Boston QuarkNet Workshop
Photons:
Numbering the Elements

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The effort to identify and enumerate the elements that make up all visible things has a long history …

- Chinese – Earth, Wood, Metal, Water, Fire
- Greeks – Thales (*c*. 600 BCE) → water
  Anaximander (*c*. 550 BCE) → air
  Heraclitus (*c*. 500 BCE) → fire
  Empedocles (*c*. 450 BCE) → Earth, Water, Air, Fire
  Plato (*c*. 400 BCE) → Earth, Water, Air, Fire
  Aristotle (*c*. 350 BCE) → Earth, Water, Air, Fire, Quintessence
- Paracelsus (1493-1541), an alchemist and physician advocated mercury, sulfur, salt as fundamental principles of all matter.

Robert Boyle (1627 – 1691)

- *The Sceptical Chymist* (1661)
- Matter consists of corpuscles (small bodies) in motion.
- “I now mean by Elements … perfectly unmingled bodies.”
- But no visible substances are elements. All observed bodies are compounds.

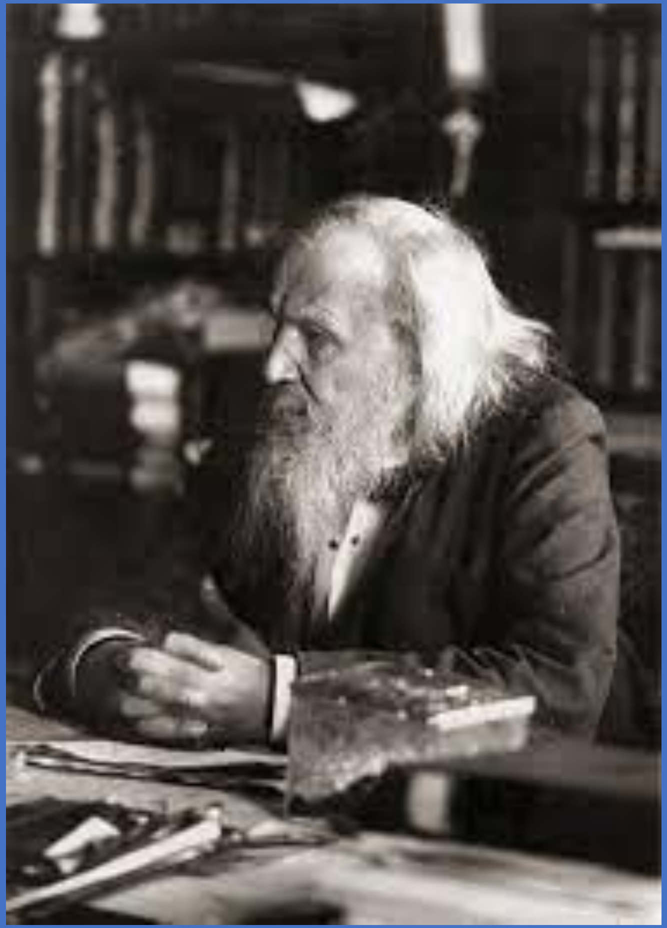
Antoine Lavoisier (1743 – 1794)

- *Elements of Chemistry* (1789)
- Lavoisier established the conservation of mass in chemical reactions
- Chemical element is a substance that cannot be separated into simpler substances by ordinary chemical processes.
- List of 3 gaseous elements, 6 non-metallic solids, 17 metals, 5 ”earthy substances”, plus light and caloric

John Dalton 1766 – 1844)

- 1808 – In *A New System of Chemical Philosophy*, Dalton listed 20 elements and 17 molecules of simple compounds, *e. g.* water, ammonia, composed of elemental atoms.
- Dalton developed a list of relative atomic weights from hydrogen (1) to mercury (167) based on his ideas of compounds and chemical analysis of elements in compounds.

Dmitri Mendeleev (1834-1907)



- 1869 – Mendeleev published a table of 64 elements, increasing in relative atomic mass and organized by similar chemical properties.
- 1871 – revised table included several blank spots for undiscovered elements, including three for which he predicted atomic mass and chemical properties

Mendeleev's Periodic Table

MENDELÉEFF'S TABLE I.—1871.

Series.	GROUP I. R_2O.	GROUP II. RO.	GROUP III. R_2O_3.	GROUP IV. RH_4. RO_2.	GROUP V. RH_3. R_2O_5.	GROUP VI. RH_2. RO_3.	GROUP VII. RH. R_2O_7.	GROUP 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, Ce=59 Ni=59, Cu=63
5	(Cu=63)	Zn=65	—=68	—=72	As=75	Se=78	Br=80	
6	Rb=85	Sr=87	? Y=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	I=127	
8	Cs=133	Ba=137	? Di=138	? Ce=140	....	....	....	....
9	....	....	....	....	....	....	....	....
10	....	....	? Er=178	? La=180	Ta=182	W=184	....	Os=195, In=197 Pt=198, Au=199
11	(Au=199)	Hg=200	Tl=204	Pb=207	Bi=208	....	....	
12	....	....	....	Th=231	....	U=240	....	....

- Mendeleev's "eka-aluminum" purified in 1875:
  Ga (gallium) M = 69.7
- Mendeleev's "eka-silicon" isolated in 1886:
  Ge (germanium) M = 72.6
- Mendeleev's "eka-boron" identified by spectrum in 1879, separated in 1937:
  Sc (scandium) M = 45.0

More Elements Discovered

- 1870s, 1880s – 11 new elements discovered, primarily from the Lanthanide "rare earth" series
- 1890s – Noble gases discovered, Ar in 1894, Kr, Ne, Xe in 1898, Rn in 1899
- Radioactive elements discovered in 1890s and early 1900s
- Are there undiscovered elements lighter than H or between H and He?
- Is there a limit to the number of elements?
- Before Henry Moseley atomic numbers were a convenient ordering system starting with the lightest know element, hydrogen.
- Atomic numbers were not recognized as fundamental.

From A to Z,
Atomic Weight to Atomic Number

- Mendeleev's periodic table, ordered by atomic weight, contained anomalies in order to group similar chemical properties in vertical columns, *e. g.* Co (Z = 27, M = 58.9), Ni (Z = 28, M = 58.7),
  Ar (Z = 18, M = 39.9), K (Z = 19, M = 39.1), and
  Te (Z = 52, M = 127.6), I (Z = 53, M = 126.9).
- 1913 – Antonius van der Broek, used Geiger and Marsden data on Rutherford theory for scattering of a particles by thin foils of five metal to propose that atomic number was a better indication of nuclear charge than (atomic weight)/2, as suggested by Geiger and Marsden
- 1913 – Frederick Soddy introduced the term "isotope" for atoms with the same atomic number but different weights, *e. g.* an atom undergoing α decay followed by two β decays. Soddy supported van der Broek's idea.

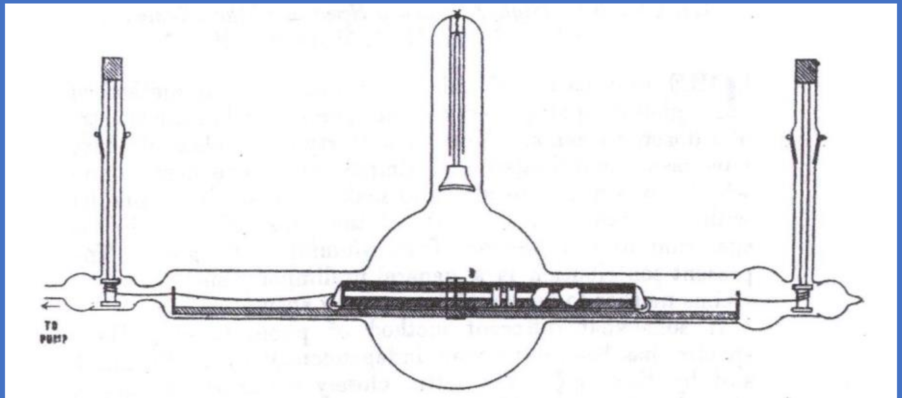
Henry Gwyn Jeffreys Moseley (1887 – 1915)

- After graduating from Oxford (1910), Moseley worked with Rutherford in Manchester until late 1913, when he returned to Oxford.
- While at Manchester he began his studies of x-rays with C. G. Darwin and built an x-ray spectrometer with photographic plates to detect the diffracted x-rays.
- The Braggs used their spectrometer to study crystal structure. Moseley used his to study the elements.

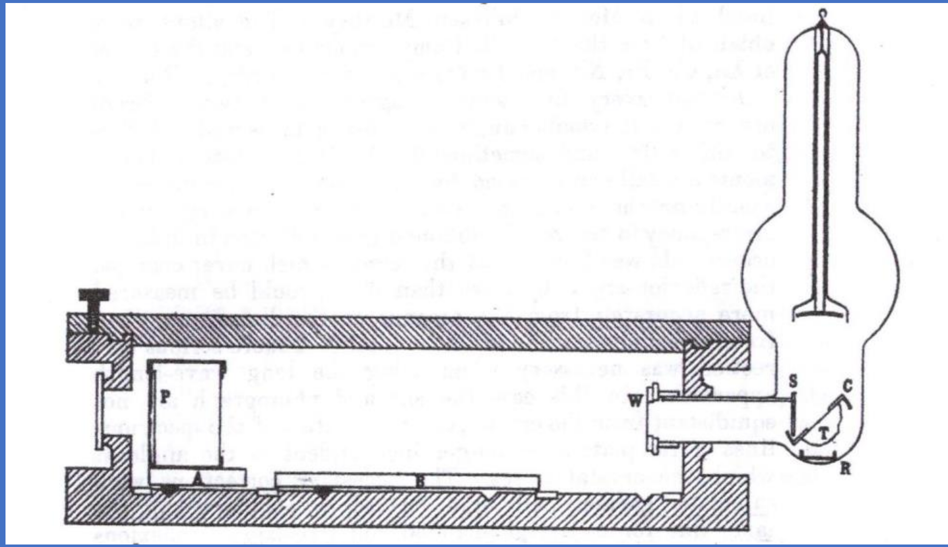
Moseley’s X-ray Tube

(*Phil. Mag.*, **27** (1914), 704, 705)

- Side view with truck holding metal samples as anodes



- End view with evacuated iron spectrometer box, crystal table (B), and photographic plate (P)



From Moseley’s Letters

- 13 August 1913 to his sister Margery:
  “I am now struggling with an X ray tube with a truck inside carrying pieces of all the metals I can get hold of …. I want in this way to find the wave-lengths of the X ray spectra of as many elements as possible, as I believe they will prove much more important and fundamental than ordinary light spectra.”

- 16 November 1913 to Niels Bohr:
  “I have found that they [K_α x-ray wavelengths] lend great weight to the general principles which you use.”

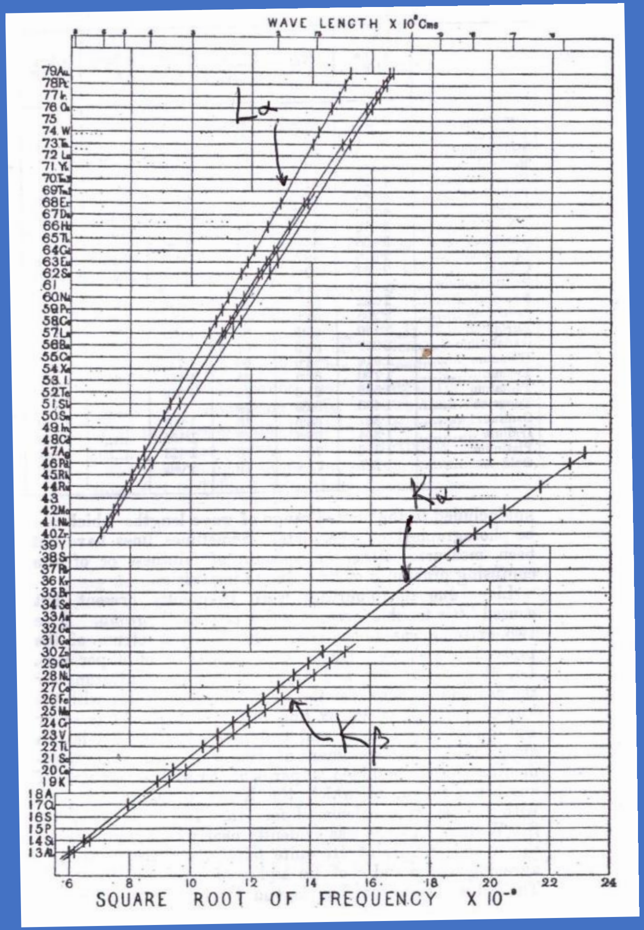
Successes of Moseley’s Analysis

- “The prevalence of [x-ray spectral] lines due to impurities suggests that this may prove a powerful method of chemical analysis.”

  “It may even lead to the discovery of missing elements, as it will be possible to predict the position of their characteristic [spectral] lines.” (*Phil Mag.,* **26** (1913), 1030.)

- French chemist George Urbain after two days with Mosley examining his samples: Moseley “untangled in a few days conundrums [about the identities and periodic table positions of proposed rare earth elements] that had taken chemists six generations merely to propose.”

Aluminum (Z = 13) to Gold (Z = 79)



- Empty spots for Z = 43, 61, and 75
- Later discovered and identified:
  Z=43 Tc (technetium - radioactive) predicted in 1871 by Mendeleev as eka-manganese,

  Z=61 Pm (promethium - radioactive), isolated in 1945 ,

  Z=75 Re (rhenium) isolated in 1925, last stable element isolated

Subsequent Developments

- Walther Kossel argued that K_α x-rays resulted from and electron from the n=2 shell to the n=1 shell after an n=1 electron was ejected by an incident x-ray, K_β arose from an n=3 to n=1 electron transition, and La x-rays were produced by n=3 to n=2 electron transitions.
- With Arnold Sommerfeld's extensions to Bohr's theory with azimuthal and magnetic quantum numbers, the results of Franck-Hertz experiments, and Kossel's account of K and L x-rays, Bohr's theory of atomic structure and the association of atomic number with the number of positive nuclear charges became widely accepted by 1920.