THE ATOM

Model: A nucleus: a dense central area made up of

- protons: p^+
- neutrons: n^o

A cloud of electrons around the nucleus: e^-

CHEM 1101 lecture will start on slide 13; slides 1-12 are for background.

protons: p^+

neutrons: n^o

IT IS THE NUMBER OF PROTONS IN THE NUCLEUS THAT DETERMINES ***WHAT KIND OF ATOM*** WE HAVE – ***WHAT ELEMENT*** IT IS.

ATOMIC NUMBER: Symbol Z

- the number of protons in the nucleus

PERIODIC TABLE: An organized list of all known elements, arranged in order of atomic number

- element names
- behaviour

Z

SYMBOL

name

average mass

IT IS THE NUMBER OF PROTONS IN THE NUCLEUS THAT DETERMINES ***WHAT KIND OF ATOM*** WE HAVE – ***WHAT ELEMENT*** IT IS.

ATOMIC NUMBER: The atomic number is all you need to define the element

Every element with Z = 8 is oxygen. There are NO EXEPTIONS.

Every atom of oxygen has Z = 8. There are NO EXEPTIONS.

8
O
oxygen
15.999

ATOM: by definition is **electrically neutral** (sure we can charge them, but they're not called atoms anymore!)

The protons are positively charged and the electrons are negatively charged (the neutrons are neutral)

so…there must be an equal number of protons (in the nucleus) and electrons (around it).

1
H
hydrogen
1.0079

Z is *defined* as the number of protons, but for an atom (neutral, by def'n) it is also the number of electrons.

ATOM: by definition is **electrically neutral** (sure we can charge them, but they're not called atoms anymore!)

26
Fe
iron
55.845

how many electrons are there in an atom of iron?

http://www.webelements.com/nexus/sites/default/files/webelements_table_5sf_2012-06-07.pdf

WebElements: the periodic table on the world-wide web

www.webelements.com

Key: element name / **atomic number** / **symbol** / atomic weight (mean relative mass)

1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.38	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.96	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [267]	dubnium 105 **Db** [268]	seaborgium 106 **Sg** [271]	bohrium 107 **Bh** [272]	hassium 108 **Hs** [270]	meitnerium 109 **Mt** [276]	darmstadtium 110 **Ds** [281]	roentgenium 111 **Rg** [280]	ununbium 112 **Uub** [285]	ununtrium 113 **Uut** [284]	ununquadium 114 **Uuq** [289]	ununpentium 115 **Uup** [288]	ununhexium 116 **Uuh** [293]	ununseptium 117 **Uus** —	ununoctium 118 **Uuo** [294]

*lanthanoids	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.06
**actinoids	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Symbols and names: the symbols and names of the elements, and their spellings are those recommended by the International Union of Pure and Applied Chemistry (IUPAC - http://www.iupac.org/). Names have yet to be proposed for the most recently discovered elements beyond 112 and so those used here are IUPAC's temporary systematic names. In the USA and some other countries, the spellings **aluminum** and **cesium** are normal while in the UK and elsewhere the common spelling is **sulphur.**
Group labels: the numeric system (1–18) used here is the current IUPAC convention.
Atomic weights (mean relative masses): Apart from the heaviest elements, these are the IUPAC 2007 values and given to 5 significant figures. Elements for which the atomic weight is given within square brackets have no stable nuclides and are represented by the element's longest lived isotope reported at the time of writing.

CHEM 1101 - BACKGROUND

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
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All atoms of a particular element have the same number of protons in the nucleus (Z).

Not all elements of a particular element have the same number of neutrons in the nucleus.

MASS NUMBER: Symbol A

- the total number of protons and neutrons in the nucleus

$$A = (p^{+} + n^{o})$$

7
N
nitrogen
14.007

ISOTOPES: Atoms of the same element (same Z) with different masses (different A)

ISOTOPES: Atoms of the same element (same Z) with different masses (different A)

There are three isotopes of carbon found naturally, but only two are found in any significant amount:

C with 6 neutrons A =
C with 7 neutrons A =

6
C
carbon
12.011

Full atomic symbol:

$$^{A}_{Z}X$$

ISOTOPES: Atoms of the same element (same Z) with different masses (different A)

Full atomic symbol:

$${}^{A}_{Z}X$$

- Full atomic symbol for carbon with 6 neutrons:

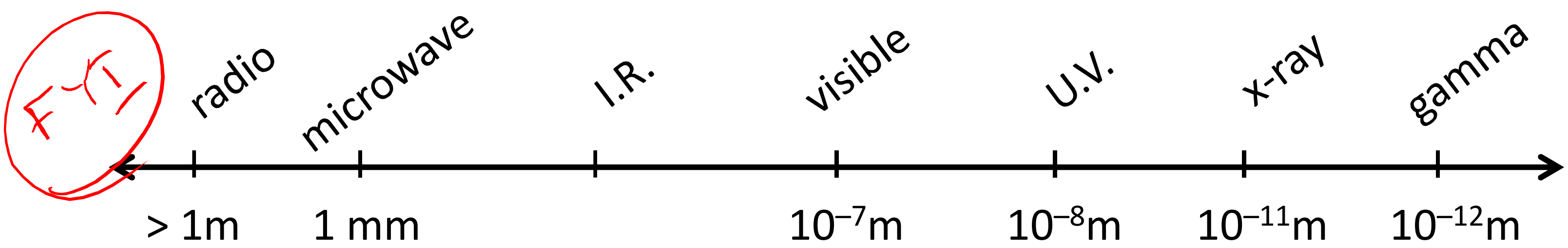
- can be ***written***:

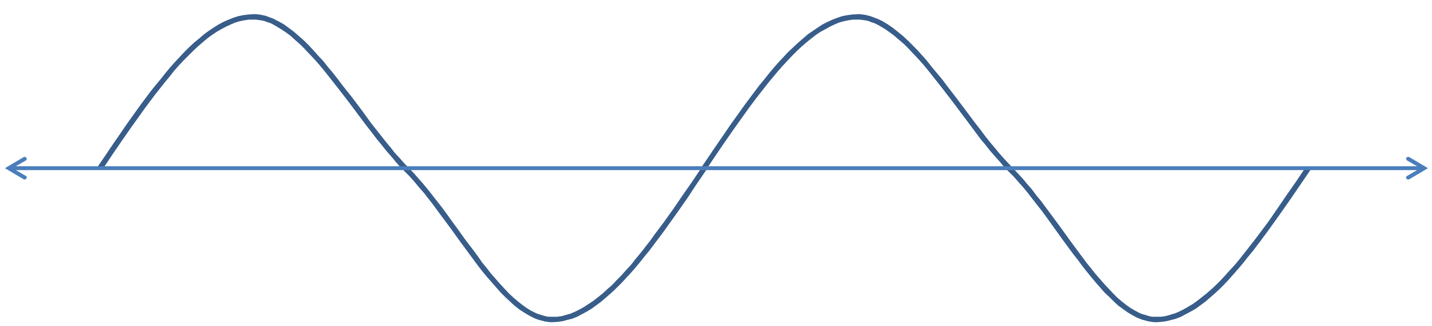
6
C
carbon
12.011

Studying the arrangement of the electrons in an atom – using

ELECTRO**M**AGNETIC **R**ADIATION – **EMR**

EMR: Light and both the lower energy and higher energy non-visible parts of the spectrum





Particle model of **EMR**

NOTE: To model EMR as waves or particles is an oversimplification, but for our purposes in studying the atom, thinking of EMR as made up of particles describes the phenomena relatively well, so we do it!

Photons: "Particle" of light, whose energy depends on the frequency or wavelength of the radiation.

If there is only one wavelength present all photons will have the same energy.

$$E = \frac{h \cdot c}{\lambda}$$

Particle model of **EMR**

If there is only one wavelength present all photons will have the same energy.

$$E = \frac{h \cdot c}{\lambda}$$

1 photon

4 SF

$h = 6.626 \times 10^{-34}\ \mathrm{J \cdot s}$ (measured)

$c = 3.00 \times 10^{8}\ \mathrm{m/s}$ (measured)

3 SF

Studying the Atom, Using EMR:

Photons may interact with the electrons of atoms, depending on their energy.

For a gas phase hydrogen atom – the photons in the visible range that interact are:

FYI

- 410 nm (violet)
- 434 nm (indigo)
- 486 nm (blue)
- 656 nm (red-orange)

$$E = \frac{h \cdot c}{\lambda}$$

Studying the Atom, Using EMR:

Photons may interact with the electrons of atoms, depending on their energy.

The nuclear model of the atom was already known, but this observation led to the idea of electrons having:

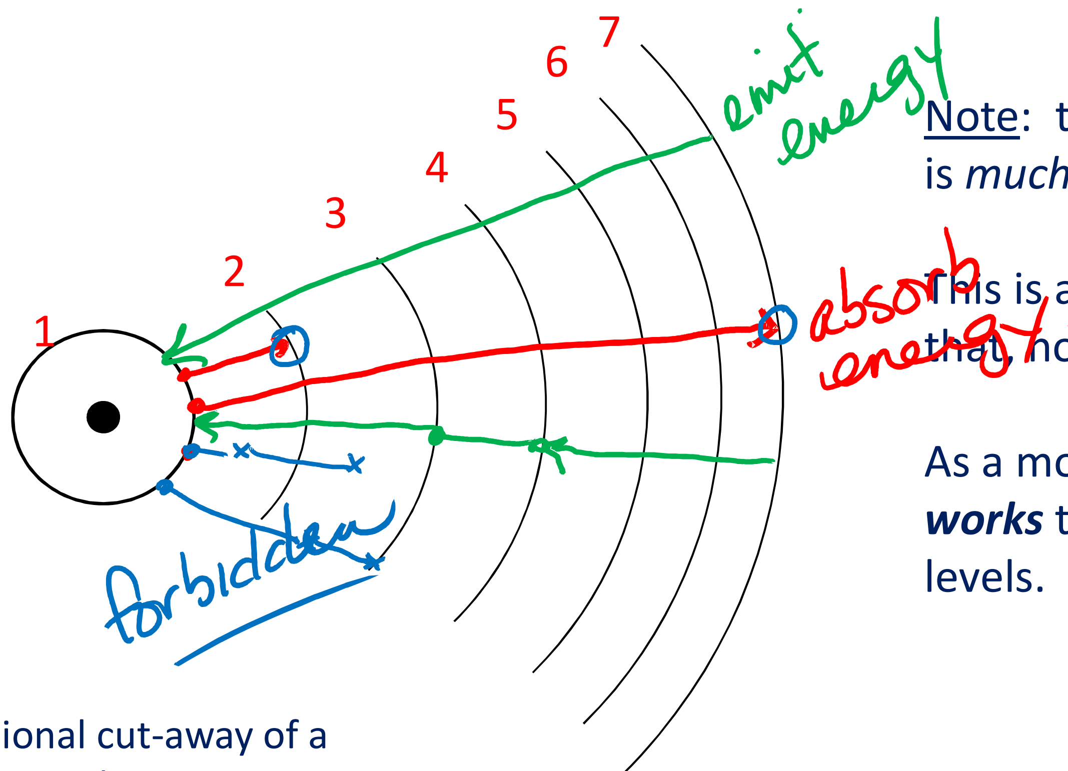
- Certain specific allowed energy states
- The ability to: * Absorb energy to move to higher states
  * Release energy to fall to lower states

$$E = \frac{h \cdot c}{\lambda}$$

Studying the Atom, Using EMR:

$$E = \frac{h \cdot c}{\lambda}$$

- Certain specific allowed energy states
- The ability to: Absorb energy to move to higher states
  Release energy to fall to lower states



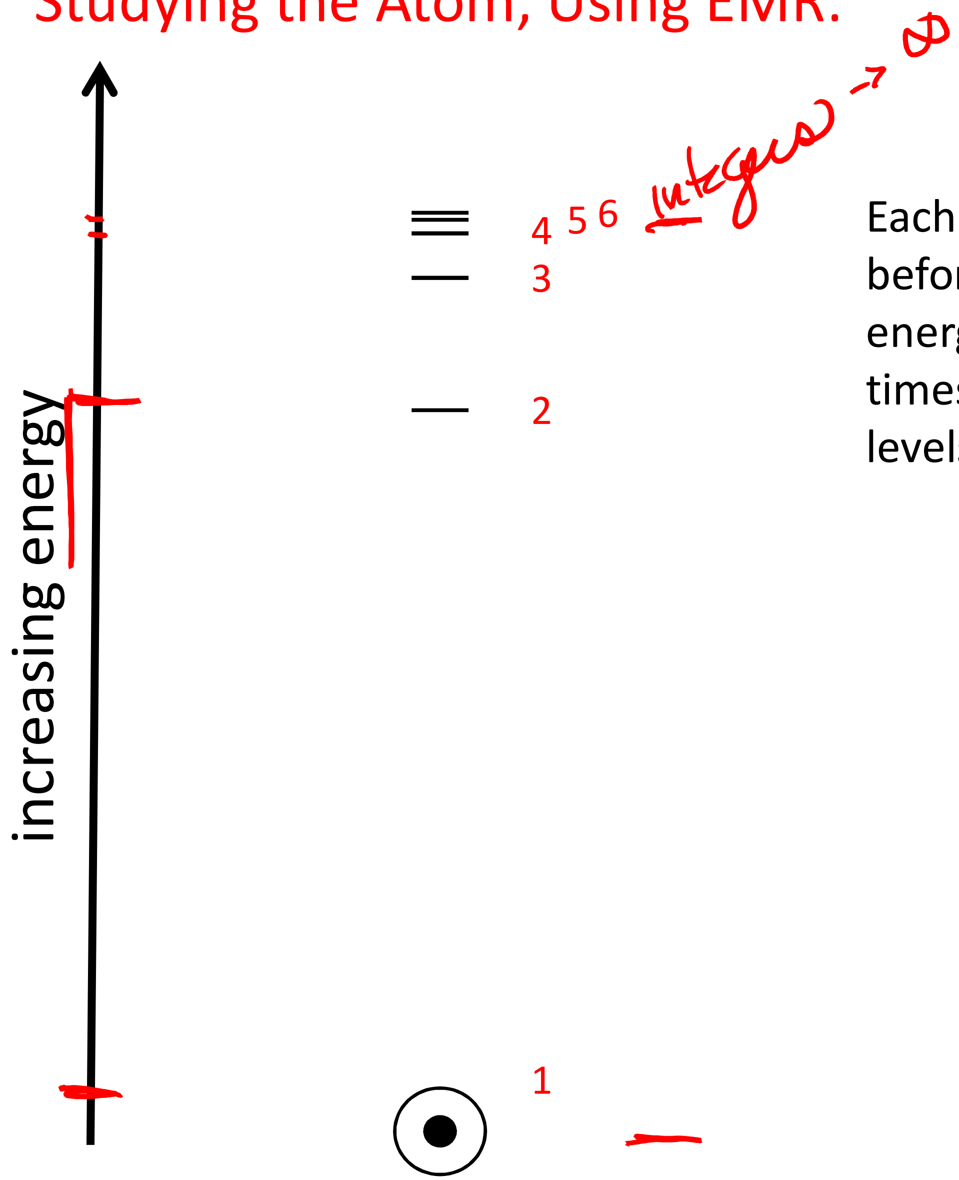
Two-dimensional cut-away of a three-dimensional picture.

Note: the modern picture is *much* more complex.

This is a starting point for that, no more.

As a model, however, ***it works*** to predict energy levels.

Studying the Atom, Using EMR:

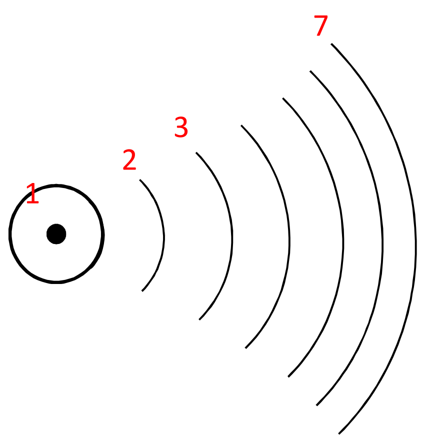


Each successive level is closer to the one before. The difference between the energy of levels 1 and 2 is more than five times larger than the difference between levels 2 and 3…

Studying the Atom, Using EMR: **Rydberg Equation**:

$$E = \frac{h \cdot c}{\lambda}$$

- Certain specific allowed energy states
- The ability to: Absorb energy to move to higher states
  Release energy to fall to lower states



The **energy gap** between the energy levels in a **hydrogen atom** can be described by an equation:

$$E_{gap} = R_H \,(1/n_i^2 - 1/n_f^2)$$

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

n_i: electron's initial level

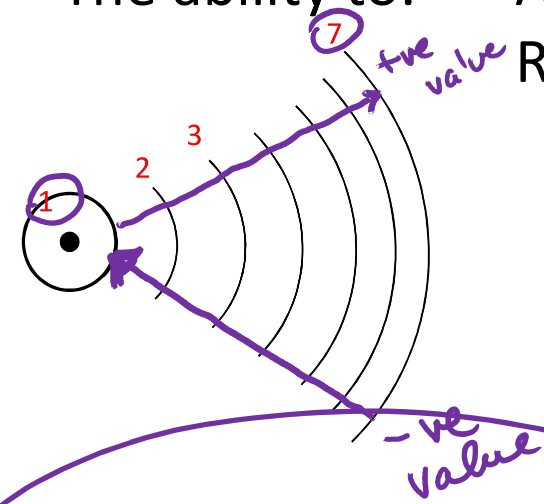
n_f: electron's final level

Note: you can relate the initial and final levels to wavelength (1/λ) and/or frequency (ν) as well as energy; you just use a different constant.

Studying the Atom, Using EMR: **Rydberg Equation**:

$$E = \frac{h \cdot c}{\lambda}$$

- Certain specific allowed energy states
- The ability to: Absorb energy to move to higher states
  Release energy to fall to lower states



$$E_{gap} = R_H\,(1/n_i^2 - 1/n_f^2)$$

Since the energy of the photon involved must be equal to the energy of the gap, this can also be written:

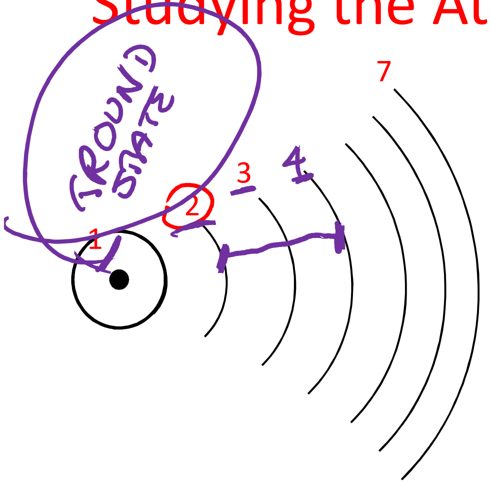
$$E_{photon} = R_H\,(1/n_i^2 - 1/n_f^2)$$

!

When the energy is positive, the photon is being absorbed by the atom.

When it is negative, the photon is being emitted (released) by the atom.

Studying the Atom, Using EMR: **Rydberg Equation**:



$$E = \frac{h \cdot c}{\lambda}$$

$$E = R_H \,(1/n_i^2 - 1/n_f^2)$$

R_H : 2.18 x 10^{-18} J

Calculate the energy required for a photon to promote an electron from the second to the fourth energy level in hydrogen:

$n_i = 2$

$n_f = 4$

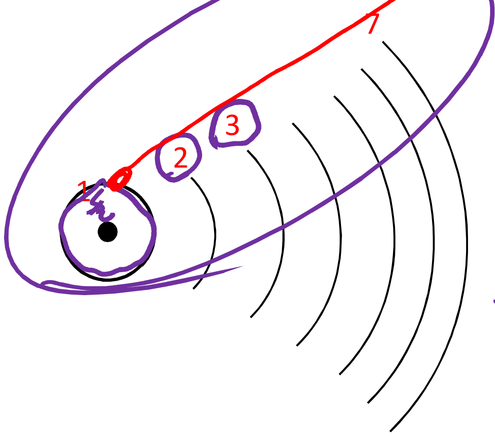
$E_{photon} = E_{2\to4} = (2.18 \times 10^{-18}\ J)\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$

$E_{2\to4} = [4.0875 \times 10^{-19}]$

$E_{photon} = 4.09 \times 10^{-19}\ J$

4.09 x 10^{-19} J

Studying the Atom, Using EMR: **Rydberg Equation**:



$$E = R_H\,(1/n_i^2 - 1/n_f^2)$$

R_H : 2.18 x 10^{-18} J

b) What will be the wavelength of the photon in nanometers?

$$E = \frac{h \cdot c}{\lambda}$$

$h = 6.626 \times 10^{-34}$ J · s

$c = 3.00 \times 10^{8}$ m/s

$E_{photon} = \frac{hc}{\lambda}$

$$\lambda = \frac{(6.626\times10^{-34}\ \text{J s})(3.00\times10^{8}\ \text{m/s})}{(4.0875\times10^{-19}\ \text{J})}$$

$= 4.86\times10^{-7}$ m

$= 486$ nm

$\frac{10^9\ \text{nm}}{1\ \text{m}}$

4.86 x 10^{-7} m

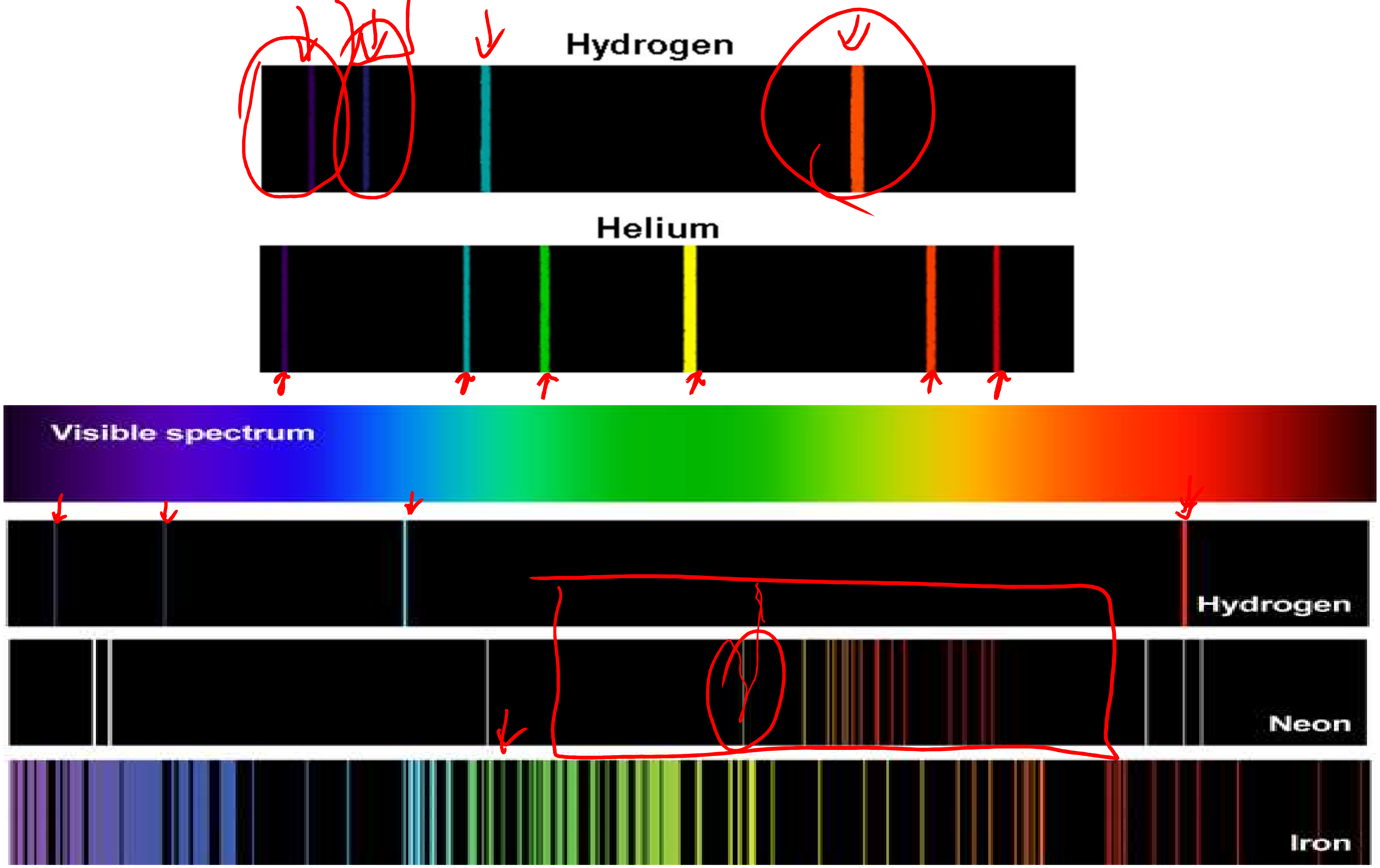
Studying the Atom, Using EMR: **Atoms other than hydrogen**:

Every atom has a characteristic emission/absorption spectrum.

Hydrogen is only unique in that we can build a mathematical equation to describe all of the emission levels.

For other atoms, we have not found a single relationship that describes the energy gaps.

Studying the Atom, Using EMR: **Atoms other than hydrogen**:



Photoelectric Effect:

When a beam of photons of sufficient energy strikes a collection of atoms of any element, electrons are emitted from the atoms.

From a chemical point of view:

- Take a gas-phase sample of an element
- shine EMR of relatively low energy into it
- increase the energy of the photons gradually
- note the point where electrons ***just start to appear*** outside the atom

e^{-} are coming out of the atom.

$$E = \frac{h \cdot c}{\lambda}$$

Photoelectric Effect:

$$E = \frac{h \cdot c}{\lambda}$$

- Take a **gas-phase** sample of an element
- shine EMR of relatively low energy into it
- increase the energy of the photons gradually
- note the point where electrons ***just start to appear***

What useful knowledge about the atom can this give you?

Ionization Energy.

Photoelectric Effect:

$$E = \frac{h \cdot c}{\lambda}$$

The photoelectric effect involves the collision of ONE photon with ONE electron.

- If you want to remove electrons from a dozen atoms – you'll need a dozen photons
- if you want to remove electrons from a mole of atoms – you'll need a mole of photons

Photoelectric Effect:

$$E = \frac{h \cdot c}{\lambda}$$

given

You find that EMR of wavelength of 155.8 nm is just sufficient to ionize silicon.

a) What is the ionization of a silicon atom?

b) What is the ionization energy of silicon, in kJ/mol?

for one mole of atoms

$$I.E._{atom} = E_{\text{of the photon that ionized it}} = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\ J\cdot s)(3.00\times10^{8}\ m/s)}{(155.8\times10^{-9}\ m)}$$

$$= [1.275866\times10^{-18}]$$

$$= 1.28\times10^{-18}\ J$$

$$\equiv 1.28\times10^{-18}\ J/atom$$

in context!

1.28 x 10^{-18} J

Photoelectric Effect: J/atom → kJ/mol

$$E = \frac{h \cdot c}{\lambda}$$

155.8 nm

$$1.275866 \times 10^{-18}\ \frac{J}{atom}\left(\frac{1\ kJ}{1000\ J}\right)\left(\frac{6.02 \times 10^{23}\ atom}{1\ mol}\right)$$

$= 768.0719\ldots = 768\ kJ/mol$

$(7.68 \times 10^{2}\ kJ/mol)$

768 kJ/mol

Photoelectric Effect – Work Function:

$$E = \frac{h \cdot c}{\lambda}$$

When a beam of photons of sufficient energy strikes a collection of atoms of any element, electrons are emitted from the atoms.

If a beam of photons strike a **solid surface**:

Work Function: The minimum energy required to remove an electron from a solid surface.

If you deliver this energy using photons, then if the incident photons have more energy than the work function of the material, the *excess energy* will be converted into *kinetic energy* of the ejected electrons. (Possible when the electron *leaves* the atom, but not when it moves from one state to another within an atom!)

(note: E_{photon} = **W** + **K.E.** is "**not an equation**". It's the definition of conservation of energy! It will not be "given".)

Photoelectric Effect – work function:

$$E = \frac{h \cdot c}{\lambda}$$

The work function of gallium metal is 417 kJ/mol.

a) What is the maximum wavelength of electromagnetic radiation that will cause electrons to be ejected from the surface of gallium metal?

b) If you use EMR of wavelength 225 nm, how much kinetic energy will the ejected electrons have?

Photoelectric Effect – work function:

$$E_{1\,photon} = \frac{h \cdot c}{\lambda}$$

The work function of gallium metal is 417 kJ/mol.

a) What is the maximum wavelength of electromagnetic radiation that will cause electrons to be ejected from the surface of gallium metal?

$w = E_{(min)}$ of photon $= 417$ kJ/mol

? 417 kJ/mol $= \frac{hc}{\lambda}$?

417×10^3 J/mol / 6.02×10^{23} atom/mol

6.9246097 x 10^{-19}

287

$E_{1\,photon} = 6.9269102 \times 10^{-19}$ J

$$6.9269102 \times 10^{-19}\,J = \frac{(6.626 \times 10^{-34}\,J \cdot s)(3.00 \times 10^8\,m/s)}{\lambda}$$

$\lambda = 2.869776 \times 10^{-7}$ m

$= 2.87 \times 10^{-7}$ m (= 287 nm)

Photoelectric Effect – work function:

$\lambda_{max} = 287 nm$ $$E = \frac{h \cdot c}{\lambda}$$

The work function of gallium metal is 417 kJ/mol.

b) If you use EMR of wavelength 225 nm, how much kinetic energy will the ejected electrons have?

b) $E_{TOTAL} = \frac{hc}{\lambda}$

8.8346666 x 10^{-19}
1.9100569 x 10^{-19}

$E_{just\ to\ remove} = (417\ kJ/mol) = 6.9269102 \times 10^{-19} J$

$E_{left\ over} = K.E. = E_{TOTAL} - \omega$

$= 1.91 \times 10^{-19} J$ left over for KE

m_e = 9.109 x 10^{-31} kg

$$E = \frac{h \cdot c}{\lambda}$$

Photoelectric Effect – work function:

$KE = \frac{1}{2}mv^2$

The work function of gallium metal is 417 kJ/mol.

bonus: How fast will the electrons be moving (assume they're in a vacuum and not interacting)?

1.907756×10^{-19} J = (0.5)(9.109×10^{-31} kg)v^2

KE = 1.9100569 x 10^{-19}

647 593.822 m/s

v_{e^-} = 6.47×10^5 m/s

FYI: 2 329 200 km/h