Conceptual Physics
Matter
Atoms

Lana Sheridan

De Anza College

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Last time

- projectile motion
- orbits
- escape speed
- heliocentric model
- Kepler's laws
- review

Overview

- matter
- atoms
- elements
- atomic structure
- charge

Dividing Matter

What happens when you cut a loaf of bread in half and then in half again, and again, and again...?

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Can you just keep cutting bread forever?

Or is there some smallest bit of bread, that you can't cut further?

Or at some point, does it stop being bread?

Some History

People have speculated on the underlying nature of matter for far longer than there has been good evidence to decide the question.

Ancient Greece:

- Plato (c. 427-c. 347 BCE) thought there were 4 basic kinds of corpuscles, each in a different geometric shape
- Aristotle (sometime before 330 BCE) decided that the 4 basic elements (earth, water, fire, air) were continuous
- Democritus, Leucippus, and Epicurus ($\sim$ 500-270 BCE) believed all matter was composed of small indivisible particles and that there was empty space, "void", in between them to allow for motion

Ancient Rome:

- Lucretius observed that everything decays, but that everything can also be reconstituted, suggesting that there are underlying building blocks of matter that are eternal.

Some History

Ancient India:

- thinking about atomic concepts seems to have sprouted from reasoning about linguistics in India
- *anor* (atom) is mentioned in the Bhavagad Gita (∼500-200 BCE)
- Nyaya-Vaisesika school developed an early idea about atoms (∼600-0 BCE) and how they combine
- Buddhist school (prior to ∼400 BCE?) had a concept of 4 kinds of atoms very similar to Aristotle's idea of 4 elements
- Jaina school (600-500 BCE) conceived of atoms as the basic building blocks of matter, and had some concepts of sub-atomic constituents

Some History

Later thinkers in the Middle East were influenced by Greek and Indian ideas.

In Europe philosophers were exposed to Greek and Roman ideas, with Aristotle's continuous matter idea very popular for a long time.

Nevertheless, ideas about "corpuscles" (small particles) were important for Newton and his contemporaries.

A chemist, Robert Boyle (1627-1692) speculated that if atoms / corpuscles made up matter, that much resolve problems arising in chemistry.

He proved correct.

Understanding from Chemical Reactions

John Dalton, a physicist and chemist in ~1803 started trying to understand the patterns of chemical reactions.

Dissociating pure water:

$$\text{water} \longrightarrow \text{oxygen} + \text{hydrogen}$$

and always hydrogen and oxygen were produced in the same proportions!

This lead him to suppose that

- matter was composed of atoms
- chemical substances that could not be dissociated were **elements**
- chemical substances that could be dissociated were formed from combinations of atoms

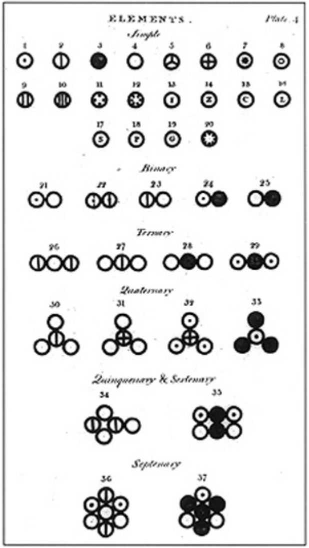
Understanding from Chemical Reactions

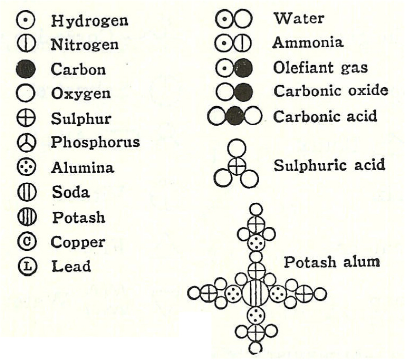
Rules of Dalton's theory[1]:

- Elements are made of extremely small particles called atoms.
- Atoms of a given element are identical in size, mass, and other properties; atoms of different elements differ in size, mass, and other properties.
- Atoms cannot be subdivided, created, or destroyed.
- Atoms of different elements combine in simple whole-number ratios to form chemical compounds.
- In chemical reactions, atoms are combined, separated, or rearranged.

[1] Wikipedia, Dalton, "A New System of Chemical Philosophy" (1808)

Understanding from Chemical Reactions





[1]Images from Dalton, "A New System of Chemical Philosophy" (1808) and Wikimedia.

Elements

Group→ ↓Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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	*	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	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
		*	57 La	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	
		**	89 Ac	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	

Brownian Motion

In 1827 Robert Brown, a botanist, observed pollen grains suspended in water through a microscope.

He expected to see them suspended at rest, but did not.

Instead the grains of pollen seemed to jump and wiggle about for no discernible reason.

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Instead the grains of pollen seemed to jump and wiggle about for no discernible reason.

He wondered if it was something peculiar that pollen did so he tried again with dust and soot – and saw the same thing!

This motion is called **Brownian Motion**.

Brownian Motion

Brownian motion remained a mystery until 1905.

Einstein, building on tools he had just developed in his doctoral thesis, developed a theory describing Brownian motion.

It is the result of fast-moving water molecules (too small to see) colliding with the pollen molecules, and jostling them.

About Atoms

Facts about atoms:

- atoms are very small: $\sim 10^{-10}$ m
- there are 10^{23} in just a gram of water!
- they move around when not at absolute zero temperature (which is always)
- atoms of heavier elements are formed in stars. Most atoms are very stable and therefore almost as old as the universe.

Electric Charge

Charge is an intrinsic (essential) property of subatomic particles.

Charge can be positive or negative.

Particles can also be "chargeless", ie. have zero net charge.

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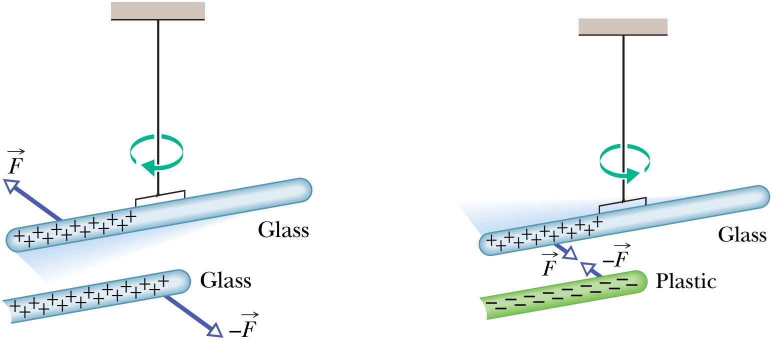
Static electric charge can be experienced on a large scale through static electricity.

Charge on larger objects

Most large objects around us have (approximately) zero net charge.

Objects can become charged when rubbed against one another.



[1]Diagrams from Halliday, Resnick, Walker, 9th ed.

Electrostatic force

Charged objects exert a force (the electrostatic force) on one another.

Charges with the **same** electrical sign **repel** each other.

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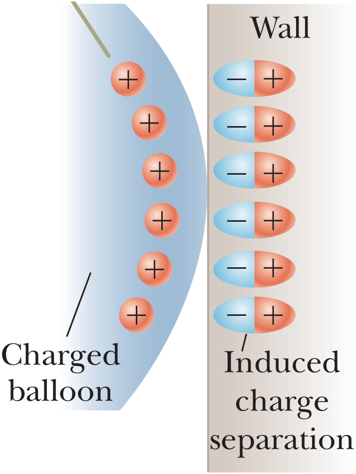
The unit for charge is the Coulomb, written with the symbol C.

Induced Charge Polarization



Charged objects can also be attracted to neutrally-charged objects because neutral objects are composed of charged particles.

[1] Fig from Serway & Jewett, "Physics for Scientists and Engineers", 9th ed.

Fundamental Unit of Charge

The smallest unit of charge is called e.

$$e = 1.602 \times 10^{-19}\ \text{C}$$

Electrons

Electrons are tiny negatively charged particles.

J.J. Thompson is credited with their discovery, because he determined their charge and mass, which showed that they were not a kind of charged atom of molecule, but a new kind of particle.

Symbol: e^-

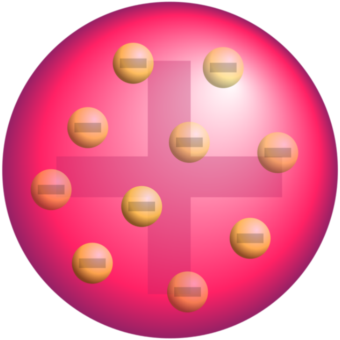
Negatively charged: charge $-e$

Very low mass: 9.11×10^{-31} kg

Atomic Structure

Thompson knew that electrons could be extracted from atoms. The remaining portion of the atom was positively charged.

He developed a model of what the atom could look like, called the Thompson Model or the Plum Pudding Model.



[1]Left: whatscookingamerica.net/Cake/plumpuddingTips.htm;
Right: www.boundless.com/physics/textbooks/boundless-physics-textbook

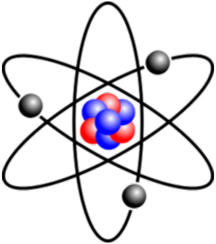
Atomic Structure

Because of an experiment by Rutherford, Geiger, and Marsden, we know that Thompson's model is not correct.

There are other kinds of particles in atoms also.

Atoms are made up of subatomic particles:

- protons
- neutrons
- electrons



Atoms of different elements have different numbers of protons.

[1]Figure from Wikipedia.

Protons

Symbol: p (or p^+)

Positively charged: charge $+e$

Much larger mass than an electron: 1.673×10^{-27} kg

Protons

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Positively charged: charge $+e$

Much larger mass than an electron: 1.673×10^{-27} kg

This is 1837 times the mass of the electron!

Neutrons

Symbol: n (or n^0)

The neutron has no electric charge. (It is neutral.)

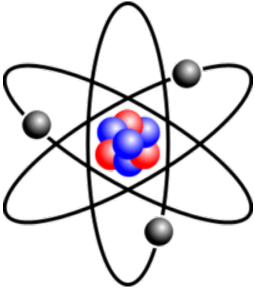
Very similar mass to a proton: 1.675×10^{-27} kg. (Just slightly heavier.)

Atomic Structure

Atoms have a compact nucleus composed of **protons** and **neutrons**.

The nucleus therefore has an overall positive charge.

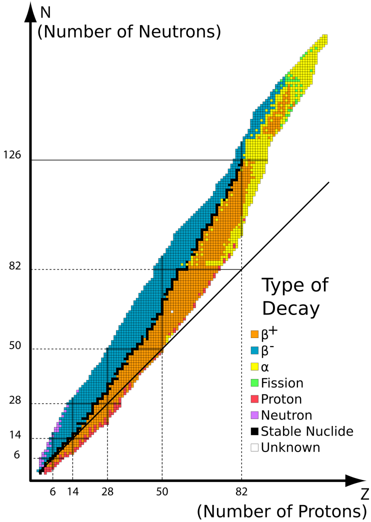
A cloud of electrons surrounds the nucleus, attracted by the electrostatic force.



[1]Figure from Wikipedia.

Nuclei

Usually, atoms have a similar number of neutrons to the number of protons in their nuclei.



[1] Figure from UC Davis ChemWiki.

Kinds of Atoms

Atoms are neutral (net charge 0), so each atom has the same number of protons and electrons.

The atomic mass is the sum of the number of protons and neutrons ($\times 1.67 \times 10^{-27}$ kg). Electrons can be neglected because they have so little mass.

Kinds of Atoms

Element	# Protons/Electons	# Neutrons	Atomic Mass
Hydrogen	1	0	1
Helium	2	2	4
Lithium	3	4	7
Berylium	4	5	9
Boron	5	6	11
Carbon	6	6	12
Nitrogen	7	7	14
Oxygen	8	8	16
Fluorine	9	10	19
Neon	10	10	20

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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
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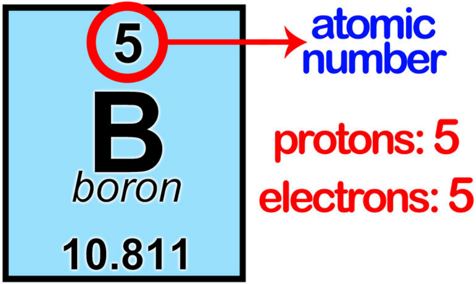
How to read each element square



[1]Diagram from WikiPhoto, WikiHow

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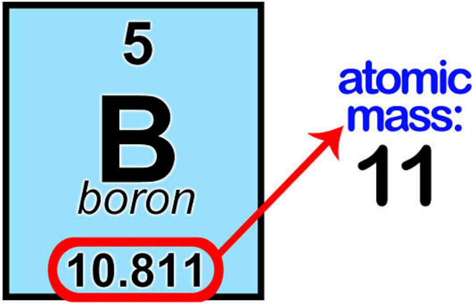

Boron has a mass of 11 amu or "atomic mass units".

1 amu $= 1/12$ of the mass of one carbon atom.

[1]Diagram from WikiPhoto, WikiHow

Summary

- matter
- atoms
- atomic structure
- elements

Homework

- charge worksheet (see website or course studio)

Hewitt,

- Ch 11, onward from page 211. Ranking: 1; Exercises: 1, 9, 11, 13, 15, 17, 21, 27
- Ch 22, onward from page 403. Exercises: 3.