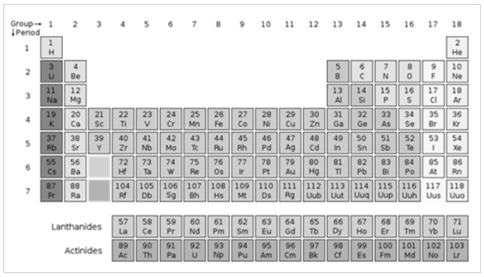
Lecture 5:
The Chemical Revolution and the Nature of Matter



Astronomy 141 – Winter 2012

This lecture explores the chemical revolution that revealed the nature of matter.

Trace the history of our recognition of the true nature of the chemical elements.

Advances made possible by new experimental techniques.

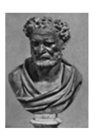
Periodic Table was an important organizing principle that gave further important insights.

Spectroscopy reveals the internal structure of atoms, and gives us a powerful tool for measuring the universe.

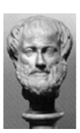
The elements that make up the Earth and life are common throughout the Universe.

The ancient Greeks conceived of matter as composed of 4 elements: Earth, Air, Fire and Water

Two main schools of thought:



Atomists (Leucippus & Democritus)
- Elements made of indivisible tiny "atoms"
- Same matter in the heavens as on the Earth



Aristotelians
- 4 Elements only found on the Earth
- Heavens were composed of Aether ("fifth essense")

In the Middle Ages, alchemists added new elements to the 5 classical elements.

Paracelsus (15th century):
Sulfur, Mercury, and Salt.

Later additions of specific metals, like Gold, Silver, and Lead.

Sought to transform one element into another (transmutation)

Joseph Wright – *The Alchemist* (1771)

Antoine Lavoisier (1743-1794) was the first quantitative chemist.

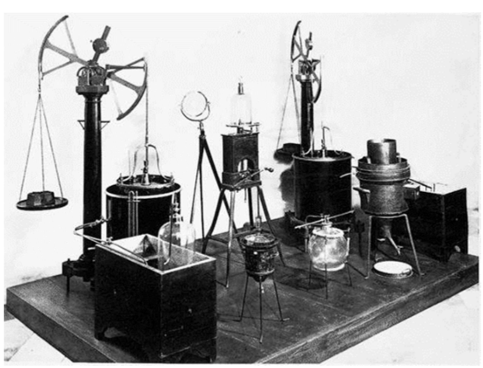
Described 33 distinct chemical elements, including Hydrogen and Oxygen.

These elements were *immutable*.

Compounds were combinations of these elements.

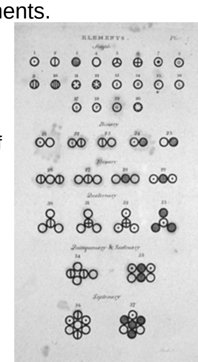
Performed detailed, quantitative experiments that mark the birth of modern Chemistry.

David – *Lavoisier and his wife* (1788)



Some of Lavoisier's experimental apparatus

John Dalton (1766-1844) introduced a new atomic theory to explain the elements.

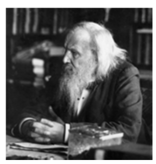


Each chemical element is composed of atoms of a single, unique type.

They cannot be changed or destroyed by chemical means.

They can combine to form compounds from simple to complex.

Dmitri Mendeleev (1834 – 1907) found patterns in the properties of elements.



In 1869, he arranged 67 known elements by weight and bonding type, noting repeating patterns.

The result was the first **periodic table**.

Reihen	Gruppe I. — R^2O	Gruppe II. — RO	Gruppe III. — R^2O^3	Gruppe IV. RH^4 RO^2	Gruppe V. RH^3 R^2O^5	Gruppe VI. RH^2 RO^3	Gruppe VII. RH R^2O^7	Gruppe VIII. — RO^4
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	—=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59, Ni=59, Cu=63.
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	?Yt=88	Zr=90	Nb=94	Mo=96	—=100	Ru=104, Rh=104, Pd=106, Ag=108.
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	?Di=138	?Ce=140	—	—	—	— — — —
9	(—)	—	—	—	—	—	—	
10	—	—	?Er=178	?La=180	Ta=182	W=184	—	Os=195, Ir=197, Pt=198, Au=199.
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	—	—	
12	—	—	—	Th=231	—	U=240	—	— — — —

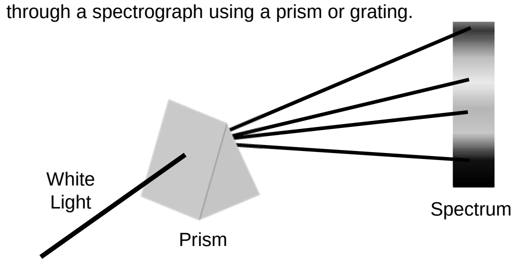
Modern Periodic Table of the Elements

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 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

Lanthanides	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
Actinides	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

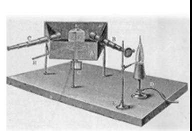
Spectroscopy is a technique for sorting light from a source by its component colors.

Spectra are observed by passing light from a source through a spectrograph using a prism or grating.



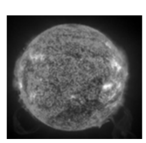
Each Element has a unique emission-line spectrum

Spectroscopy was a powerful tool that revealed new elements



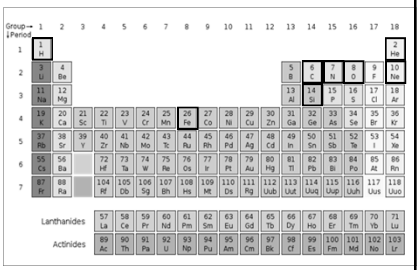
Kirchhoff & Bunsen discovered the elements cesium & rubidium using spectroscopy.

Helium was discovered in the spectrum of the Sun before it was identified on Earth (1895)!



The Eight Most Abundant Elements in the Universe are…

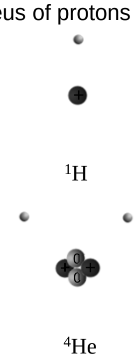
Hydrogen
Helium
Oxygen
Carbon
Neon
Nitrogen
Silicon
Iron



The main elements of life on Earth are **C**, **H**, **O**, and **N**.

The Earth itself is mostly made of **Fe**, **O**, and **Si**.

Atoms are composed of a heavy nucleus of protons and neutrons orbited by electrons.



Nucleus of heavy subatomic particles:
proton: positively charged
neutron: uncharged (*neutral*)

Electrons orbiting the nucleus:
Negatively charged particles with 1/1836th the mass of a proton

Atoms are mostly empty space:
Only 1 part in 10^{15} of the space is occupied
The rest is threaded by electromagnetic fields

The chemical elements are distinguished by the *number of protons* in the nucleus.

Called the <u>Atomic Number</u> of the element:

1 proton = Hydrogen

2 protons = Helium

3 protons = Lithium ... and so on

Proton

Neutron

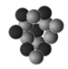
Number of electrons = Number of protons

An element can have one or more *Isotopes* with different numbers of neutrons

Example:

^{12}C has 6 protons and 6 neutrons 

^{13}C has 6 protons and *7* neutrons 

^{14}C has 6 protons and *8* neutrons 

All isotopes of a given element are chemically identical, but they have *different* atomic masses.

If a nucleus has too many or too few neutrons, it is unstable to *radioactive decay*

Examples:

^{3}H (1p+2n) $\rightarrow$ ^{3}He (2p+1n) + $e^- + \nu_e$

^{14}C (6p+8n) $\rightarrow$ ^{14}N (7p+7n) + $e^- + \nu_e$
(basis of radioactive carbon dating)

Free neutrons are also *unstable*:

$$n \rightarrow p + e^- + \nu_e$$

Radioactivity is characterized by the *Half-Life*: the time for half the atoms in a sample to decay.

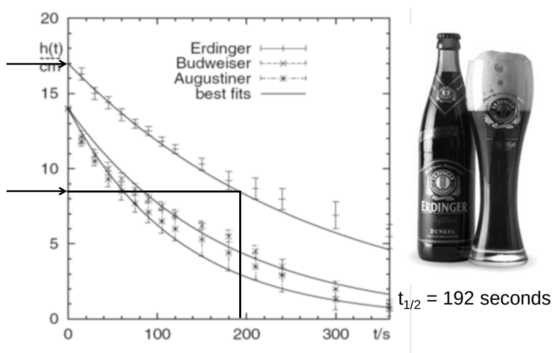
The *more* radioactive an element, the *shorter* the half-life.

Examples:

$^{3}H \rightarrow {}^{3}He + e^- + \nu_e$: half-life = 12.26 years

$^{14}C \rightarrow {}^{14}N + e^- + \nu_e$: half-life = 5730 years

$n \rightarrow p + e^- + \nu_e$: half-life = 12 minutes



From A. Leike, "*Demonstration of the Exponential Decay of Beer Froth*", 2002, Eur.J.Phys., 23, 21-26.

Spectroscopy of stars and planets reveals that they are made of the same elements found on Earth.

Not only do the same physical laws apply to other stars and planets…

The stars and planets are made out of the *same elements* as the Earth (though with a wide variation in proportions).

This means that lessons about chemistry on Earth will apply to other worlds.