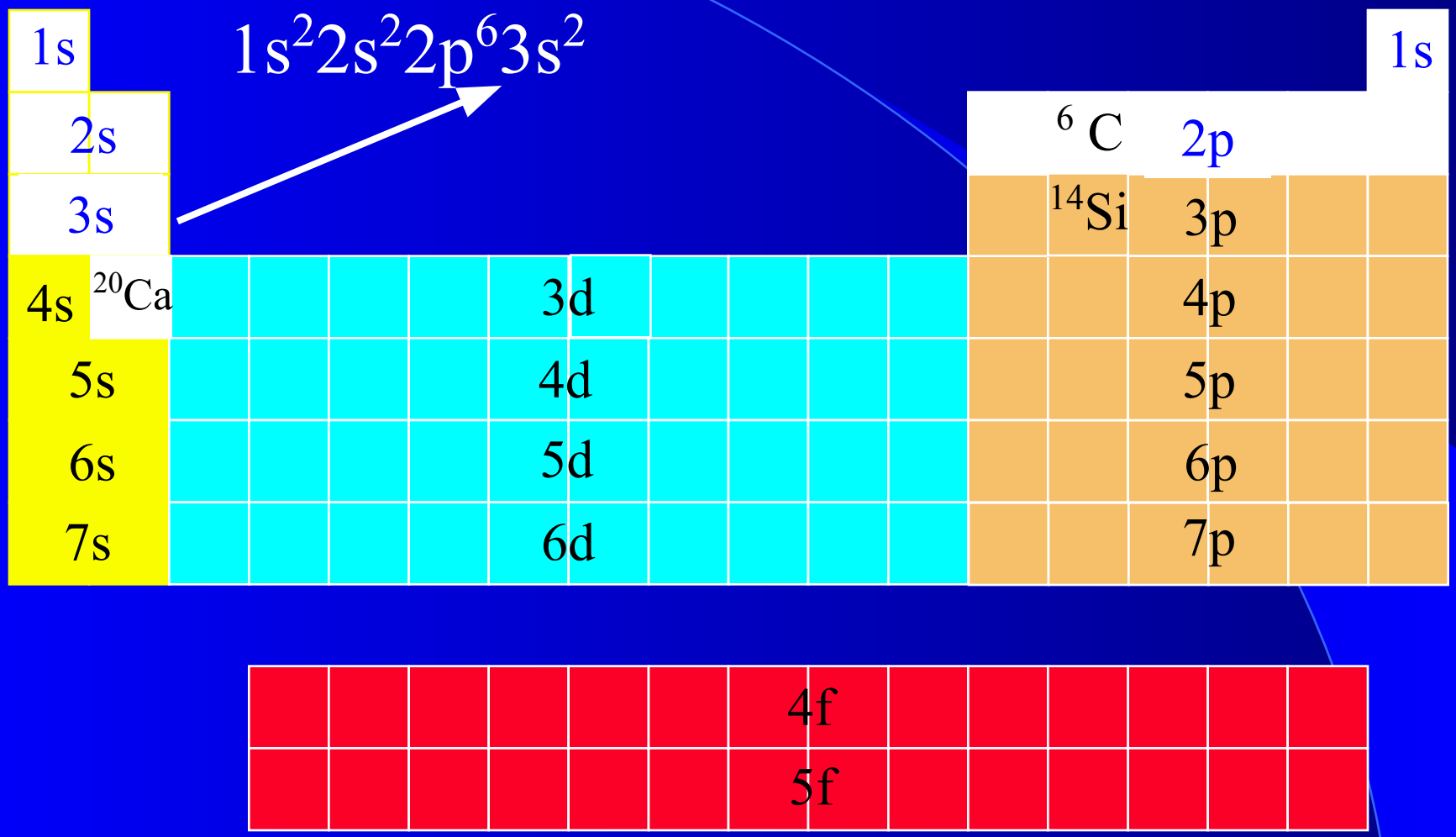
Calcium's Electron Configuration



Calcium's Electron Configuration

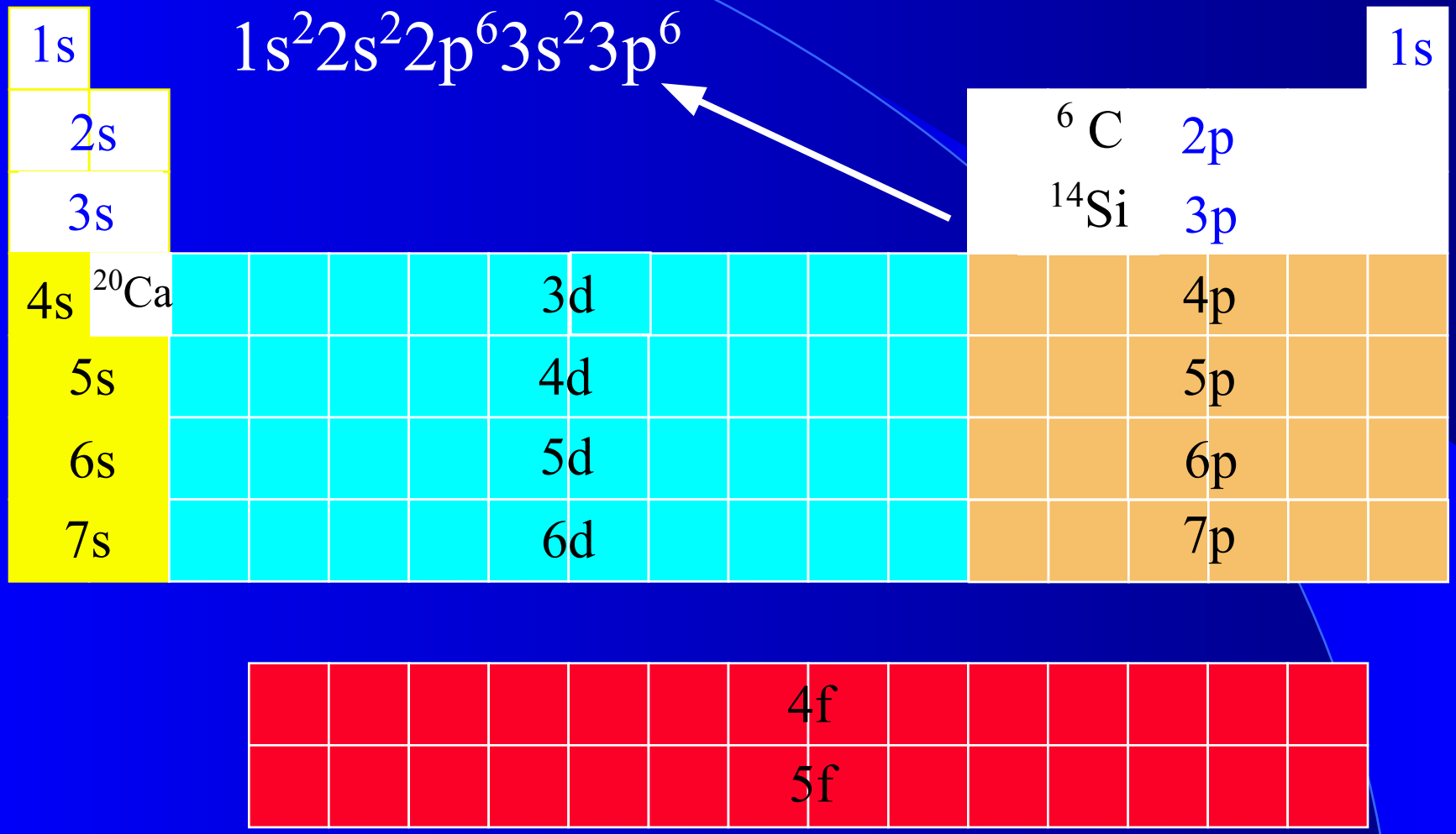


Calcium's Electron Configuration



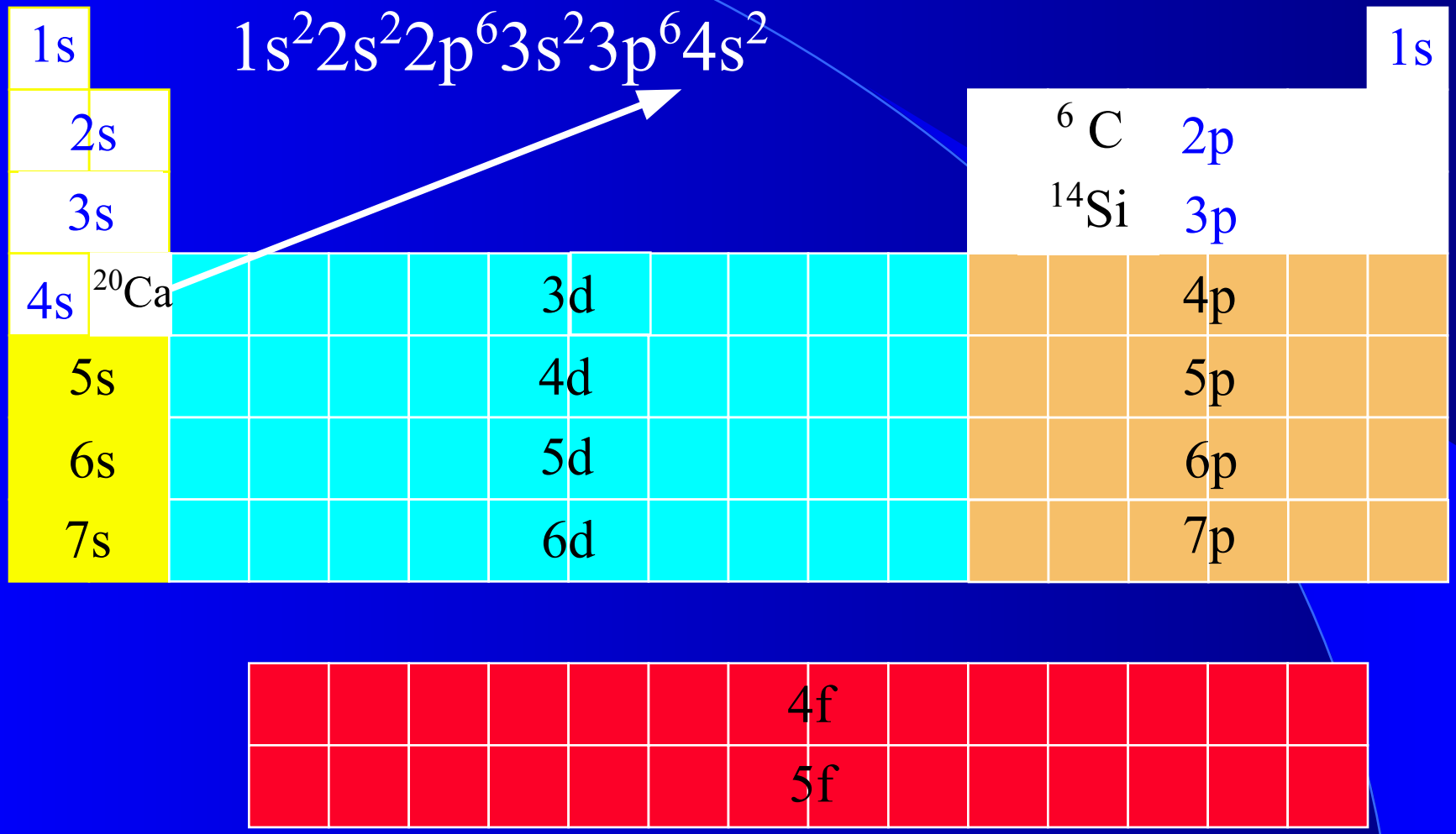
Calcium's Electron Configuration

$1s^2 2s^2 2p^6 3s^2 3p^6$



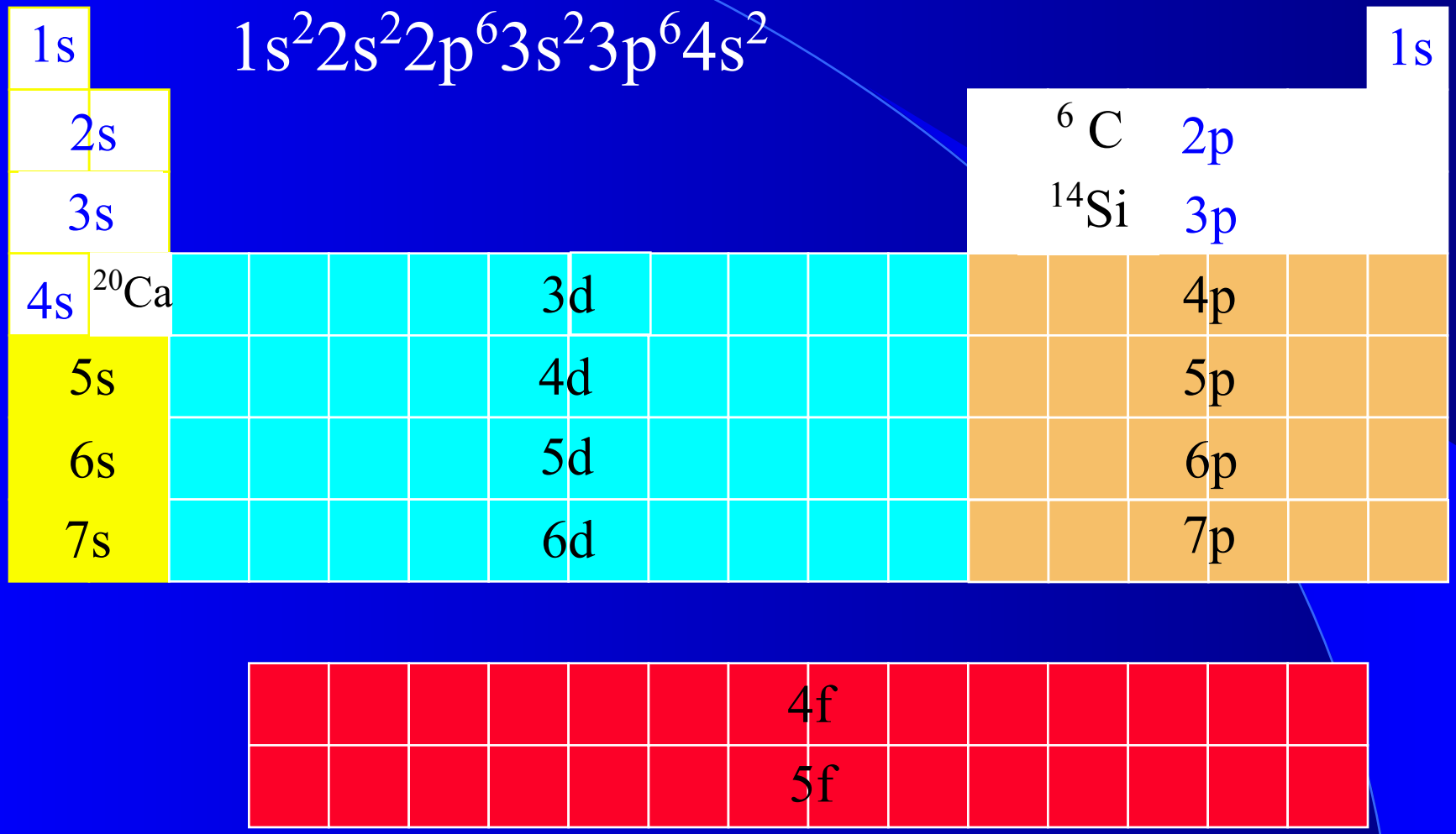
Calcium's Electron Configuration

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$



Calcium's Electron Configuration

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$



Ca^{2+} Stability

- Calcium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

- What's the configuration for a Ca^{2+} cation?

Ca^{2+} Stability

- Calcium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

  Remove 2 e^-'s from outermost shell

- What's the configuration for a Ca^{2+} cation?

Ca^{2+} Stability

- Calcium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- Ca^{2+} ion: $1s^2 2s^2 2p^6 3s^2 3p^6$

Ca^{2+} Stability

- Calcium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- Ca^{2+} ion: $1s^2 2s^2 2p^6 3s^2 3p^6$
- Notice anything "noble" about the ion's electron configuration?

Ca^{2+} Stability

- Calcium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- Ca^{2+} ion: $1s^2 2s^2 2p^6 3s^2 3p^6$
- Ar atom: $1s^2 2s^2 2p^6 3s^2 3p^6$

Ca^{2+} and Ar are isoelectronic, that is, they have identical electron configurations

Ca^{2+} Stability

- Calcium atom: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$
- Ca^{2+} ion: $1s^2 2s^2 2p^6 3s^2 3p^6$
- Ar atom: $1s^2 2s^2 2p^6 3s^2 3p^6$

Ca^{2+} and Ar are isoelectronic, that is, they have identical electron configurations

Ca^{2+} Stability

- Calcium atom: [Ar]$4s^2$
- Ca^{2+} ion: [Ar]
- Ar atom: [Ar]

Ca^{2+} is a stable chemical species because it has a noble gas configuration

Group 2A Ions

- Magnesium Mg^{2+}
- Calcium Ca^{2+}
- Strontium Sr^{2+}
- Barium Ba^{2+}

- Notice any pattern?

Group 2A Ions

- Magnesium Mg^{2+} [Ne]
- Calcium Ca^{2+} [Ar]
- Strontium Sr^{2+} [Kr]
- Barium Ba^{2+} [Xe]

- Notice any pattern?

Group 2A Ions

- Mg [Ne]$3s^2$ Mg^{2+} [Ne]
- Ca [Ar]$4s^2$ Ca^{2+} [Ar]
- Sr [Kr]$5s^2$ Sr^{2+} [Kr]
- Ba [Xe]$6s^2$ Ba^{2+} [Xe]

Neutral atoms

Group 2A Ions

Neutral atoms		Stable ions	
Mg	[Ne]$3s^2$	Mg^{2+}	[Ne]
Ca	[Ar]$4s^2$	Ca^{2+}	[Ar]
Sr	[Kr]$5s^2$	Sr^{2+}	[Kr]
Ba	[Xe]$6s^2$	Ba^{2+}	[Xe]

Group 2A Ions

Neutral atoms		Stable ions	
Mg	[Ne]$3s^2$	Mg^{2+}	[Ne]
Ca	[Ar]$4s^2$	Ca^{2+}	[Ar]
Sr	[Kr]$5s^2$	Sr^{2+}	[Kr]
Ba	[Xe]$6s^2$	Ba^{2+}	[Xe]

All Group 2A elements lose 2 e^-'s to achieve a noble gas look

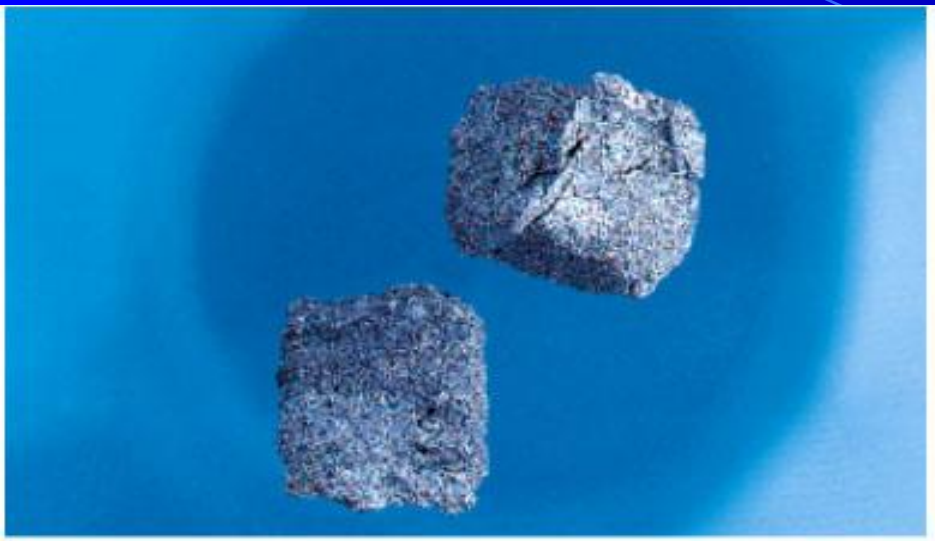
Stable ions of Group 2A

- Group 2A elements lose both of their s-electrons to form +2 cations
- They form stable +2 ions that are isoelectronic with the preceding noble gas

Group 2A Cation

1A	2A
+1	
+1	+2
+1	+2
+1	+2
+1	+2
+1	+2
+1	+2

Group 3A Elements (ns^2np^1, $n \geq 2$)



Boron (B)

Aluminum (Al)

Gallium (Ga)

Indium (In)

What ion charge do you think would be particularly stable for a Group 3A element like aluminum?

1. -3
2. 0
3. +1
4. +3

What ion charge do you think would be particularly stable for a Group 3A element like aluminum?

1. -3
2. 0
3. +1
4. +3

- Aluminum forms a stable Al^{3+} cation which is isoelectronic with the preceding noble gas Ne.

What ion charge do you think would be particularly stable for a Group 3A element like aluminum?

1. -3
2. 0
3. +1
4. +3

- Aluminum forms a stable Al^{3+} cation which is isoelectronic with the preceding noble gas Ne.

Al [Ne]$3s^2 3p^1$

What ion charge do you think would be particularly stable for a Group 3A element like aluminum?

1. -3
2. 0
3. +1
4. +3

- Aluminum forms a stable Al^{3+} cation which is isoelectronic with the preceding noble gas Ne.

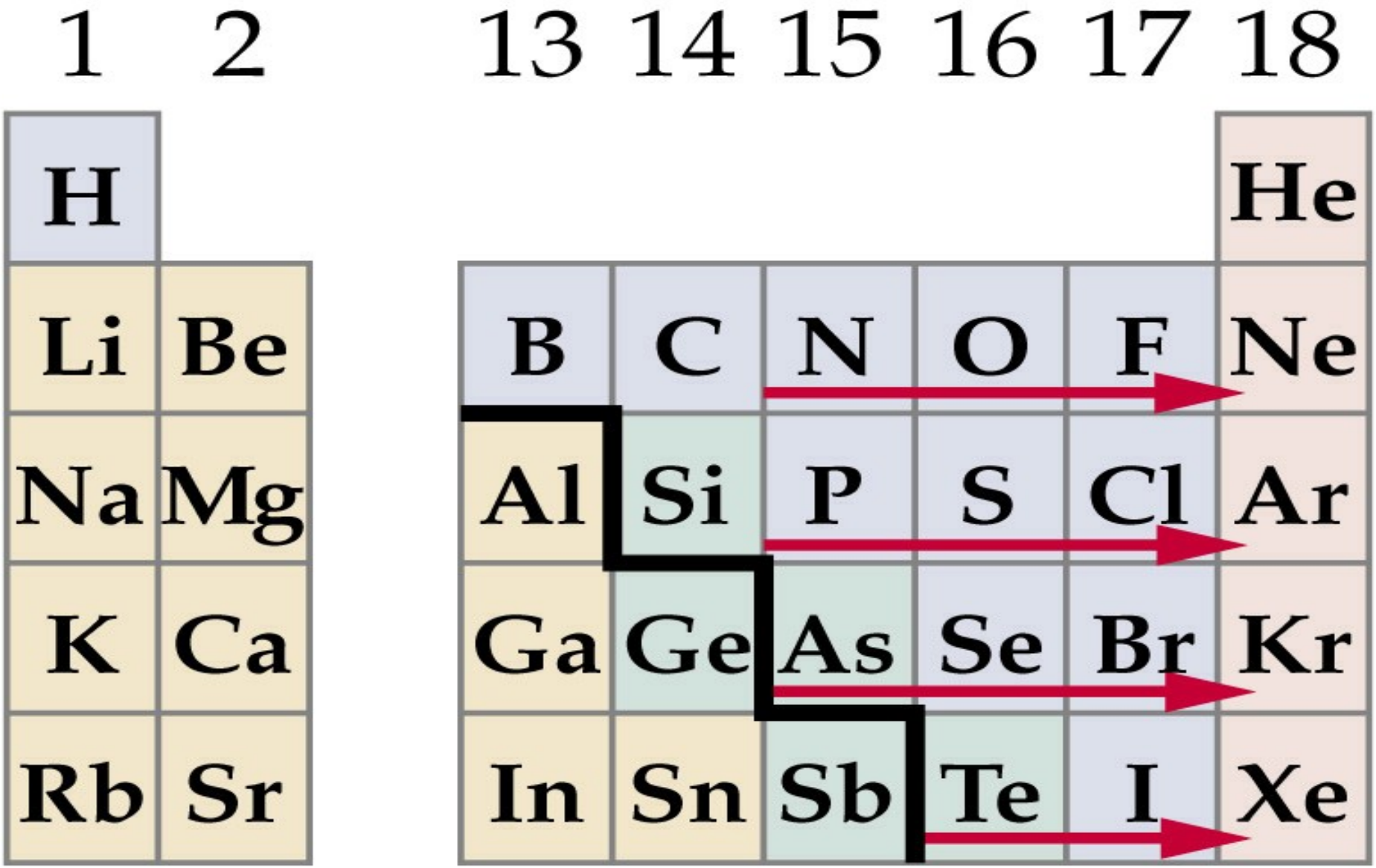
Al [Ne]$3s^2 3p^1$ Al^{3+} [Ne]

Group 3A Cation

1A	2A										3A					
+1																
+1	+2										+3					
+1	+2										+3					
+1	+2										+3					
+1	+2										+3					
+1	+2										+3					
+1	+2										+3					

Nonmetals Tend to Gain Electrons

Nonmetals Tend to Gain Electrons



Ions of Nonmetals

- Chlorine has an electron configuration one short of a noble gas
- Cl $1s^2 2s^2 2p^6 3s^2 3p^5$

Ions of Nonmetals

- Chlorine has an electron configuration one short of a noble gas
- Cl $1s^2 2s^2 2p^6 3s^2 3p^5$ ← One e^- short

Ions of Nonmetals

- Chlorine has an electron configuration one short of a noble gas
- Cl $1s^2 2s^2 2p^6 3s^2 3p^5$

- Picking up one extra electron completes an argon configuration

Ions of Nonmetals

- Chlorine has an electron configuration one short of a noble gas
- Cl $1s^2 2s^2 2p^6 3s^2 3p^5$

- Picking up one extra electron completes an argon configuration
- Cl^- ion $1s^2 2s^2 2p^6 3s^2 3p^6$

Ions of Nonmetals

- Chlorine has an electron configuration one short of a noble gas
- Cl $1s^2 2s^2 2p^6 3s^2 3p^5$

- Picking up one extra electron completes an argon configuration
- Cl^- ion $1s^2 2s^2 2p^6 3s^2 3p^6$ ← 8 valence electrons, isoelectronic with argon

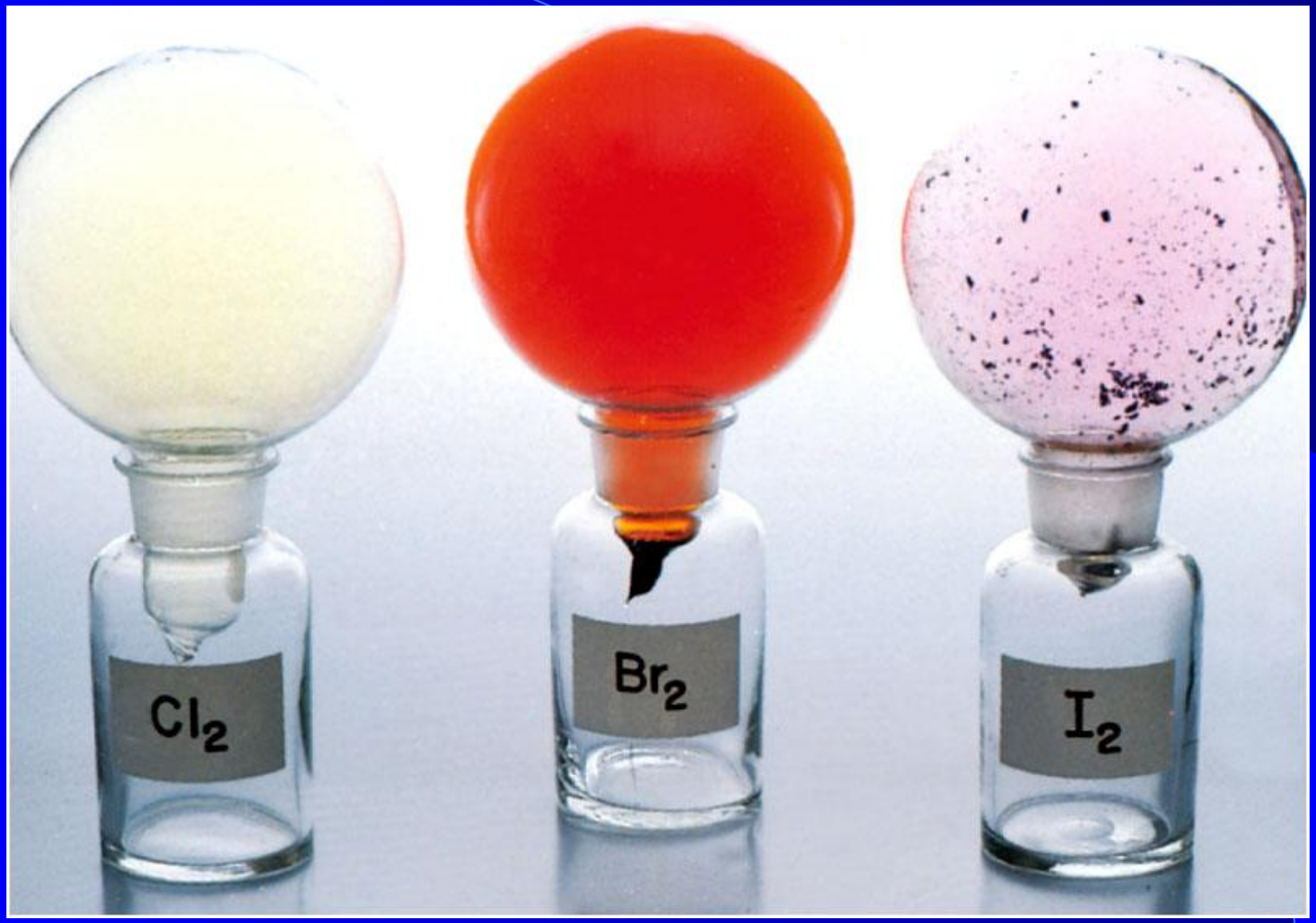
Monatomic Ions of Halogens

- Chloride Cl^-
- Fluoride F^-
- Bromide Br^-
- Iodide I^-
- Notice any pattern?
- (Note: monatomic ions formed by adding e^-'s until a noble gas configuration has been achieved always end in "-ide")

Group 7A Anions

1A	2A										3A				7A	0
+1																
+1	+2										+3				-1	0
+1	+2										+3				-1	0
+1	+2										+3				-1	0
+1	+2										+3				-1	0
+1	+2										+3				-1	0
+1	+2										+3					

Group 7A Elements (ns^2np^5, $n \geq 2$)



More Nonmetal Ions

- Oxide O^{2-}
- Sulfide S^{2-}
- Nitride N^{3-}
- Phosphide P^{3-}

- Notice any pattern?
- (More '-ide" anions)

Group 6A Elements (ns^2np^4, $n \geq 2$)

Sulfur (S_8)

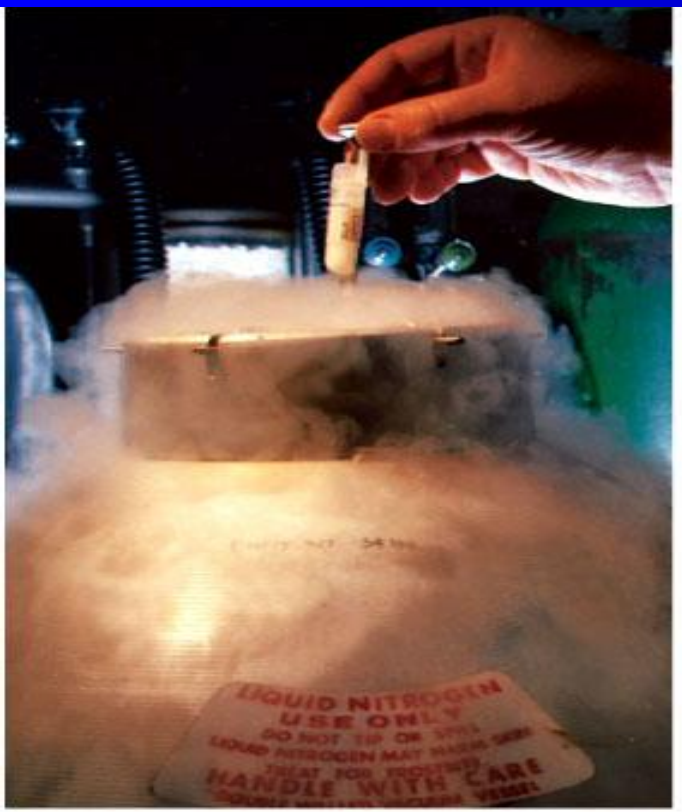
Selenium (Se_8)

Tellurium (Te)

More Anions

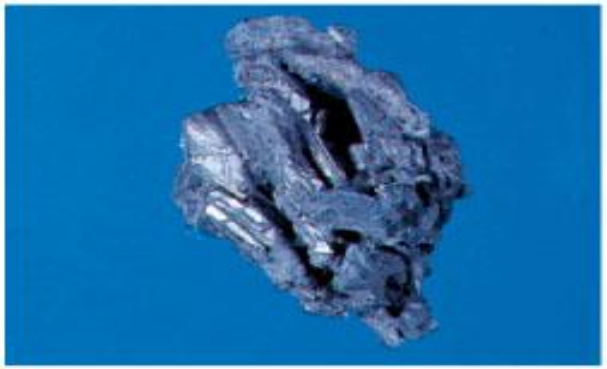
1A	2A										3A		5A	6A	7A	0
+1																
+1	+2										+3		-3	-2	-1	0
+1	+2										+3		-3	-2	-1	0
+1	+2										+3		-3	-2	-1	0
+1	+2										+3		-3	-2	-1	0
+1	+2										+3		-3	-2	-1	0
+1	+2															

Group 5A Elements (ns^2np^3, $n \geq 2$)

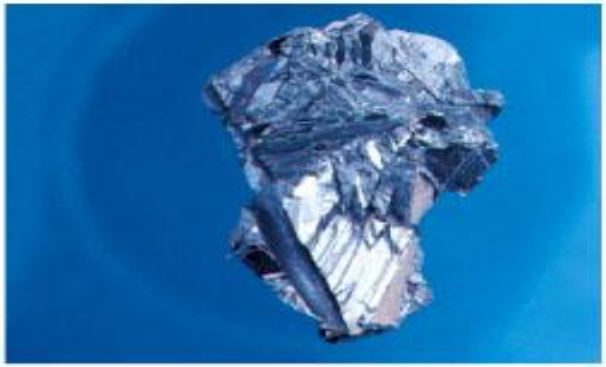


Nitrogen (N_2)

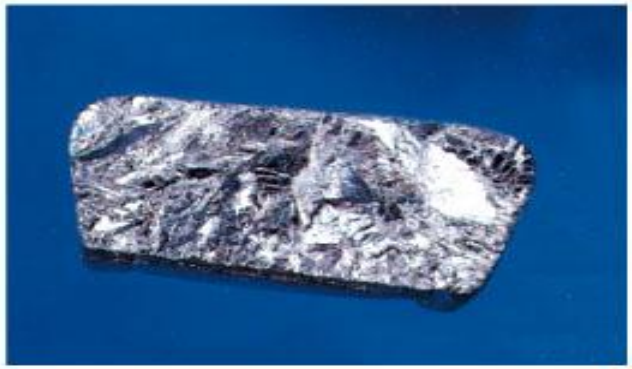
White and red phosphorus (P)



Arsenic (As)



Antimony (Sb)



Bismuth (Bi)

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion
- O^{2-} oxide ion
- F^{-} fluoride ion
- Ne neutral neon atom
- Na^{+} sodium ion
- Mg^{2+} magnesium ion
- Al^{3+} aluminum ion

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion
- F^{-} fluoride ion
- Ne neutral neon atom
- Na^{+} sodium ion
- Mg^{2+} magnesium ion
- Al^{3+} aluminum ion

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion [Ne]
- F^{-} fluoride ion
- Ne neutral neon atom
- Na^{+} sodium ion
- Mg^{2+} magnesium ion
- Al^{3+} aluminum ion

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion [Ne]
- F^{-} fluoride ion [Ne]
- Ne neutral neon atom
- Na^{+} sodium ion
- Mg^{2+} magnesium ion
- Al^{3+} aluminum ion

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion [Ne]
- F^{-} fluoride ion [Ne]
- Ne neutral neon atom [Ne]
- Na^{+} sodium ion
- Mg^{2+} magnesium ion
- Al^{3+} aluminum ion

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion [Ne]
- F^{-} fluoride ion [Ne]
- Ne neutral neon atom [Ne]
- Na^{+} sodium ion [Ne]
- Mg^{2+} magnesium ion
- Al^{3+} aluminum ion

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion [Ne]
- F^{-} fluoride ion [Ne]
- Ne neutral neon atom [Ne]
- Na^{+} sodium ion [Ne]
- Mg^{2+} magnesium ion [Ne]
- Al^{3+} aluminum ion

Write the condensed electron configuration for the following stable species...

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion [Ne]
- F^{-} fluoride ion [Ne]
- Ne neutral neon atom [Ne]
- Na^{+} sodium ion [Ne]
- Mg^{2+} magnesium ion [Ne]
- Al^{3+} aluminum ion [Ne]

They're all isoelectronic and possess the configuration of a noble gas

- N^{3-} nitride ion [Ne]
- O^{2-} oxide ion [Ne]
- F^{-} fluoride ion [Ne]
- Ne neutral neon atom [Ne]
- Na^{+} sodium ion [Ne]
- Mg^{2+} magnesium ion [Ne]
- Al^{3+} aluminum ion [Ne]

Isoelectronic: have the same number of electrons, and hence the same ground-state electron configuration

Na^+: [Ne] Al^{3+}: [Ne] F^-: $1s^2 2s^2 2p^6$ or [Ne]

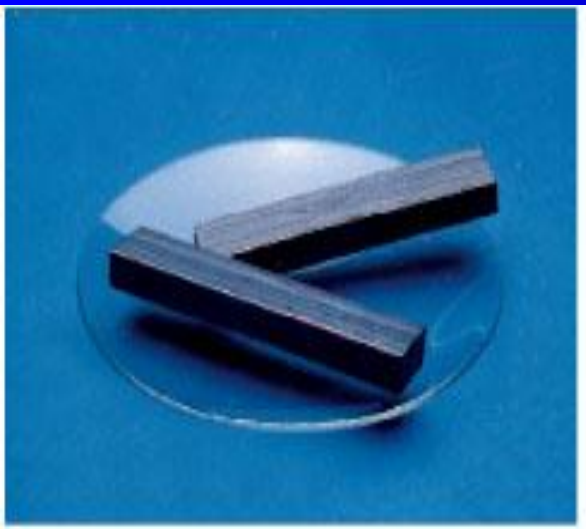
O^{2-}: $1s^2 2s^2 2p^6$ or [Ne] N^{3-}: $1s^2 2s^2 2p^6$ or [Ne]

Na^+, Al^{3+}, F^-, O^{2-}, and N^{3-} are all ***isoelectronic*** with Ne

What neutral atom is isoelectronic with H^- ?

H^-: $1s^2$ same electron configuration as He

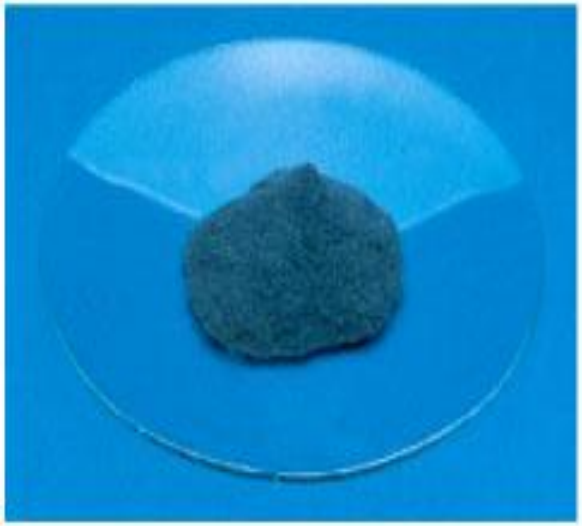
Group 4A Elements (ns^2np^2, $n \geq 2$)



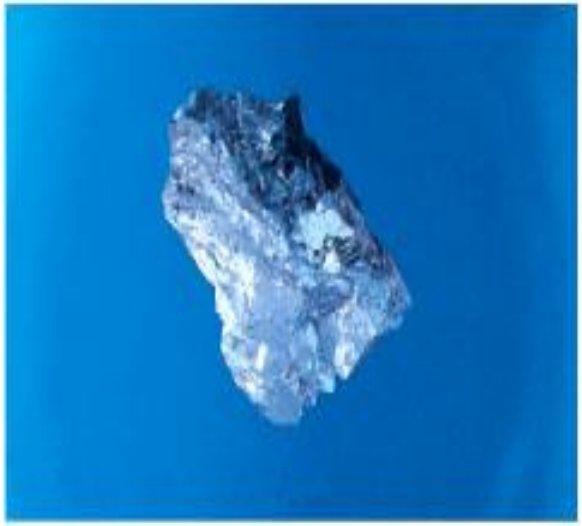
Carbon (graphite)

Carbon (diamond)

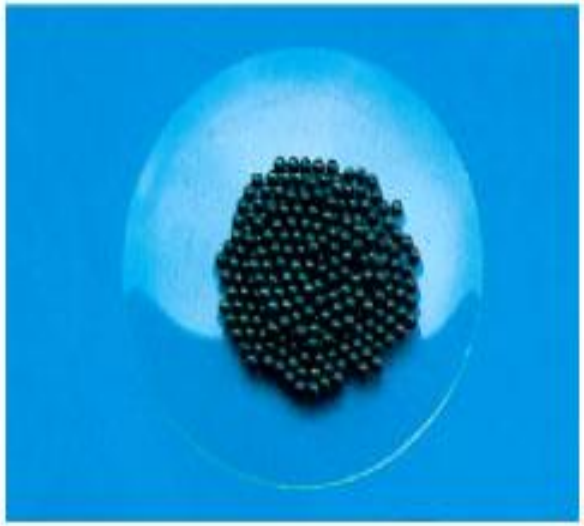
Silicon (Si)



Germanium (Ge)



Tin (Sn)



Lead (Pb)

Transition Metal Ions

- Copper(I) Cu^{+}
- Copper(II) Cu^{2+}
- Iron(II) Fe^{2+}
- Iron(III) Fe^{3+}
- Mercury(II) Hg^{2+}
- Silver Ag^{+}
- Notice any pattern?
- There isn't much of one!!!!!!

Transition Metal Cation

1A	2A										3A				7A	0
+1													-3	-2	-1	0
+1	+2												-3	-2	-1	0
+1	+2										+3		-3	-2	-1	0
+1	+2						+2/+3			+1/+2			-3	-2	-1	0
+1	+2									+1			-3	-2	-1	0
+1	+2										+1/+2		-3	-2	-1	0
+1	+2															

Effective Nuclear Charge (Z_{eff})

Effective Nuclear Charge (Z_{eff})

Effective nuclear charge (Z_{eff}) is the "positive charge" felt by an electron.

$Z_{eff} = Z - \sigma$ $\quad 0 < \sigma < Z$ (σ = shielding constant)

$Z_{eff} \approx Z$ – number of inner or core electrons

	Z	Core	Z_{eff}	Radius (pm)
Na	11	10	1	186
Mg	12	10	2	160
Al	13	10	3	143
Si	14	10	4	132

Effective Nuclear Charge (Z_{eff})

$Z_{eff} = Z_{actual}$ – No. of Core Electrons **or** Electron shielding

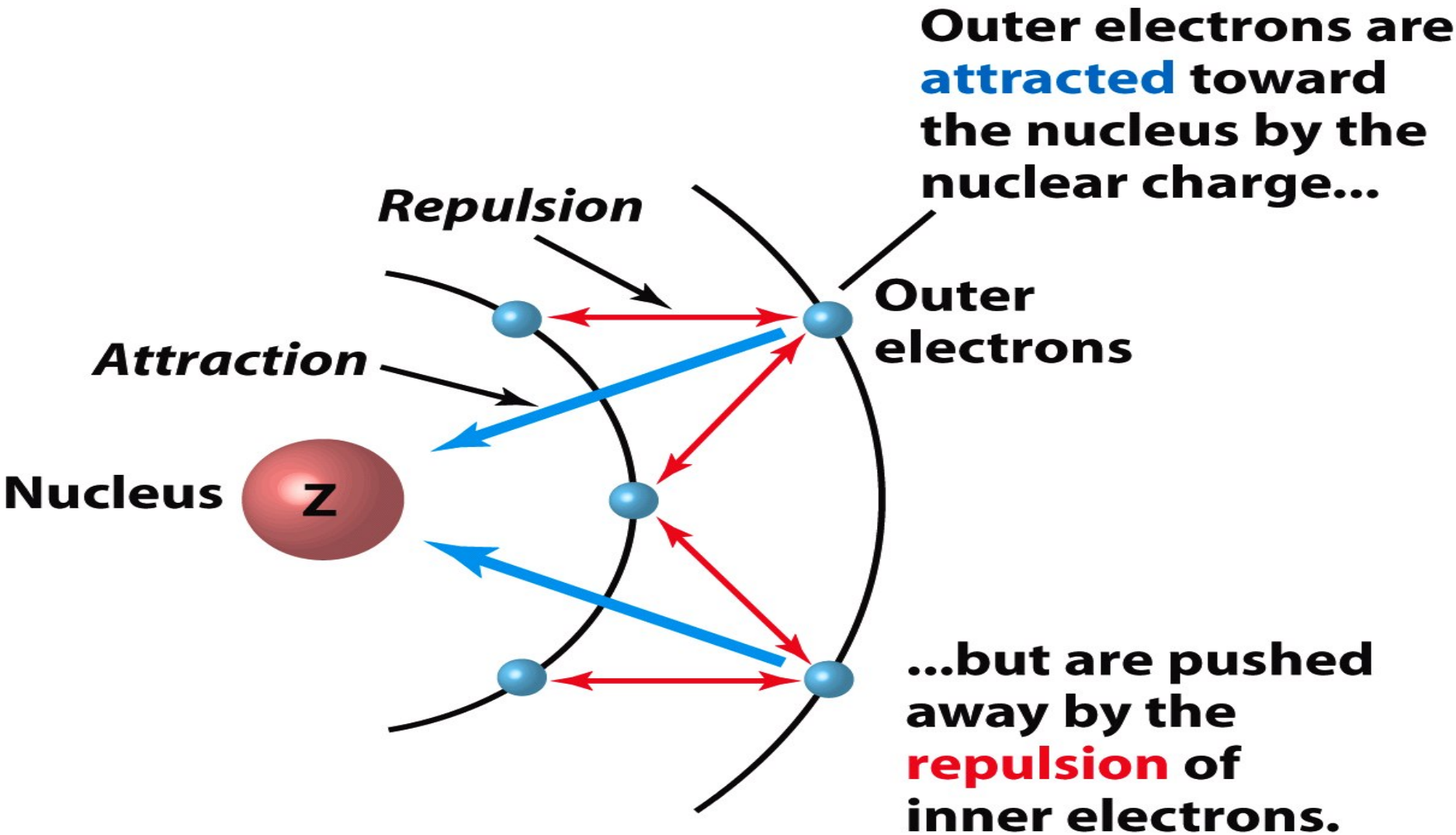


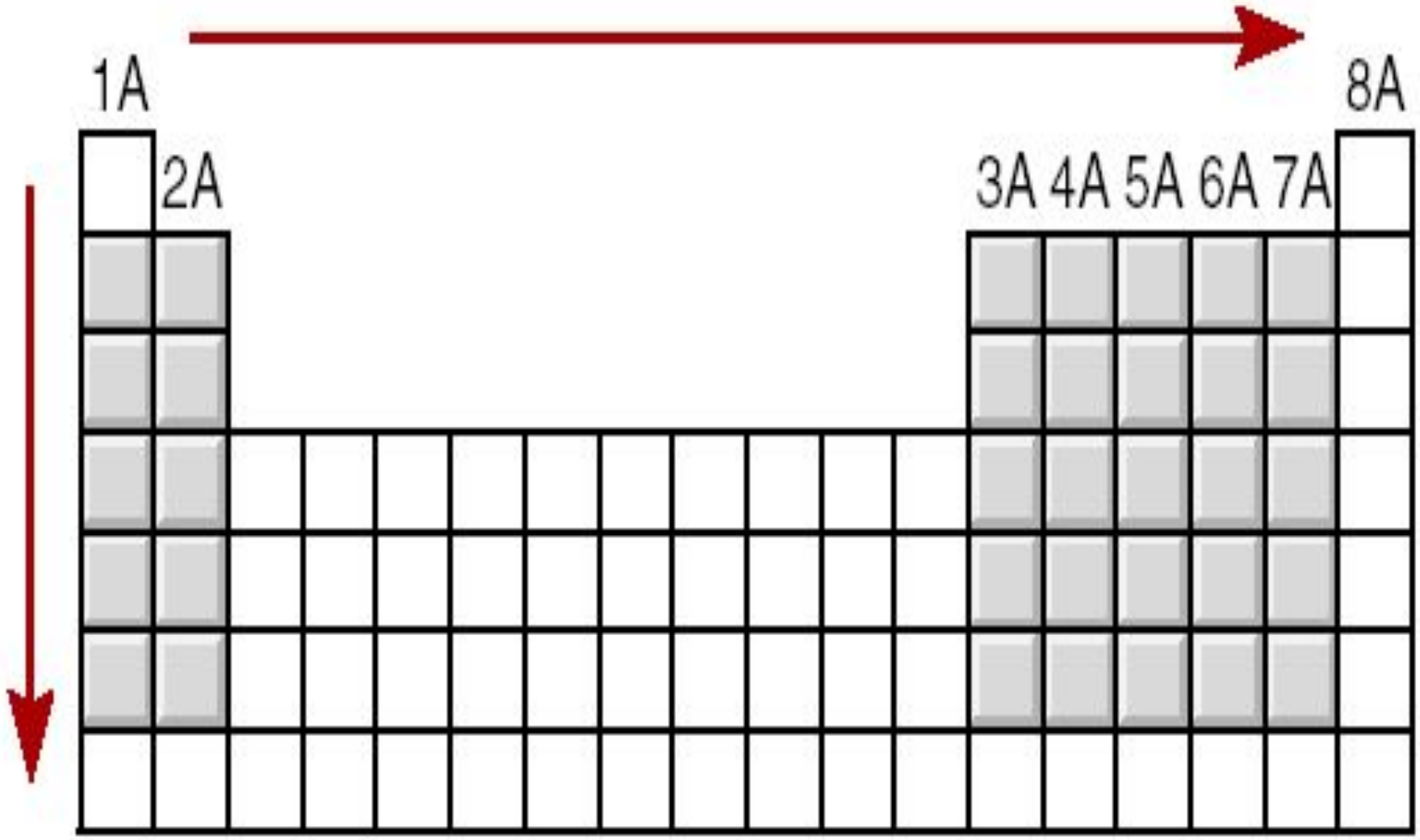
Figure 5-16 Chemistry, 5/e

© 2008 Pearson Prentice Hall, Inc.

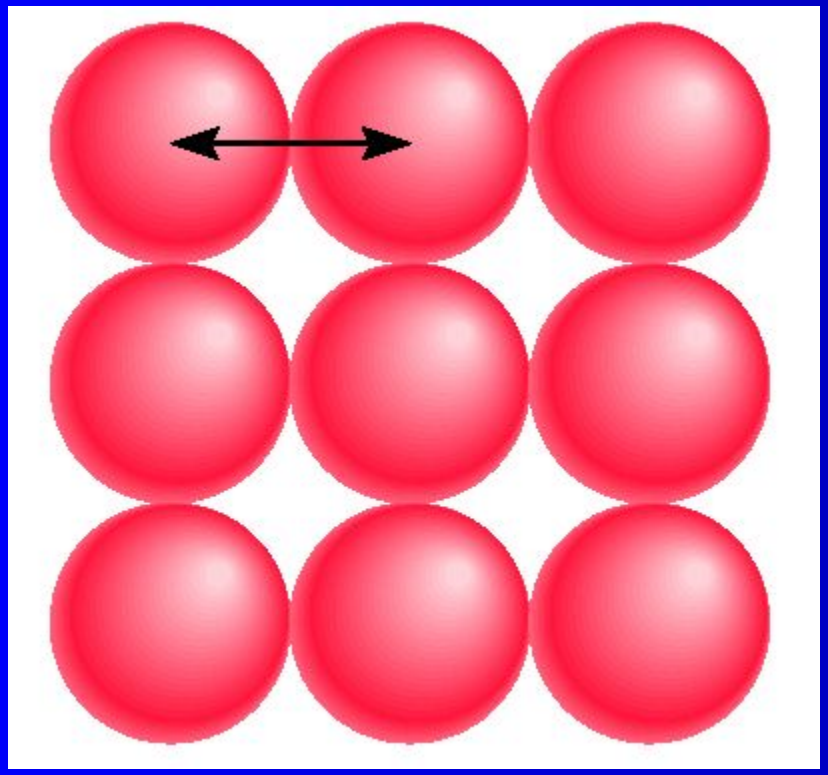
Effective Nuclear Charge (Z_{eff})

increasing Z_{eff}

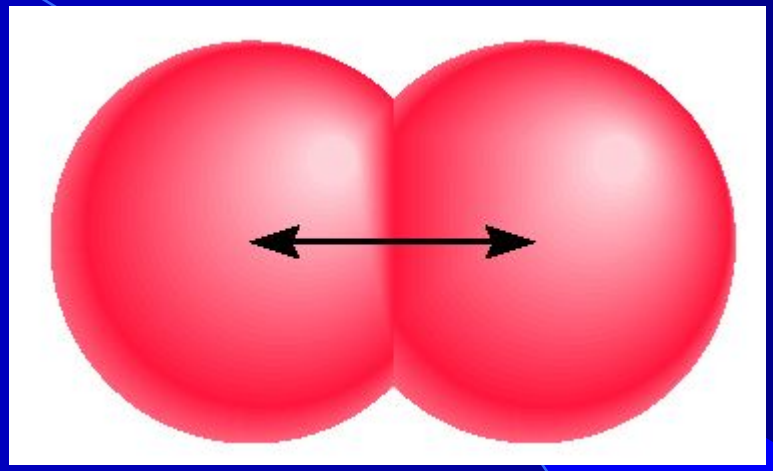
decreasing Z_{eff}



Atomic Radii



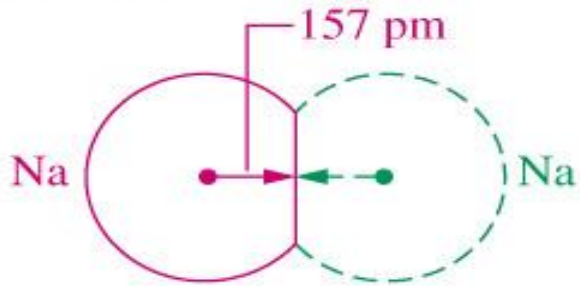
metallic radius



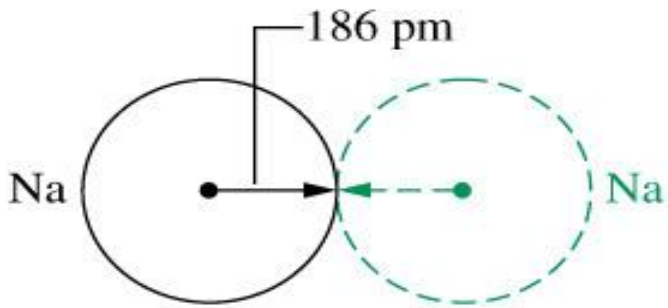
covalent radius

The Sizes of Atoms and Ions

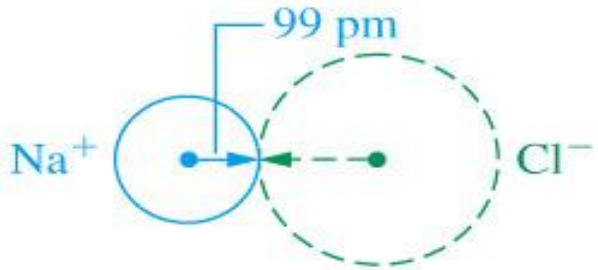
Covalent radius:

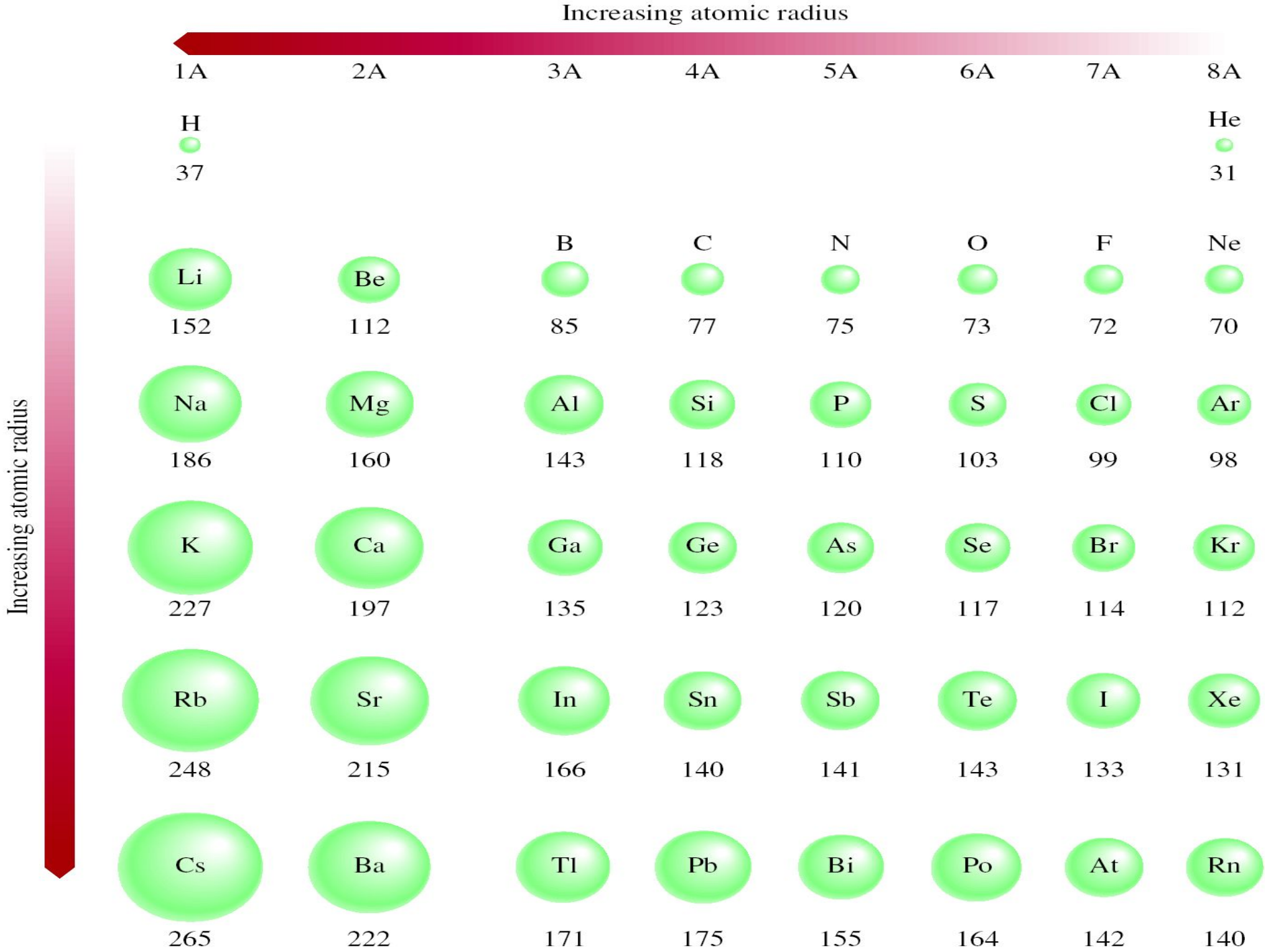


Metallic radius:



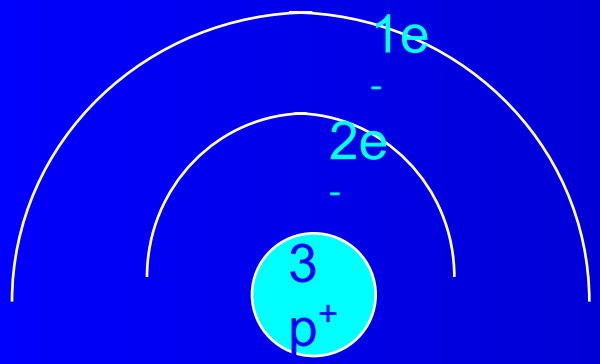
Ionic radius:



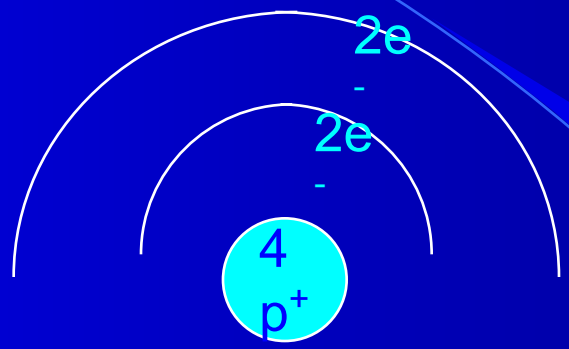

Increasing atomic radius
1A
2A
3A
4A
5A
6A
7A
8A
H
37
He
31
B
C
N
O
F
Ne
Li
152
Be
112
85
77
75
73
72
70
Na
186
Mg
160
Al
143
Si
118
P
110
S
103
Cl
99
Ar
98
K
227
Ca
197
Ga
135
Ge
123
As
120
Se
117
Br
114
Kr
112
Rb
248
Sr
215
In
166
Sn
140
Sb
141
Te
143
I
133
Xe
131
Cs
265
Ba
222
Tl
171
Pb
175
Bi
155
Po
164
At
142
Rn
140
Increasing atomic radius

Atomic Radii Decreases Across the Period

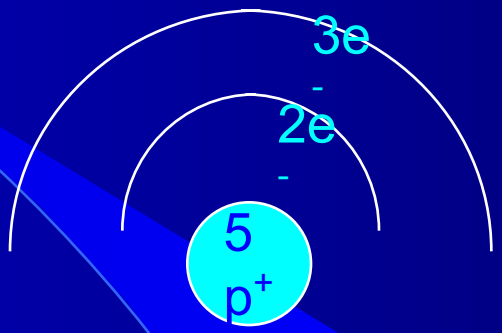
Period 2	Li	Be	B	C	N	O



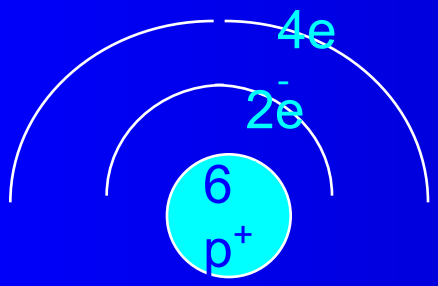
Li ($3p^+$ & $3e^-$)



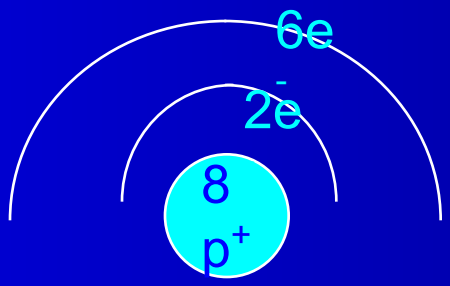
Be ($4p^+$ & $4e^-$)



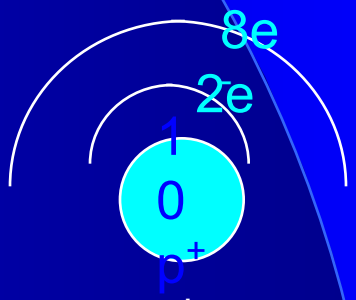
B ($5p^+$ & $5e^-$)



C ($6p^+$ & $6e^-$)



O ($8p^+$ & $8e^-$)



Ne ($10p^+$ & $10e^-$)

Atomic Radii Increases Down the Group

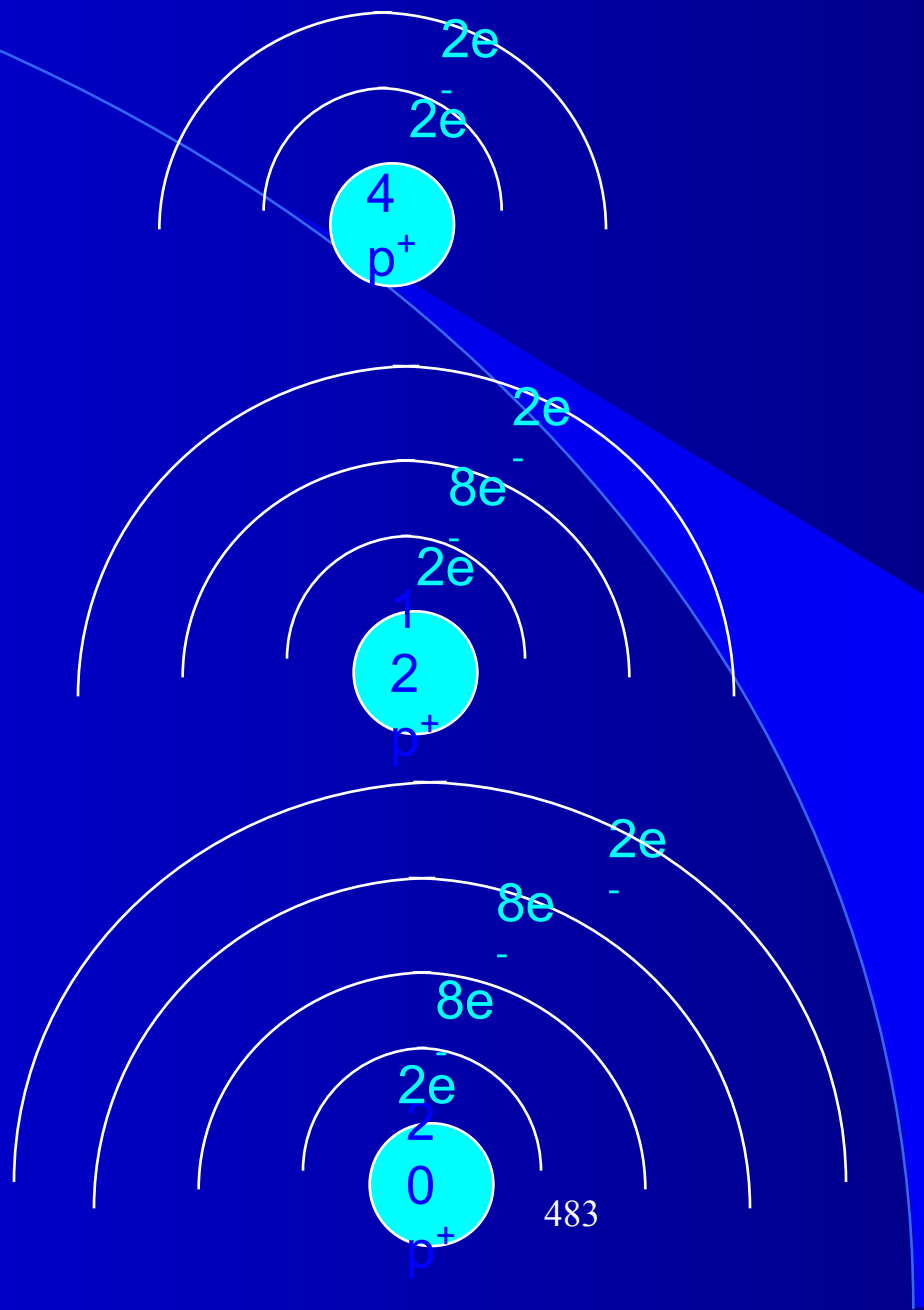
Group IIA

Be
Mg
Ca
Sr
Ba
Ra

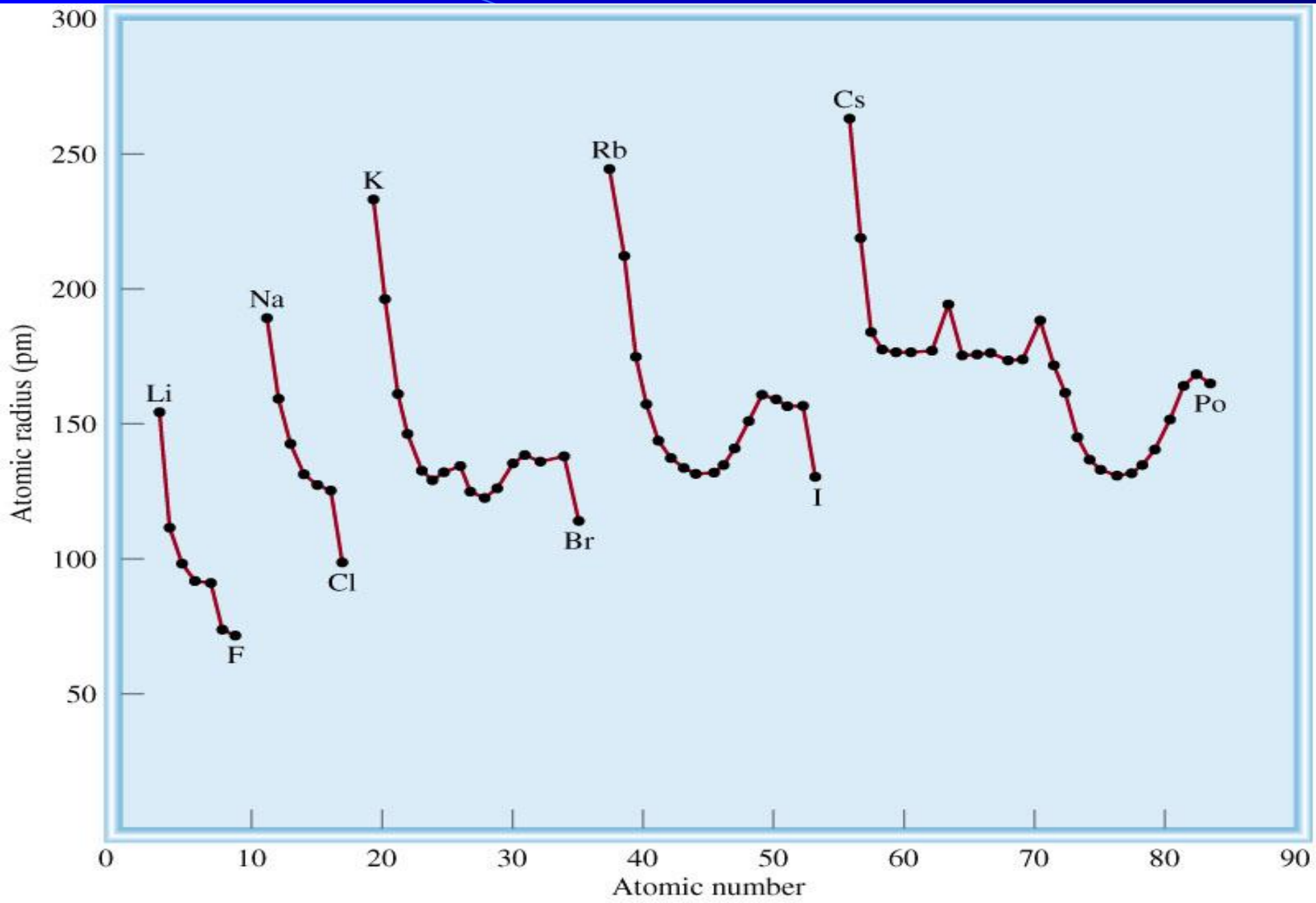
Be ($4p^+$ & $4e^-$)

Mg ($12p^+$ & $12e^-$)

Ca ($20p^+$ & $20e^-$)



Trends in Atomic Radii



Ionization Energy

Ionization Energy

Ionization energy is the minimum energy (kJ/mol) required to remove an electron from a gaseous atom in its ground state.

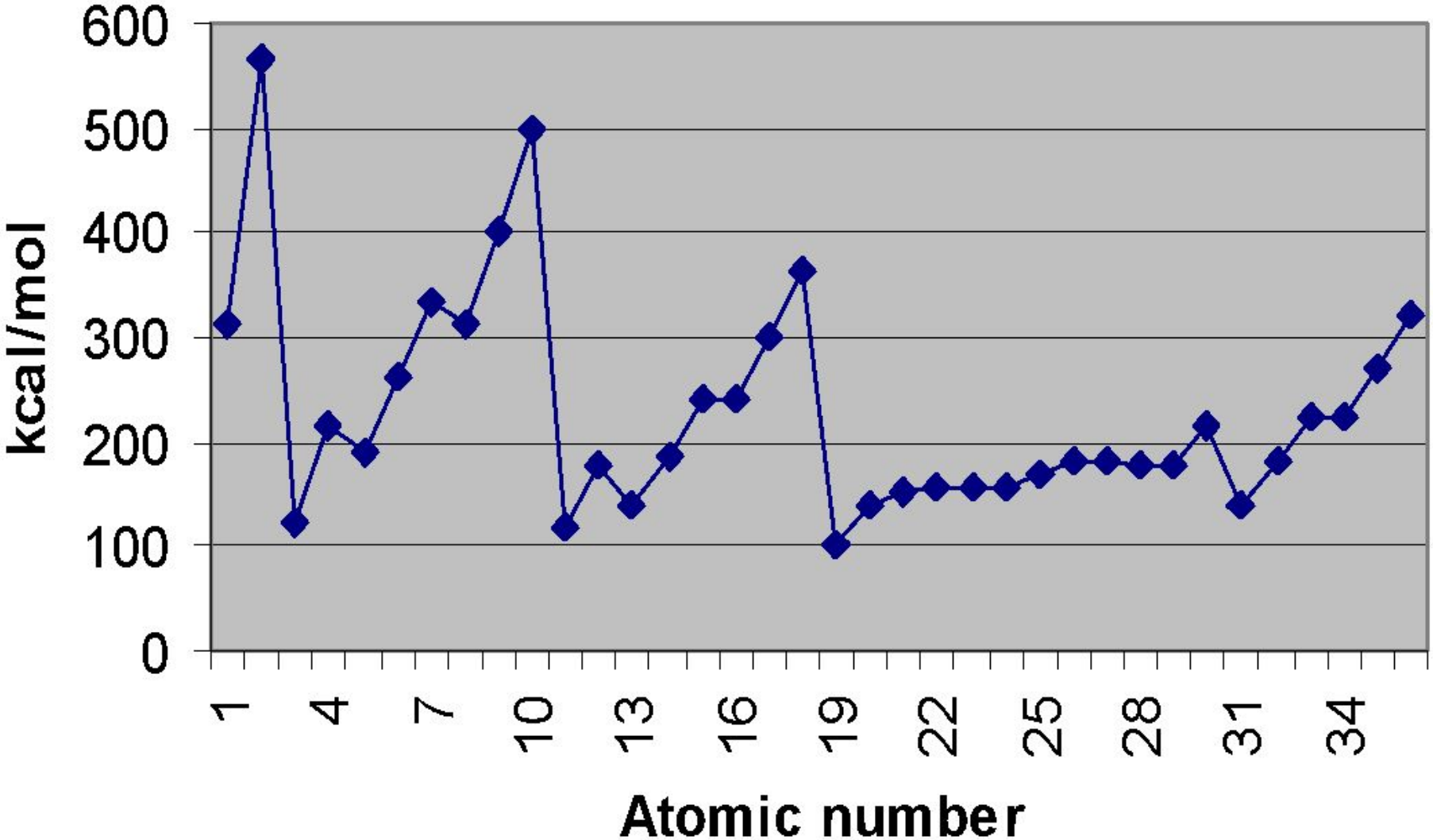
$I_1 + X_{(g)} \longrightarrow X^+_{(g)} + e^-$ $\quad$ I_1 first ionization energy

$I_2 + X^+_{(g)} \longrightarrow X^{2+}_{(g)} + e^-$ $\quad$ I_2 second ionization energy

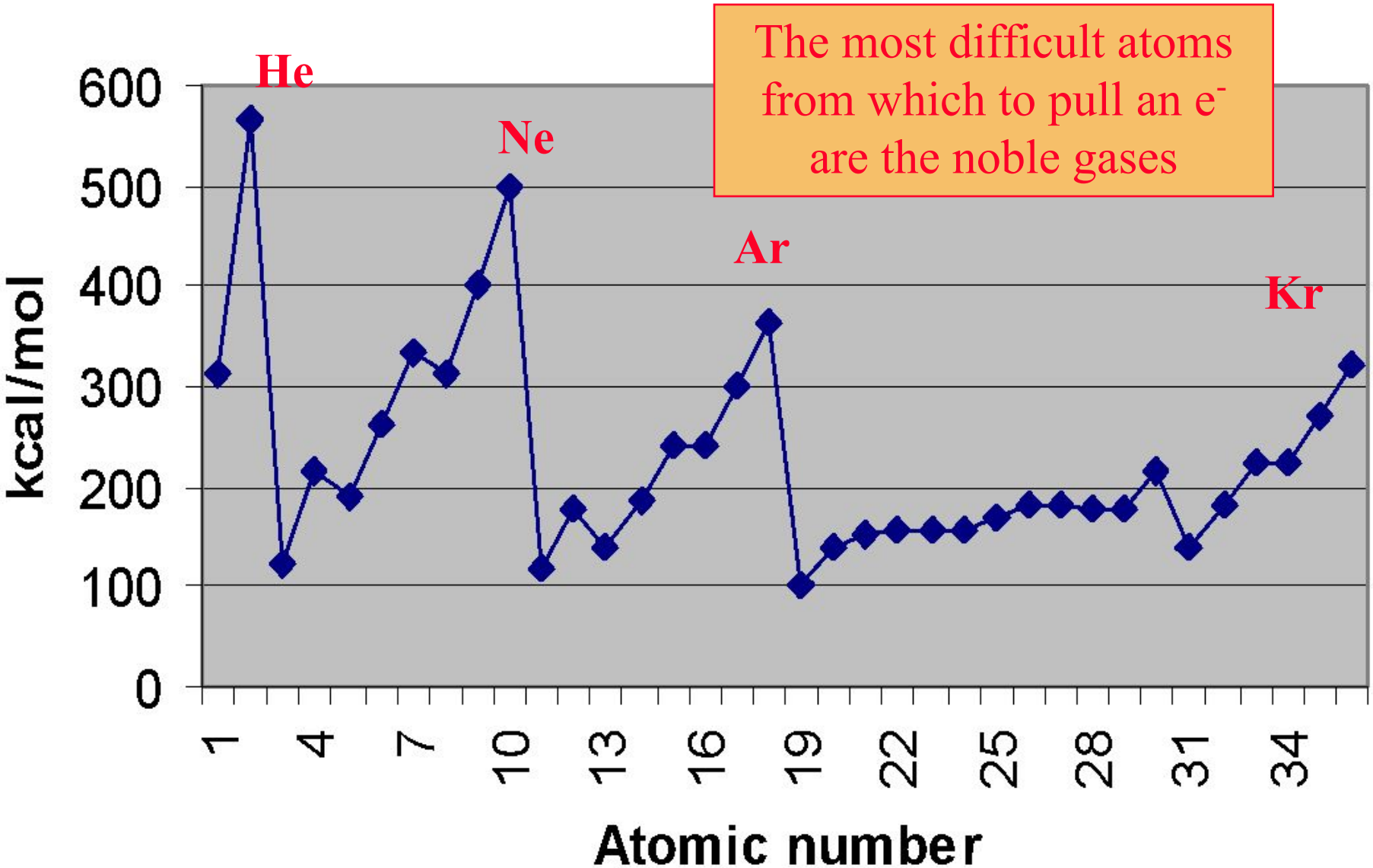
$I_3 + X^{2+}_{(g)} \longrightarrow X^{3+}_{(g)} + e^-$ $\quad$ I_3 third ionization energy

$$I_1 < I_2 < I_3$$

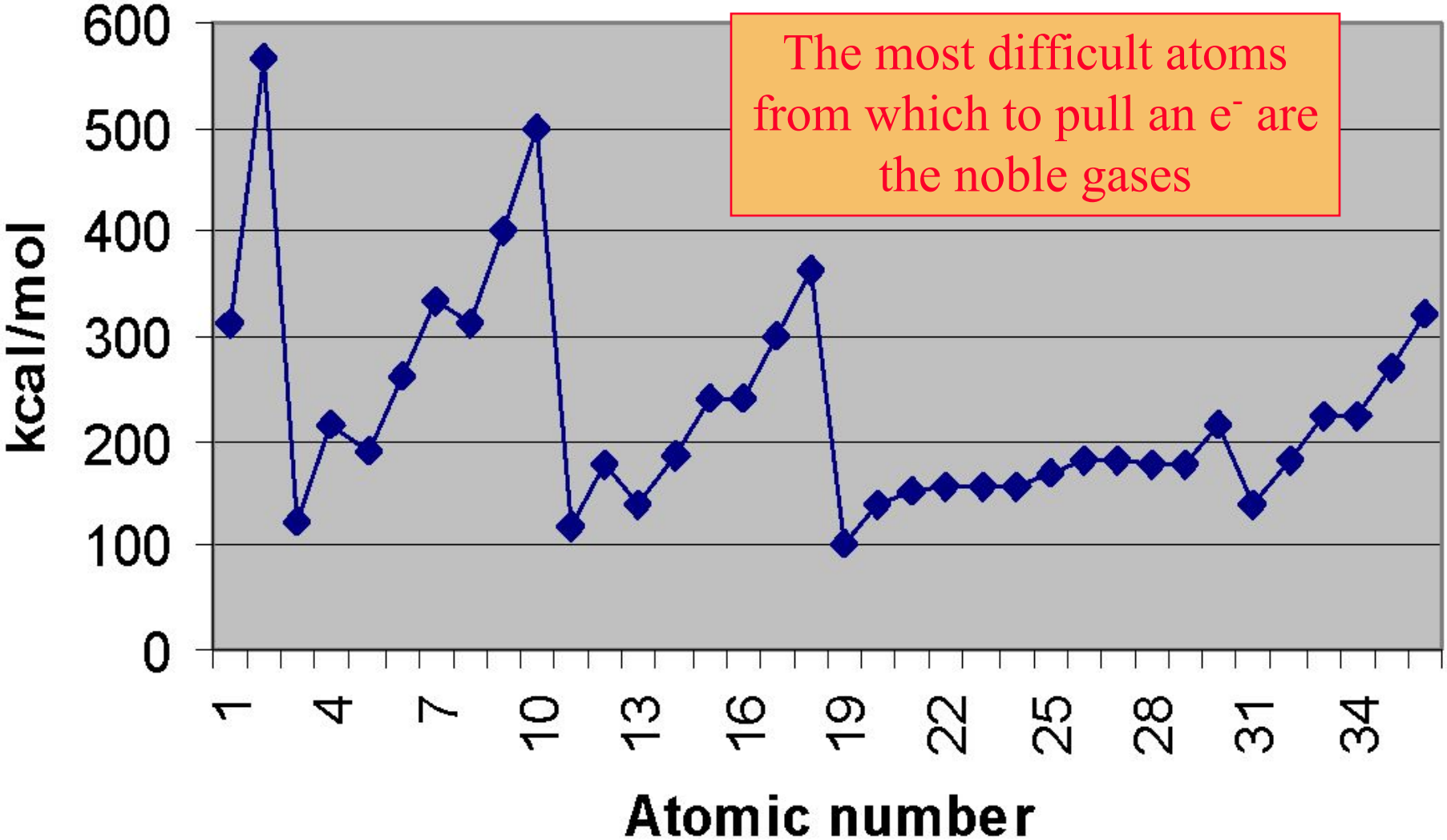
1st Ionization Energy



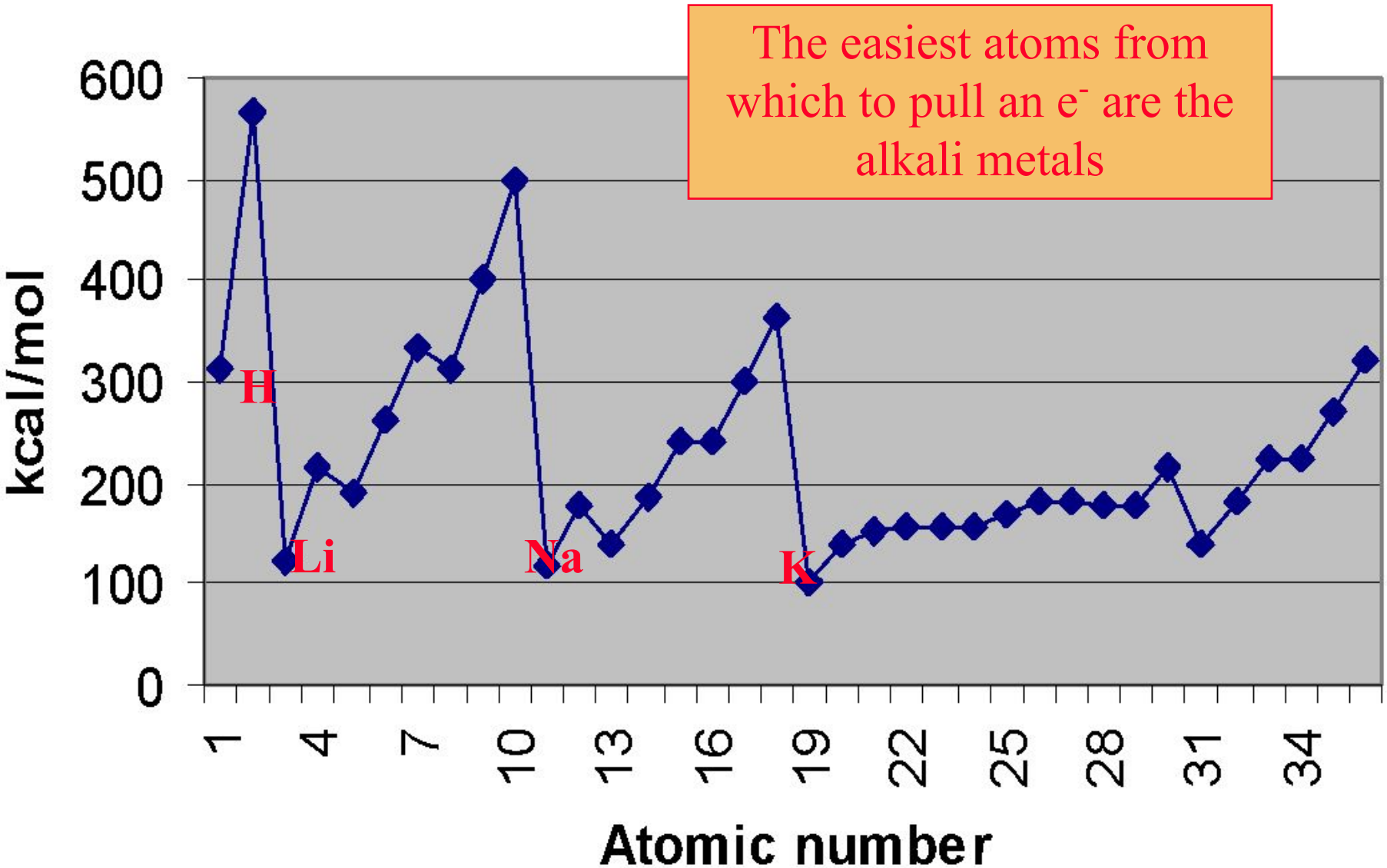
1st Ionization Energy



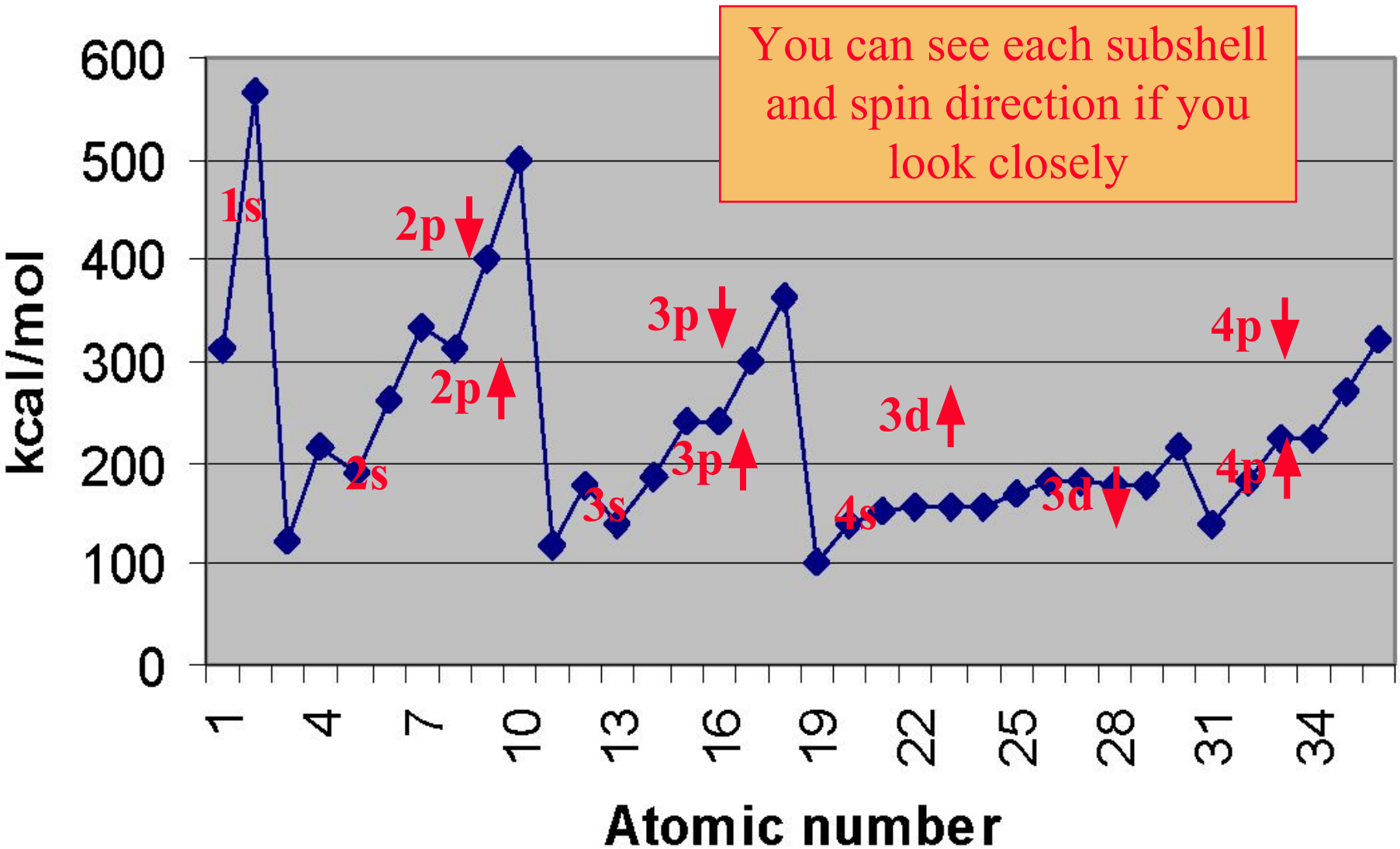
1st Ionization Energy



1st Ionization Energy



1st Ionization Energy



General Trends in First Ionization Energies

Increasing First Ionization Energy

Increasing First Ionization Energy

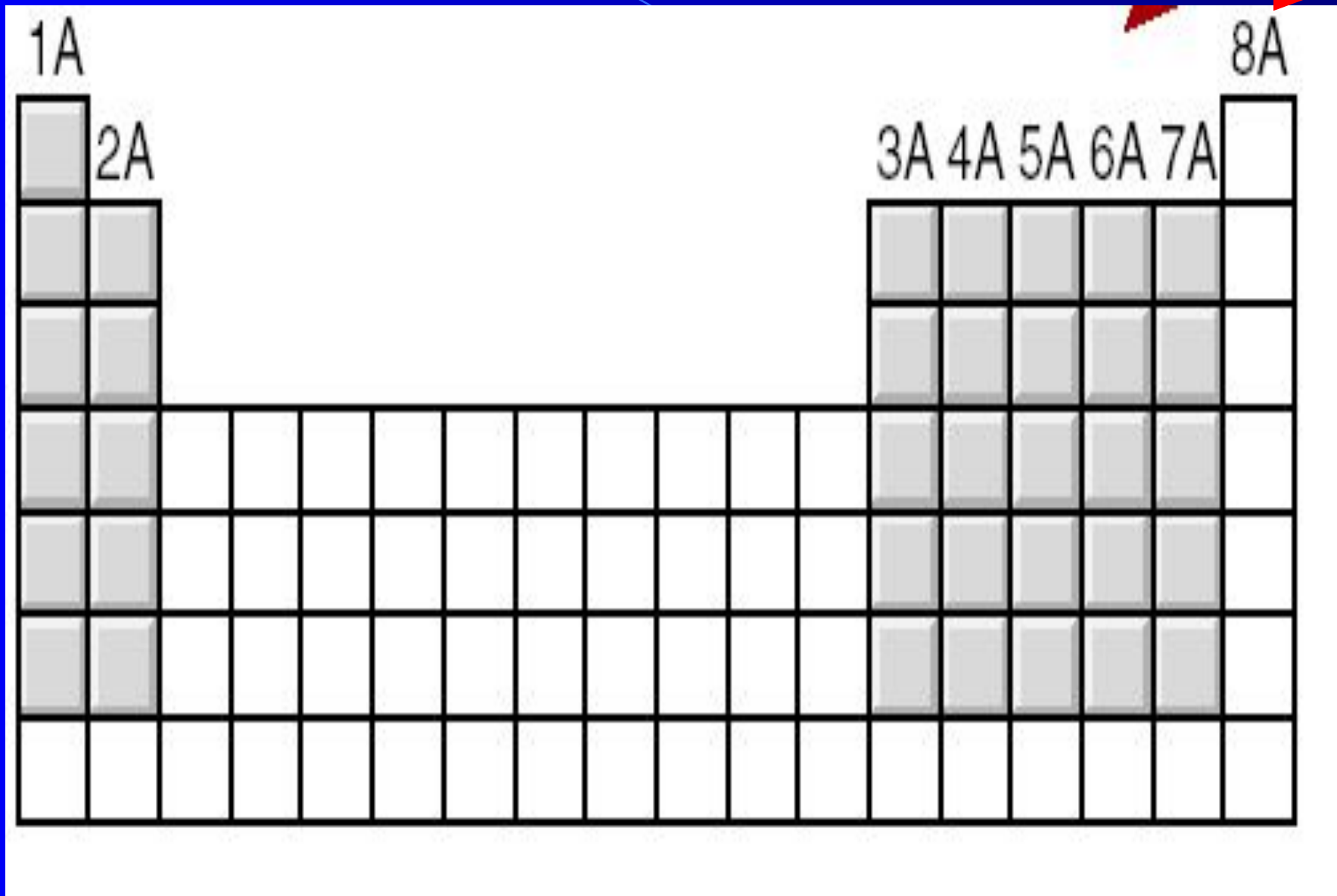


TABLE 8.2 The Ionization Energies (kJ/mol) of the First 20 Elements

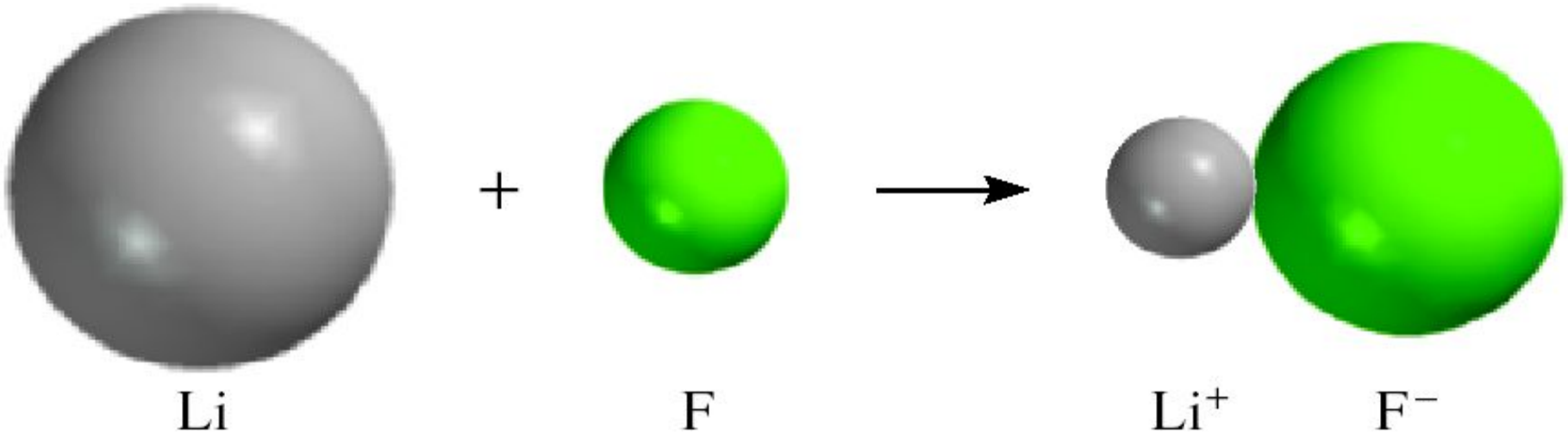
Z	Element	First	Second	Third	Fourth	Fifth	Sixth
1	H	1,312					
2	He	2,373	5,251				
3	Li	520	7,300	11,815			
4	Be	899	1,757	14,850	21,005		
5	B	801	2,430	3,660	25,000	32,820	
6	C	1,086	2,350	4,620	6,220	38,000	47,261
7	N	1,400	2,860	4,580	7,500	9,400	53,000
8	O	1,314	3,390	5,300	7,470	11,000	13,000
9	F	1,680	3,370	6,050	8,400	11,000	15,200
10	Ne	2,080	3,950	6,120	9,370	12,200	15,000
11	Na	495.9	4,560	6,900	9,540	13,400	16,600
12	Mg	738.1	1,450	7,730	10,500	13,600	18,000
13	Al	577.9	1,820	2,750	11,600	14,800	18,400
14	Si	786.3	1,580	3,230	4,360	16,000	20,000
15	P	1,012	1,904	2,910	4,960	6,240	21,000
16	S	999.5	2,250	3,360	4,660	6,990	8,500
17	Cl	1,251	2,297	3,820	5,160	6,540	9,300
18	Ar	1,521	2,666	3,900	5,770	7,240	8,800
19	K	418.7	3,052	4,410	5,900	8,000	9,600
20	Ca	589.5	1,145	4,900	6,500	8,100	11,000

Ionic Radius

Cation is always **smaller** than atom from which it is formed.

Anion is always **larger** than atom from which it is formed.

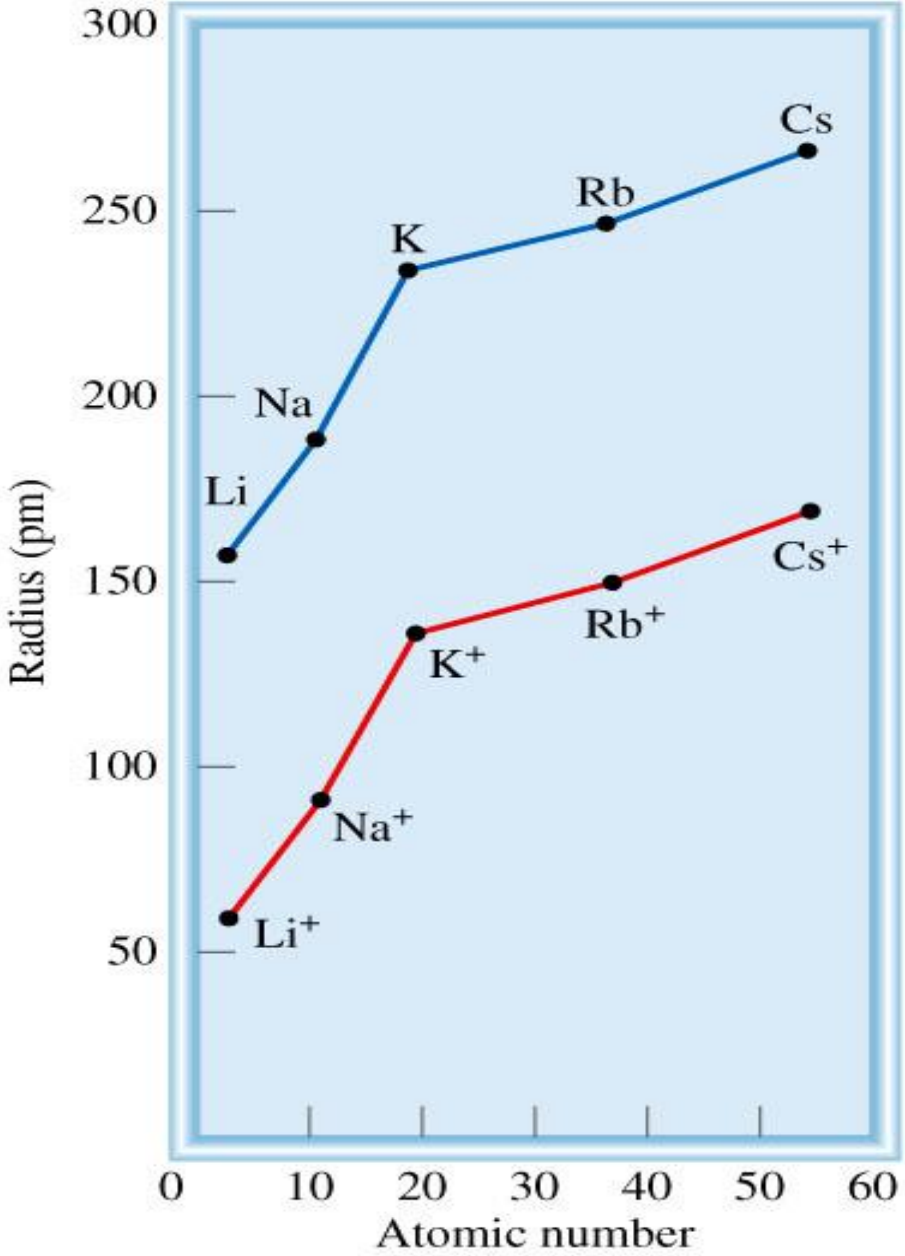
Atomic Radii & Ionic Radii

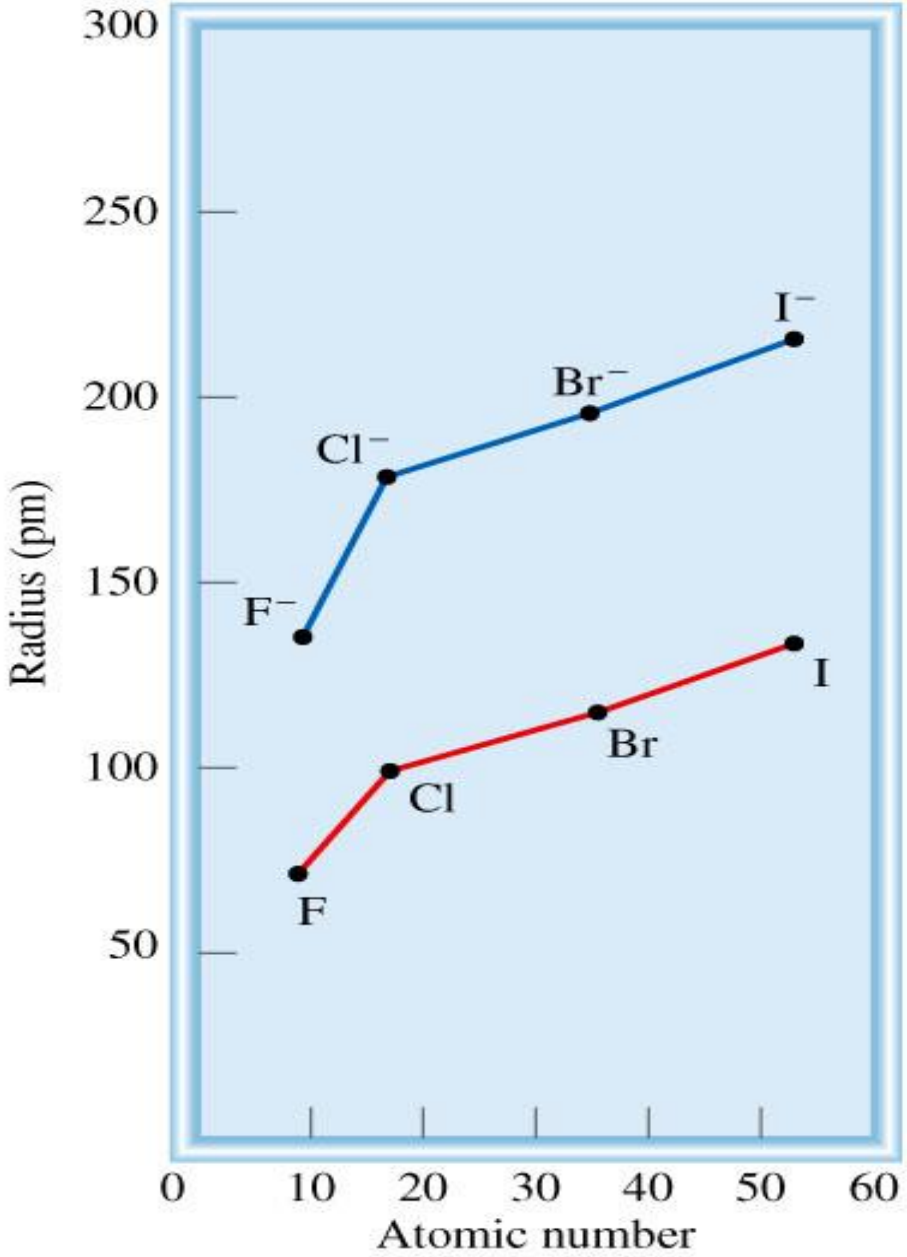


Cation is always **smaller** than atom from which it is formed.

Anion is always **larger** than atom from which it is formed.

Comparison of Atomic Radii with Ionic Radii

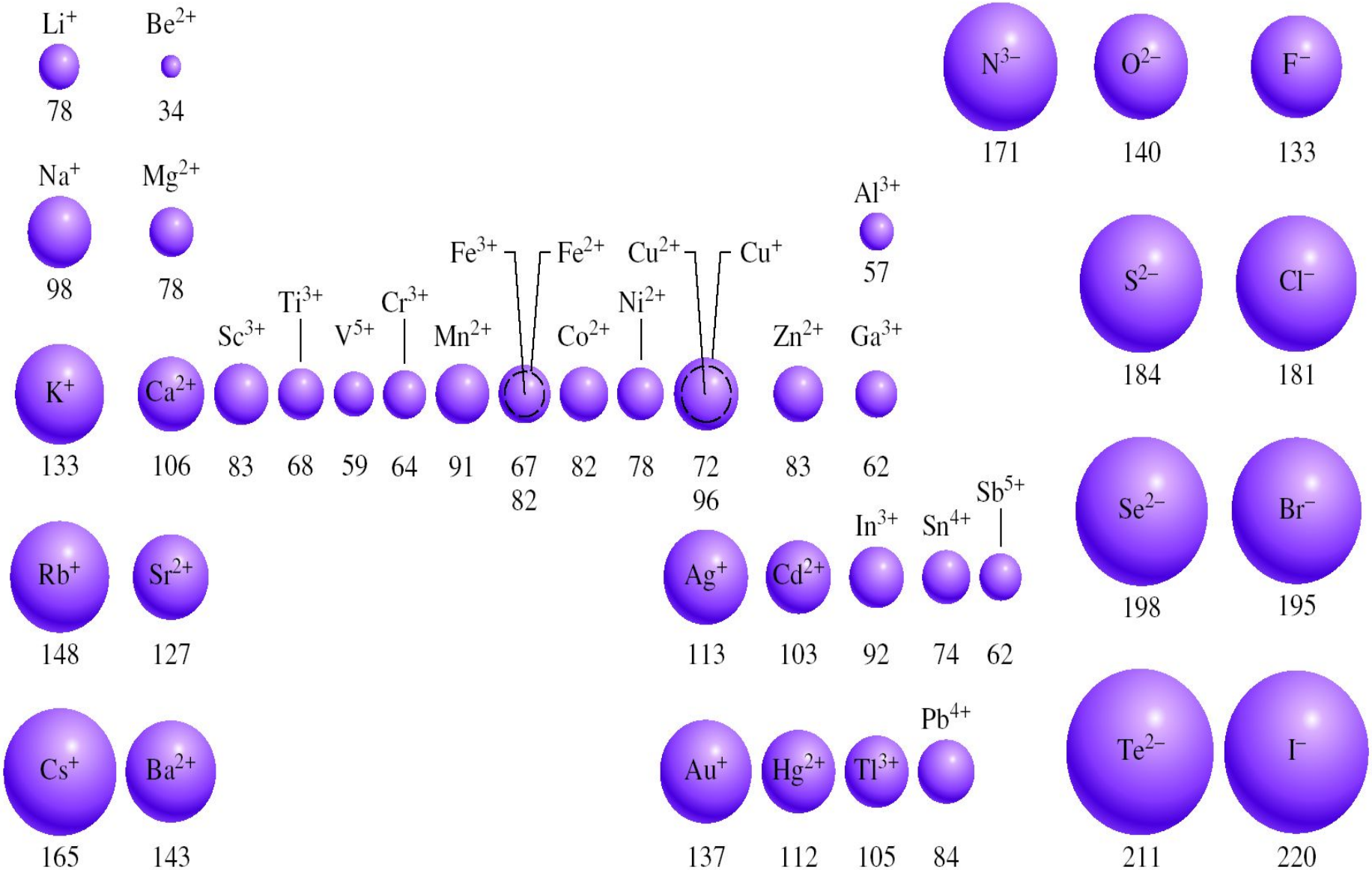




Radii for Isoelectronic atoms or ions

Atom or Ion	Radius (nm)	Electron config.
C^{4-}	0.260	$1s^2 2s^2 2p^6$
N^{3-}	0.171	$1s^2 2s^2 2p^6$
O^{-2}	0.140	$1s^2 2s^2 2p^6$
F^-	0.136	$1s^2 2s^2 2p^6$
Ne	0.112	$1s^2 2s^2 2p^6$
Na^+	0.095	$1s^2 2s^2 2p^6$
Mg^{2+}	0.065	$1s^2 2s^2 2p^6$
Al^{3+}	0.050	$1s^2 2s^2 2p^6$

The Radii (in pm) of Ions of Familiar Elements



Electron Affinity

Electron Affinity

Electron affinity is the negative of the energy change that occurs when an electron is accepted by an atom in the gaseous state to form an anion.

$$X_{(g)} + e^- \longrightarrow X^-_{(g)}$$

$$F_{(g)} + e^- \longrightarrow F^-_{(g)} \qquad \Delta H = -328 \text{ kJ/mol} \qquad EA = +328 \text{ kJ/mol}$$

$$O_{(g)} + e^- \longrightarrow O^-_{(g)} \qquad \Delta H = -141 \text{ kJ/mol} \qquad EA = +141 \text{ kJ/mol}$$

$$O^-_{(g)} + e^- \longrightarrow O^{2-}_{(g)} \qquad \Delta H = +780 \text{ kJ/mol} \qquad EA = -780 \text{ kJ/mol}\ ?$$

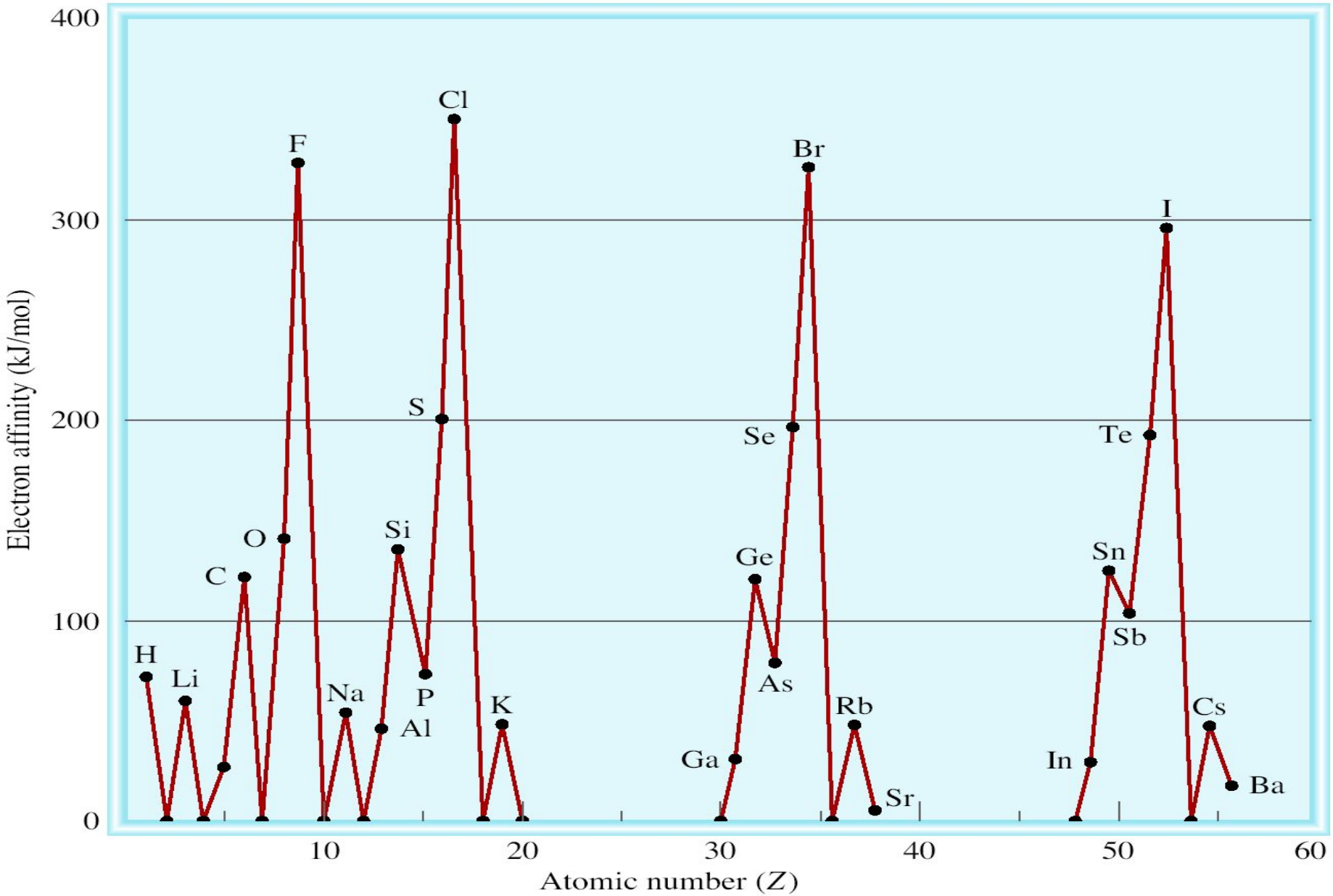
- EA of O^- is highly –ve; *i.e.* O^{2-} formation is unfavorable,
- electron-electron repulsion (*g*) > stability from noble gas configuration;
- O^{2-} ion stabilized by neighboring cation, *e.g.* Li_2O, Mg_2O

TABLE 8.3 Electron Affinities (kJ/mol) of Some Representative Elements and the Noble Gases*

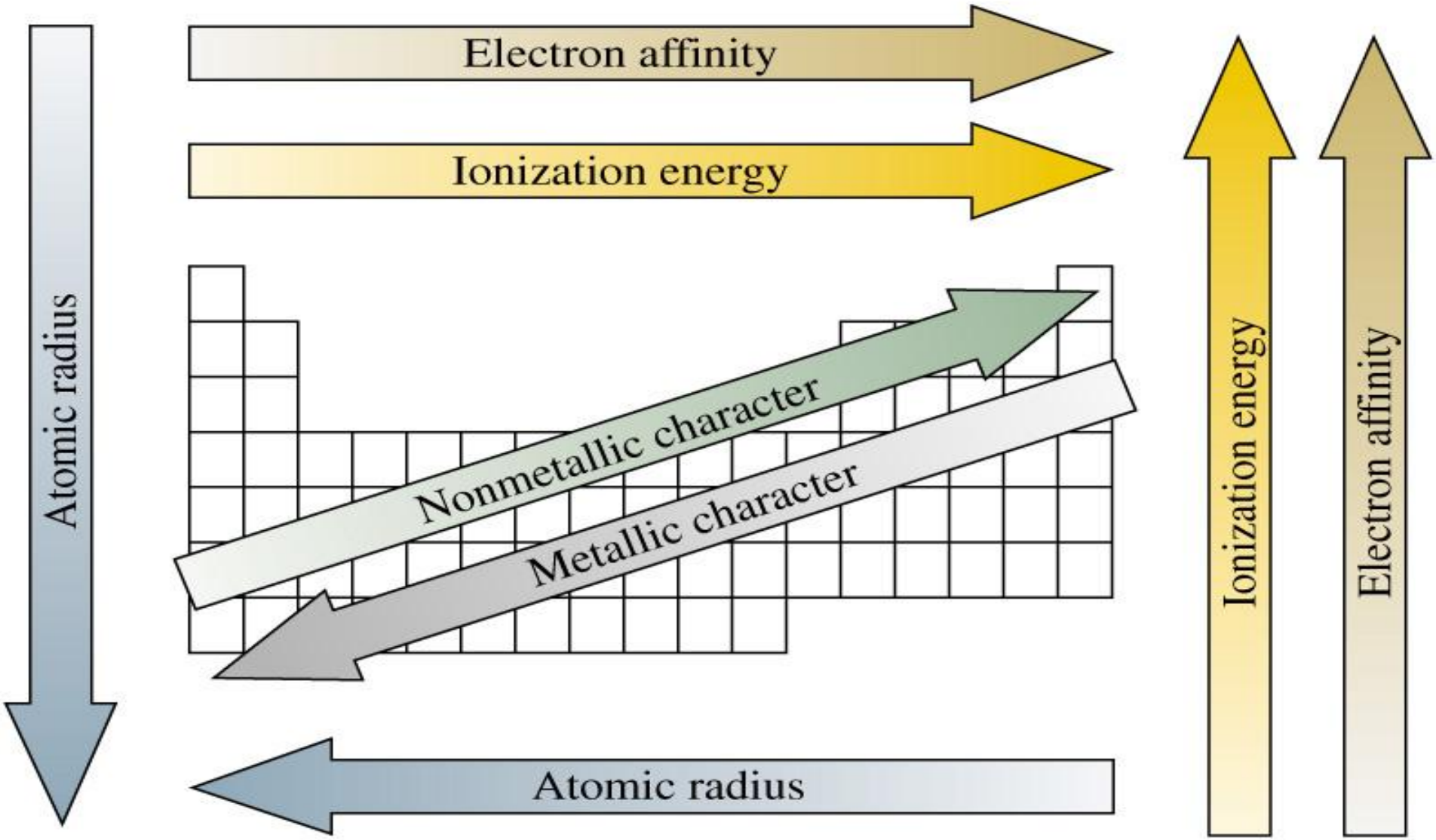
1A	2A	3A	4A	5A	6A	7A	8A
H							He
73							< 0
Li	Be	B	C	N	O	F	Ne
60	≤ 0	27	122	0	141	328	< 0
Na	Mg	Al	Si	P	S	Cl	Ar
53	≤ 0	44	134	72	200	349	< 0
K	Ca	Ga	Ge	As	Se	Br	Kr
48	2.4	29	118	77	195	325	< 0
Rb	Sr	In	Sn	Sb	Te	I	Xe
47	4.7	29	121	101	190	295	< 0
Cs	Ba	Tl	Pb	Bi	Po	At	Rn
45	14	30	110	110	?	?	< 0

*The electron affinities of the noble gases, Be, and Mg have not been determined experimentally, but are believed to be close to zero or negative.

Variation of Electron Affinity With Atomic Number (H – Ba)



Periodic Properties of the Elements



Variation in Chemical Properties of the Representative Elements

Ionization energy (IE) and electron affinity (EA) help us to understand:

- the **types** of reactions an element undergo
- the **nature** of the elements' compounds formed

IE measures the attraction of an atom for its **own** electrons

EA expresses the attraction of an atom for **additional** electrons

- IE and EA together gives the insight into the **general attraction** of an atom for electron

With these concepts we can survey the chemical behavior of the elements systematically.

Variation in Chemical Properties of the Representative Elements

The metallic character of the elements

- **decreases** from left to right across a period, and
- **increases** from top to bottom within a group

Metals usually have **low** ionization energies, and Nonmetals usually have **high** electron affinity

On the basis of these trends we can predict the outcome of a reaction involving some of these elements

General Trends in Chemical Properties

Diagonal Relationships on the Periodic Table

1A	2A	3A	4A
Li	Be	B	C
Na	Mg	Al	Si

Properties of Oxides Across a Period

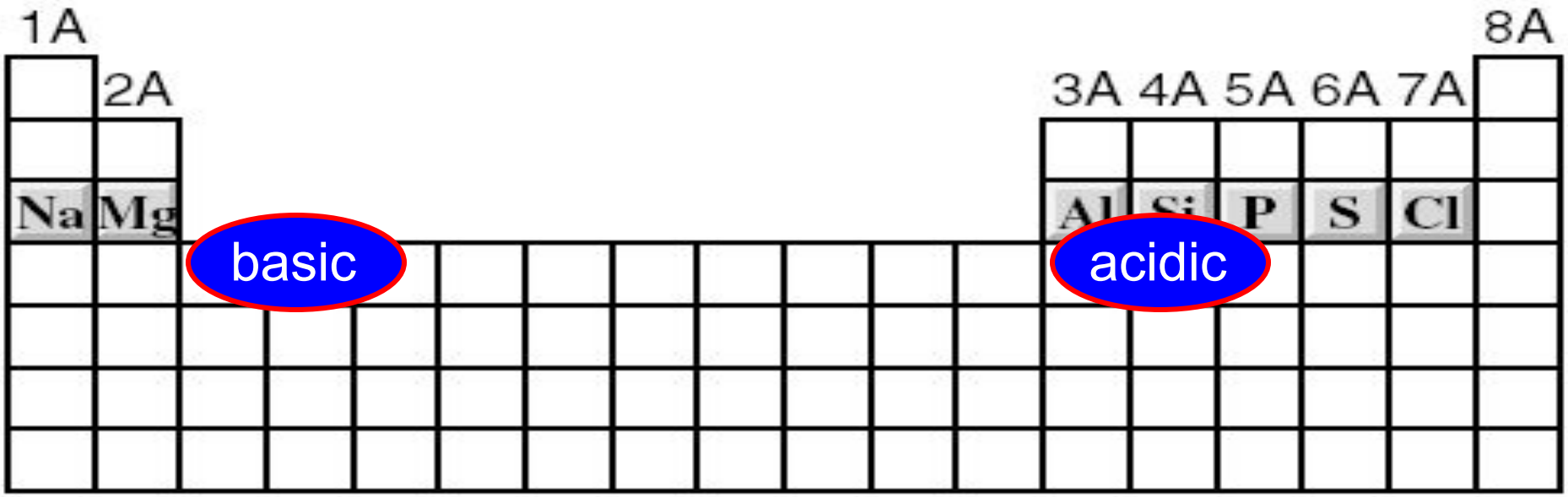


TABLE 8.4 Some Properties of Oxides of the Third-Period Elements

	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_3	Cl_2O_7
Type of compound	←	Ionic	→	←	Molecular		→
Structure	←	Extensive three-dimensional	→	←	Discrete molecular units		→
Melting point (°C)	1275	2800	2045	1610	580	16.8	−91.5
Boiling point (°C)	?	3600	2980	2230	?	44.8	82
Acid-base nature	Basic	Basic	Amphoteric	←	Acidic		→

Properties of Oxides Across a Period

- **Basic oxides:**

Na_2O and MgO are **basic** oxides,

$$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$$

$$MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$$

- **Amphoteric oxide:**

Al_2O_3 is an **amphoteric** oxide,

$$Al_2O_3(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2O(l)$$

$$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2NaAl(OH)_4(aq)$$

Other amphoteric oxides are, ZnO, BeO, and Bi_2O_3

Properties of Oxides Across a Period

- **Acidic oxides:**

SiO_2, P_4O_{10}, SO_3 and Cl_2O_7 are **acidic** oxides,

$$SiO_2(s) + 2NaOH(aq) \rightarrow Na_2SiO_3(aq) + H_2O(l)$$

$$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$$

$$SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$$

$$Cl_2O_7(l) + H_2O(l) \rightarrow 2HClO_4(aq)$$

- **Neutral oxides:**

Some oxides are **neutral**, CO and NO,
Do **not** react with water to produce acidic or basic solution

Lessons Learned

- How elements are arranged in the periodic table, their subdivisions and relation of position of elements in the periodic table to its electronic structures
- Metals vs. metalloids vs nonmetals
- Main group elements vs (outer) transition metals and inner transition metals
- Description of alkali metals, alkaline earth metals, halogens and noble gases
- Description of s-block elements, p-block elements, d-block elements and f-block elements

Lessons Learned

- Explain how the electrons are distributed in shells and subshells around the nucleus of an atom
- Know how many electrons can be found in each shell ($2n^2$), subshell and orbital
- Know the shapes, occurrence, number of lobes and orientations possible for each subshell type
- Draw a simple picture of lobe arrangements within a subshell.

Lessons Learned

- Write the electron configuration for simple elements and monatomic ions
- Construct dash-arrow diagrams to show the electron configurations of elements or ions
- Use Noble Gas core notation in electron configurations
- Draw Lewis structures of main group elements
- Predict periodic trends from an element's position in the periodic table