

# **BERKELEY MATH CIRCLE**

## **The Math of Chemistry**

### **The Make-up of Atoms I: Protons, Electrons & Neutrons**

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# The History & Make-Up of Atoms

## Atoms

Atoms are the basic building blocks for all objects in universe, and all elements discovered (or made) are made of different atoms (by elements, I mean "Carbon", Helium", Aluminum", etc.) The atom was originally thought to be smallest particle around, but then, discoveries of sub-atomic particles were made! We have:

1. Proton (+) = Defines the element!, positively charged, mass =  $1.7 \times 10^{-27}$  kilograms
2. Electron (-) = negatively charged, mass =  $9.1 \times 10^{-31}$  kilograms
3. Neutron = no charge, same mass as proton

+  
-

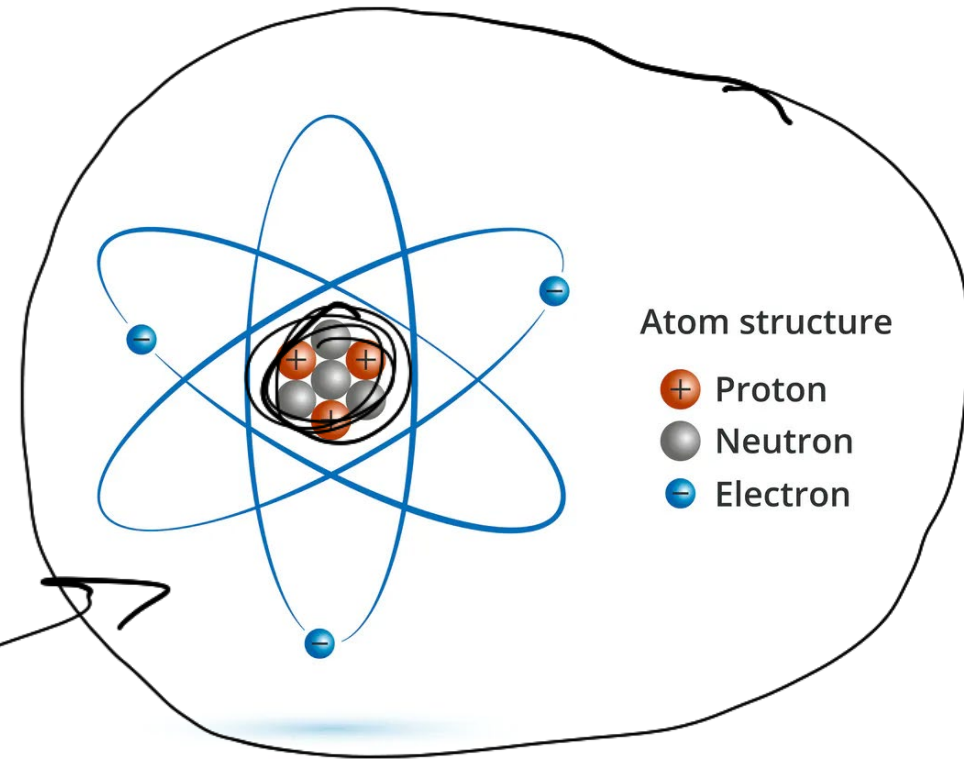
### Math Problem!

The electron's mass is considered negligible relative to the proton. Why? Show with examples or a proof.

$10^{-27}$  /  $10^{-31}$  =  $10^4$  = 10,000

### Atom Make-up

Protons & Neutron = exist in nucleus  
Electron = exist outside of the nucleus (more on this later)



# The History & Make-Up of Atoms

## Atoms

Atoms are the basic building blocks for all objects in universe, and all elements discovered (or made) are made of different atoms (by elements, I mean “Carbon”, Helium”, Aluminum”, etc.) The atom was originally thought to be smallest particle around, but then, discoveries of sub-atomic particles were made! We have:

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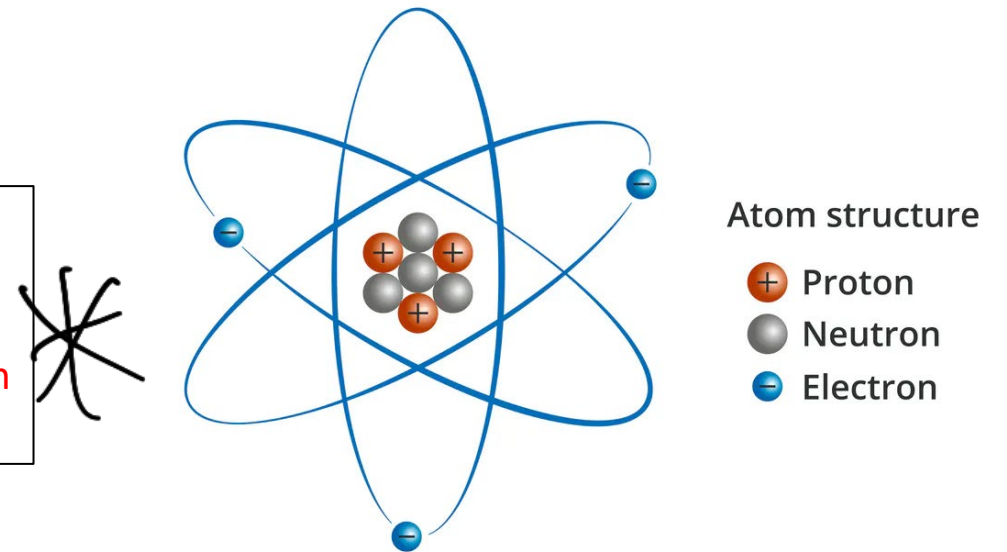
The electron’s mass is considered negligible relative to the proton. Why?  
Show with examples or a proof.

This is a COMPARATIVE size question, so we just use the exponents as a ratio to compare!  
 $10^{-27}$  vs  $10^{-31} \rightarrow 10^{-27} / 10^{-31} \rightarrow 10^{(-27-(-31))} = 10^{(-27+31)} = 10^4 = 10000$ . The proton is ten thousand times more massive than the electron!

## Atom Make-up

Protons & Neutron = exist in nucleus

Electron = exist outside of the nucleus (more on this later)



# The Periodic Table

Elements are organized into the Periodic Table of Elements. They are organized into columns by their similarities in chemical properties:

**Periodic Table of the Elements**

1 1A 11A																	18 VIII 8A
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.88	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.933	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.732	32 Ge Germanium 72.61	33 As Arsenic 74.922	34 Se Selenium 78.09	35 Br Bromine 79.904	36 Kr Krypton 84.80
37 Rb Rubidium 84.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.94	43 Tc Technetium 98.907	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.760	52 Te Tellurium 127.6	53 I Iodine 126.904	54 Xe Xenon 131.29
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.85	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.967	80 Hg Mercury 200.59	81 Tl Thallium 204.383	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium [208.982]	85 At Astatine 209.987	86 Rn Radon 222.018
87 Fr Francium 223.020	88 Ra Radium 226.025	89-103	104 Rf Rutherfordium [261]	105 Db Dubnium [262]	106 Sg Seaborgium [266]	107 Bh Bohrium [264]	108 Hs Hassium [269]	109 Mt Meitnerium [268]	110 Ds Darmstadtium [269]	111 Rg Roentgenium [272]	112 Cn Copernicium [277]	113 Uut Ununtrium unknown	114 Fl Flerovium [289]	115 Uup Ununpentium unknown	116 Lv Livermorium [298]	117 Uus Ununseptium unknown	118 Uuo Ununoctium unknown
57 La Lanthanum 138.906	58 Ce Cerium 140.115	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.24	61 Pm Promethium 144.913	62 Sm Samarium 150.36	63 Eu Europium 151.966	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930	68 Er Erbium 167.26	69 Tm Thulium 168.934	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967			
89 Ac Actinium 227.028	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.048	94 Pu Plutonium 244.064	95 Am Americium 243.061	96 Cm Curium 247.070	97 Bk Berkelium 247.070	98 Cf Californium 251.080	99 Es Einsteinium [254]	100 Fm Fermium 257.095	101 Md Mendelevium 258.1	102 No Nobelium 259.101	103 Lr Lawrencium [262]			

Alkali Metal

Alkaline Earth

Transition Metal

Semimetal

Nonmetal

Basic Metal

Halogen

Noble Gas

Lanthanide

Actinide

For each element, we can directly relate the amount of protons, electrons and neutrons that exist. But first, we need to learn some terms!

### Symbol of Element

1 or 2 letter abbreviation for each element

### Mass Number

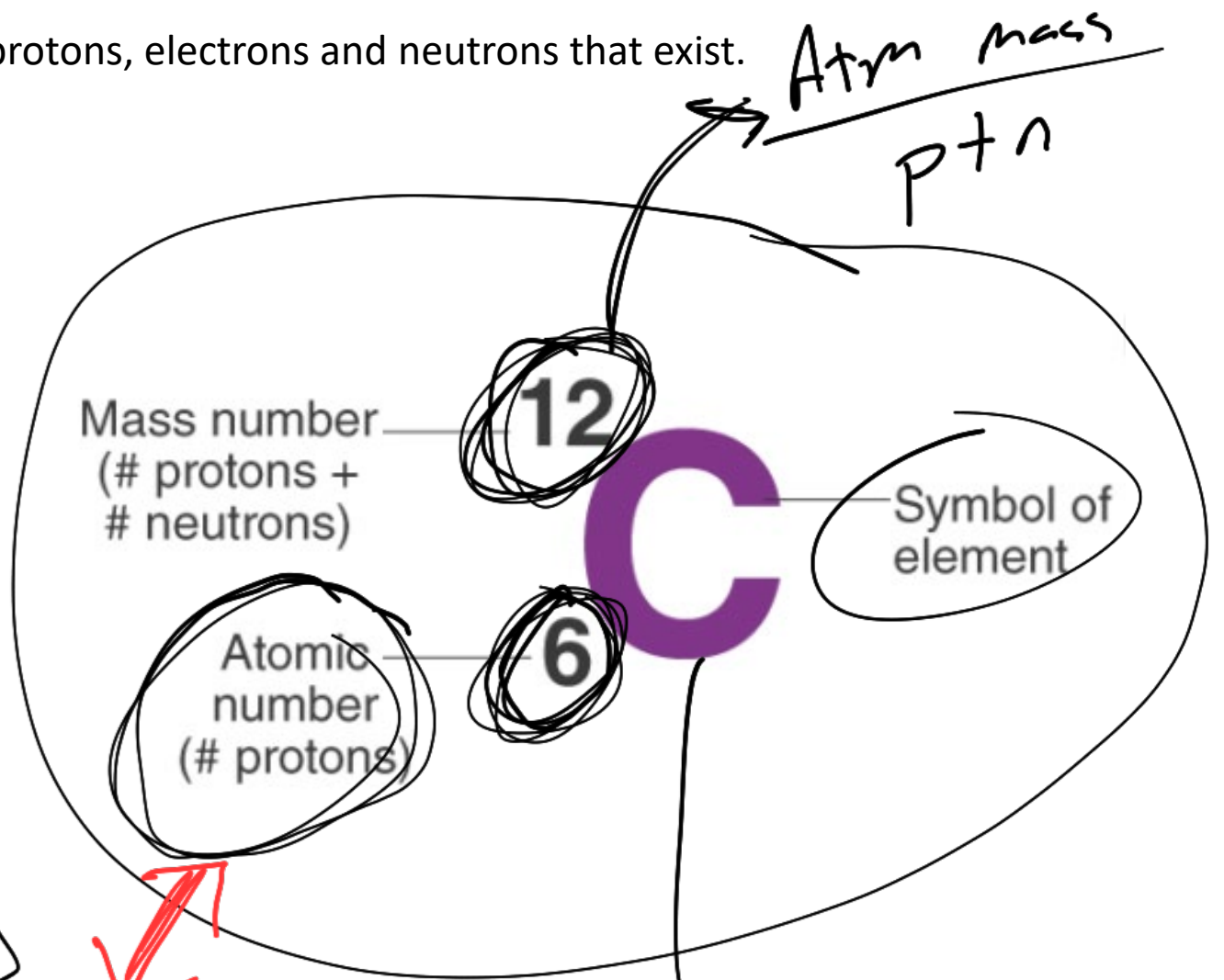
- Not always a whole number (more on this later!)
- #protons + #neutrons

### Atomic Number

#protons (defines the element!)

Thus,

- # of protons = atomic number (defines the element!)
- # of electrons = # of protons (if neutral)
- # of neutrons = Mass Number - Atomic number



Atm # = # of protons  
# e's = # of protons [ (-) = (+) ]

Carbon  
C

## Math Problem!

Using the provided periodic table, calculate the number of protons, electrons, and neutrons for each of the following:

1. Fluorine (F)
2. Iron (Fe)
3. Charged Oxygen ( $O^{-2}$ )
4. Chlorine (Cl)

1	2											3	4	5	6	7	0		
<b>H</b> lithium 3	<b>Be</b> beryllium 4											<b>B</b> boron 5	<b>C</b> carbon 6	<b>N</b> nitrogen 7	<b>O</b> oxygen 8	<b>F</b> fluorine 9	<b>He</b> helium 2		
<b>Li</b> lithium 3	<b>Be</b> beryllium 4											<b>Al</b> aluminium 13	<b>Si</b> silicon 14	<b>P</b> phosphorus 15	<b>S</b> sulfur 16	<b>Cl</b> chlorine 17	<b>Ar</b> argon 18		
<b>Na</b> sodium 11	<b>Mg</b> magnesium 12	<b>K</b> potassium 19	<b>Ca</b> calcium 20	<b>Sc</b> scandium 21	<b>Ti</b> titanium 22	<b>V</b> vanadium 23	<b>Cr</b> chromium 24	<b>Mn</b> manganese 25	<b>Fe</b> iron 26	<b>Co</b> cobalt 27	<b>Ni</b> nickel 28	<b>Cu</b> copper 29	<b>Zn</b> zinc 30	<b>Ga</b> gallium 31	<b>Ge</b> germanium 32	<b>As</b> arsenic 33	<b>Se</b> selenium 34	<b>Br</b> bromine 35	<b>Kr</b> krypton 36
<b>Rb</b> rubidium 37	<b>Sr</b> strontium 38	<b>Y</b> yttrium 39	<b>Zr</b> zirconium 40	<b>Nb</b> niobium 41	<b>Mo</b> molybdenum 42	<b>Tc</b> technetium 43	<b>Ru</b> ruthenium 44	<b>Rh</b> rhodium 45	<b>Pd</b> palladium 46	<b>Ag</b> silver 47	<b>Cd</b> cadmium 48	<b>In</b> indium 49	<b>Sn</b> tin 50	<b>Sb</b> antimony 51	<b>Te</b> tellurium 52	<b>I</b> iodine 53	<b>Xe</b> xenon 54		
<b>Cs</b> caesium 55	<b>Ba</b> barium 56	<b>La*</b> lanthanum 57	<b>Hf</b> hafnium 72	<b>Ta</b> tantalum 73	<b>W</b> tungsten 74	<b>Re</b> rhenium 75	<b>Os</b> osmium 76	<b>Ir</b> iridium 77	<b>Pt</b> platinum 78	<b>Au</b> gold 79	<b>Hg</b> mercury 80	<b>Tl</b> thallium 81	<b>Pb</b> lead 82	<b>Bi</b> bismuth 83	<b>Po</b> polonium 84	<b>At</b> astatine 85	<b>Rn</b> radon 86		
<b>Fr</b> francium 87	<b>Ra</b> radium 88	<b>Ac*</b> actinium 89	<b>Rf</b> rutherfordium 104	<b>Db</b> dubnium 105	<b>Sg</b> seaborgium 106	<b>Bh</b> bohrium 107	<b>Hs</b> hassium 108	<b>Mt</b> meitnerium 109	<b>Ds</b> darmstadtium 110	<b>Rg</b> roentgenium 111	Elements with atomic numbers 112 – 116 have been reported but not fully authenticated								

**Key**  
relative atomic mass  
atomic symbol  
name  
atomic (proton) number

① # of protons  
② # of electrons  
③ # of neutrons

\* The Lanthanides (atomic numbers 58 – 71) and the Actinides (atomic numbers 90 – 103) have been omitted.  
Relative atomic masses for **Cu** and **Cl** have not been rounded to the nearest whole number.

**Solutions**

Fluorine (F)

19 = atm mass  
9 = atm number

# of protons = 9

# of e<sup>-</sup>s = 9

# of neutrons ⇒

atm mass = p + n

19 = 9 + n

n = 10

# of protons  
DEFINE  
the  
element

Iron (Fe)

Atm # = 26

Atm mass = 56

# of protons = 26 p<sup>+</sup>'s

# of electrons = 26 e<sup>-</sup>'s

# of neutrons = 56 - 26 = 30 neutrons

Charged Oxygen (O<sup>-2</sup>)

oxygen ⇒ -2 charge

# of protons = 8

# of electrons = 10

# of neutrons ⇒ 16 - 8 = 8

Chlorine (Cl)

protons = 17

electrons = 17

neutrons = 35.5 - 17  
= 18.5

\* Is there more than one answer possible for #3? Why or Why not?

What do you notice about Chlorine?

1/2 neutron ????

## **Solutions**

### **Fluorine (F)**

Protons = atm # = 9

Neutrons:  $19 - 9 = 10$  neutrons

Electrons = protons = 9

### **Iron (Fe)**

Protons = atm # = 26

Neutrons:  $56 - 26 = 30$  neutrons

Electrons = protons = 26

### **Charged Oxygen (O<sup>-2</sup>)**

Protons = atm # = 8

Neutrons:  $16 - 8 = 8$  neutrons

*2 more electrons = 10 electrons*

### **Chlorine (Cl)**

Protons = 17

Neutrons:  $35.5 - 17 = 18.5$  neutrons

Protons = atm # = 17

### **Is there more than one answer possible for #3? Why or Why not?**

Mathematically yes, BUT if the proton number changes, then we no longer have Oxygen, so there is only the one answer possible (above).

### **What do you notice about Chlorine?**

$\frac{1}{2}$  neutron! Is that possible? No, so see next page ;)