

Physics 30 Lesson 25 Early Atomic Models

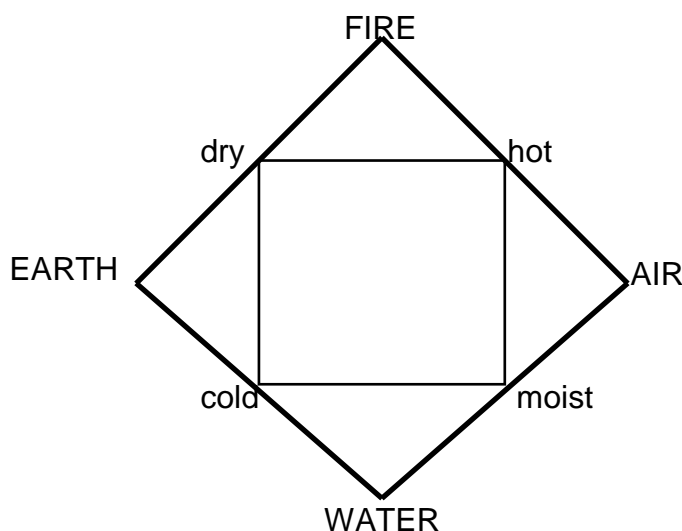
In Lessons 25 to 38 we explore the **nature of the atom**. The lessons more or less follow the historical development of our modern understanding of atoms. The purpose of this lesson is to “set the stage” by describing the understanding of atoms just prior to the beginning of the twentieth century, for it was in the early 1900’s that our modern understanding of matter began to really take shape.

Note: While this lesson is not part of the Physics 30 curriculum it provides a context for the proceeding lessons on the nature of the atom and the nucleus. Therefore, it is expected that you will read this lesson with interest.

I. Alchemy

For thousands of years, philosophers of nature held to a theory of matter put forward by Aristotle in the 6th century BCE. All matter was composed of a combination of four **elements** (fire, air, water, earth) and a number of **principles** (dry, hot, moist, cold).

By using these principles and elements in various combinations, the varying properties of different compounds could be “explained.” Alchemy was a mixture of philosophy, astrology, mysticism, magic, science and many other subjects. It was an attempt to unify one’s knowledge through a search for the **philosopher’s stone** (no, not Harry Potter’s stone). The philosopher’s stone was believed to be the pure substance underlying all of matter, thought, and creation which could transmute anything into gold. Gold was symbolic of the material form of God – permanent, incorruptible and pure. Many scientists, including Newton, were very interested in the study of alchemy.



II. Dalton and the postulates of chemical philosophy

John Dalton (1766-1844) is known as the father of chemistry. He was colour blind and therefore had great difficulty working in the laboratory. His accomplishments rest on his ingenious interpretation of the work of previous experimenters like Francis Bacon, Benjamin Franklin, William Gilbert, Charles Coulomb, Antoine Lavoisier, and many others. Before the time of John Dalton, chemistry did not exist. All research was classified as alchemy, and most of the relevant information in the field existed because of the commitment of alchemists into turning base metals (lead, antimony, etc.) into gold. Many alchemists went to their graves as a direct result of heavy metal poisoning.

Dalton synthesized all previous research in the field of alchemy into **five basic postulates of chemical philosophy** that gave a starting point for all further research. He published the five postulates in 1808 and chemistry began.

The Five Postulates of Chemical Philosophy

1. Matter is composed from indivisible atoms.
2. Each element consists of a characteristic kind of identical atom.
3. Atoms are unchangeable.
4. When different elements combine and form a compound, the smallest possible portion of the compound (molecule) is a group containing a definite, whole number of atoms of each element.
5. In chemical reactions, atoms are neither created nor destroyed, but only rearranged.

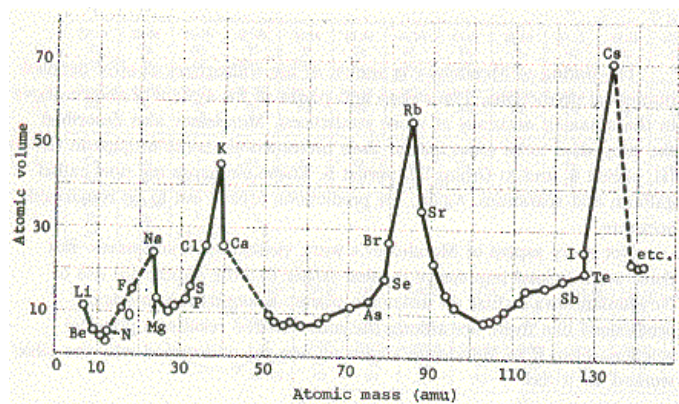
In general, Dalton believed that all elements were composed of extremely tiny, indivisible and indestructible atoms (i.e. solid spheres) and that all substances were composed of various combinations of these atoms. He also believed that atoms of different elements were different in size and mass. In keeping with the quantitative spirit of the times, he tried to determine numerical values for their **relative masses**. We refer to Dalton's relative mass as **atomic mass** today.

III. The periodic nature of the elements

In the year 1800, all previous work by all the alchemists over centuries has only identified 31 different elements. John Dalton's new field of chemistry encouraged the discovery of many new elements. By 1860, the number of known elements totaled 60. The sheer number of elements, plus the almost constant discovery of new elements, spurred interest in the organization of the elements into categories.

In 1865, J. Newlands produced the first list of the known elements. He ranked all the elements according to increasing atomic mass. When this was done, a surprising observation became evident: Elements with similar chemical and physical properties appeared over and over in the list.

Julius Meyer (1830-1895) examined some physical properties of the elements and decided to plot relative atomic size against increasing atomic mass. His graph produced a series of peaks and valleys. The peaks corresponded to members of the alkali metals. In other words, the first peak was lithium the second peak was sodium the third peak was potassium, and so on. The valleys corresponded to the halogens. In the first valley was fluorine, the second valley was chlorine, the third valley was bromine, and so on. Meyer concluded that the properties of the elements might be a **periodic** (re-occurring) function of their atomic mass. Meyer published his research in early 1869 and he received the Copley medal for his work from the Royal Society of London in 1882.



IV. Dmitri Mendeleev

Dmitri Mendeleev (1834-1907) was unable to gain admission into the University of Moscow, but he was accepted into the University of St. Petersburg. In 1861, he received a doctorate in Chemistry for a thesis on the combination of alcohol with water. In 1869, Mendeleev began to prepare a table of the elements. Like Meyer, he recognized the importance of the recurring chemical and physical properties of the chemical families. So he began to set up a table that would increase in atomic mass while still accounting for the periodic families of elements.

In Mendeleev's table, atomic mass increases horizontally but elements are grouped vertically according to chemical and physical properties (or chemical families). His 1869 version shows the vertical and horizontal combinations.

1	H																Li												
2																	Be	B	C	N	O	F	Na						
3																	Mg	Al	Si	P	S	Cl	K	Ca	-	Er?	Y?	In?	
4	Ti	V	Cr	Mn	Fe	Ni	Co	Cu	Zn	-	-	As	Se	Br	Rb	Sr	-	Ce	La	Di	Tb								
5	Zr	Nb	Mo	Rh	Ru	Pd	Ag	Cd	U	Sn	Sb	Te	I	-	Cs	Ba													
6	-	Ta	W	Pt	Ir	Os	Hg	-	Au	-	-	-	-	-	Pb														

By 1871, Mendeleev had designed a table that looks very similar to the periodic table we use today. The transition elements do not appear until the fourth horizontal row (Ti through Zn). This version of the table was actively used until 1914.

[illegible]

Mendeleev's greatest claim to fame came from the predictions he made about the blanks on his periodic table. In 1871, Mendeleev made three predictions concerning three blanks on his table. These elements were all discovered by 1886 – note Mendeleev's accuracy.

Properties of the Elements Scandium, Gallium, and Germanium

Property	Mendeleev's Predictions in 1871	Observed Properties
Scandium (Discovered in 1877)		
Molar Mass	44 g	43.7 g
Oxide formula	M ₂ O ₃	Sc ₂ O ₃
Density of oxide	3.5 g/ ml	3.86 g/ml
Solubility of oxide	Dissolves in acids	Dissolves in acids
Gallium (Discovered in 1875)		
Molar mass	68 g	69.4 g
Density of metal	6.0 g/ml	5.96 g/ml
Melting temperature	Low	30° C
Oxide formula	M ₂ O ₃	Ga ₂ O ₃
Solubility of oxide	Dissolves in ammonia solution	Dissolves in ammonia solution

Germanium (Discovered in 1886)

Molar mass	72 g	71.9
Density of metal	5.5 g/ml	5.47 g/ml
Color of metal	Dark gray	Grayish white
Melting temperature of metal	High	900°
Oxide formula	MO ₂	GeO ₂
Density of oxide	4.7 g/ml	4.70 g/ml

Mendeleev's periodic table explained all known items and the table was accurate enough to make predictions that proved to be correct. Mendeleev was rewarded with the Davy Medal (Royal Society of London) in 1882, the Faraday Medal (English Chemical Society) in 1884 and the Copley Medal (Royal Society of London) in 1905.

There are two mistakes on the periodic table produced by Mendeleev. The first one concerns an element that Mendeleev didn't even know about. Argon has a mass of 39.95 and potassium has a mass of 39.10. This is not increasing by atomic mass, but we can forgive Mendeleev for this error.

Mendeleev did know about the second error. Tellurium has a mass of 127.60 and iodine has a mass of 126.90. Once again mass is not increasing. Mendeleev was forced to place these two elements according to their chemical and physical properties. Mendeleev believed so strongly in the chemical families (vertical columns) that he believed that the mass of tellurium must be wrong. Perhaps if he had known about argon, he would have revised his model.

Henry Moseley (1887-1915) would provide the correction in 1908. While doing x-ray diffraction through crystals he discovered that the reason tellurium comes before iodine is that tellurium has 52 protons in its nucleus and iodine has 53 protons in its nucleus. Argon has 18 protons, in its nucleus and potassium has 19 protons in its nucleus. Moseley proposed that the table was correct in its vertical columns according to chemical families and the horizontal rows are actually increasing by the number of protons in the nucleus. We call that property the **atomic number**. As a result, Mendeleev's basic idea remains the same, but we now have atomic number as the controlling factor horizontally. Young Moseley would die in the trenches of World War I at the age of 28. As a result of Moseley's early death, a law was passed in the English Parliament banning active service for scientists.

Today, as young students begin studying chemistry, they begin with a periodic table listing an incredible amount of information.

Group-Period	I	II																	III	IV	V	VI	VII	0	
1	1.0080 H 1																								4.0026 He 2
2	6.939 Li 3	9.012 Be 4																	10.811 B 5	12.011 C 6	14.007 N 7	15.999 O 8	18.998 F 9	20.183 Ne 10	
3	22.990 Na 11	24.312 Mg 12																	26.982 Al 13	28.086 Si 14	30.974 P 15	32.04 S 16	35.453 Cl 17	39.984 Ar 18	
4	39.10 K 19	40.08 Ca 20	44.96 Sc 21	47.90 Ti 22	50.94 V 23	52.00 Cr 24	54.94 Mn 25	55.85 Fe 26	58.93 Co 27	58.71 Ni 28	63.54 Cu 29	65.37 Zn 30	69.72 Ga 31	72.59 Ge 32	74.92 As 33	78.96 Se 34	79.91 Br 35	83.80 Kr 36							
5	85.47 Rb 37	87.62 Sr 38	88.91 Y 39	91.22 Zr 40	92.91 Nb 41	95.94 Mo 42	(99) Tc 43	101.07 Ru 44	102.91 Rh 45	106.4 Pd 46	107.87 Ag 47	112.40 Cd 48	114.82 In 49	118.69 Sn 50	121.75 Sb 51	127.60 Te 52	126.90 I 53	131.30 Xe 54							
6	132.91 Cs 55	137.34 Ba 56	*	178.49 Hf 72	180.95 Ta 73	183.85 W 74	186.2 Re 75	190.2 Os 76	192.2 Ir 77	195.09 Pt 78	196.97 Au 79	200.59 Hg 80	204.37 Tl 81	207.19 Pb 82	208.98 Bi 83	(210) Po 84	(210) At 85	222 Rn 86							
7	(223) Fr 87	226.05 Ra 88	89-103																						

* Rare-earth metals

† Actinide metals

138.91 La 57	140.12 Ce 58	140.91 Pr 59	144.27 Nd 60	(147) Pm 61	150.35 Sm 62	151.96 Eu 63	157.25 Gd 64	158.92 Tb 65	162.50 Dy 66	164.93 Ho 67	167.26 Er 68	168.93 Tm 69	173.04 Yb 70	174.97 Lu 71
(227) Ac 89	232.04 Th 90	(231) Pa 91	238.03 U 92	(237) Np 93	(242) Pu 94	(243) Am 95	(245) Cm 96	(249) Bk 97	(253) Cf 98	(255) Es 99	(255) Fm 100	(256) Md 101	(258) No 102	(257) Lr 103

V. Classical science

To many people in our culture, scientific reasoned thinking, based on evidence rather than mere belief, is seen as a natural way to think. But it may come as a shock to some that the method of scientific thinking was an **invention** of European and Arabic cultures. One of the fathers of modern scientific thinking was Rene Descartes (1596 - 1650) the French mathematician and philosopher. You have worked with some of his mathematical ideas for years – he is the inventor of Cartesian coordinates which you know as **x,y** coordinates.

Descartes was disgruntled with the ideas and beliefs he was given as he grew up. Tired of being told what to think and believe by his culture, class and church, he wanted to know if what he believed and lived his life by was true or false. Further, he wanted to find a method by which he could determine if his ideas and beliefs about the world, and himself, were trustworthy. In his *Discourse on Method*, Descartes outlined a fairly straightforward method whereby one could test one's knowledge and understanding and find the truth about things. He tried to develop a coherent system of thought based on principles which he determined to be necessarily true.

Descartes did not believe that everyone should go about testing their knowledge; only those who were disgruntled with their current beliefs were ripe for such an undertaking. The first requirement, **to strip one's self of all past beliefs**, is one that ought not to be taken lightly by everyone. This is not an easy thing to attempt since it requires years, decades, perhaps a life time to work through. This process is governed by four basic principles:

1. Never accept anything for true that which I do not know clearly as being true. Avoid any prejudice or presupposition which tends to overrule good, sound judgment. Be indifferent to the results of the method. Be ever ready to abandon ideas and notions which have been shown to be false.
2. Divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solution.
3. To conduct my thinking in such order that, by commencing with objects the simplest and easiest to know, I might ascend little by little and step by step to the knowledge of the more complex.
4. In every case, to make my statement so complete, and reviews so general, that I might be assured that nothing was omitted.

Another philosopher and father of science was Sir Francis Bacon (1561-1626). His idea was to study nature with the goal of being able to control and utilize nature to our designs and desires. His method for achieving this is one that should be even more familiar to you than Descartes' method:

1. Observe the phenomenon one wishes to understand.
2. Develop a hypothesis for why the phenomenon behaves as it does.
3. Develop an experiment which will test the hypothesis.
4. Through repeated experiment, the hypothesis will be refined into a sound theory or principle.

The ideas of Descartes and Bacon form the foundation for modern science. From the time of Galileo to the start of the twentieth century, scientists sought an objective understanding of the universe that did not depend on what one's beliefs were. The ideal was that if the science was properly done, one's beliefs would not matter – the scientific law or principle derived from experiment would speak for itself. In reality, of course, the history of science reveals that the development of theories relied as much, if not more, on intuition, imagination and accidental discovery than it did on applying a method.

Nevertheless, by the 1896 conference of the Royal Society of London, where everybody who was anybody had gathered, people were announcing that the basic understanding of the physical universe was at hand:

- ⇒ Newton's three laws of motion described how objects move and why their motion changes.
- ⇒ Newton's law of gravity explained the orbits of the Moon, planets and stars. Kepler had made the universe elliptical, parabolic and hyperbolic rather than just round.
- ⇒ Maxwell had shown that electricity, magnetism and light were all explained in one theory – electromagnetism.
- ⇒ Mendeleev had shown the intrinsic order within nature with the periodic table.
- ⇒ Mendel had discovered the laws of heredity.
- ⇒ Darwin had shown how life had evolved from the simple to the complex.

There were only a few “minor” details – radioactivity, blackbody radiation, emission and absorption spectra – to be worked out. In 1896 what we now refer to as **classical physics** had all the answers...and then the roof fell in. By 1920,

- ⇒ Newton's law of gravity (attraction between masses) would be replaced by Einstein's general theory of relativity (curvature of space-time by large masses).
- ⇒ Unchanging and constant length, mass and time would be shown to depend on the relative motion of object and observer.
- ⇒ Light, confirmed to be an electromagnetic wave, would become light confirmed as a simultaneous wave and particle called a photon.
- ⇒ Indivisible atoms would become electrons buzzing around an inconceivably small nucleus.
- ⇒ Indivisible nuclei would eventually decay.
- ⇒ Electron particles would become electron waves.
- ⇒ Certain knowledge became uncertain.

In Lessons 26 to 37 we will discover how classical physics could not understand the real nature of the atom. From a predictable and controlled view of nature, physicists would reveal that the atomic world was far stranger than anyone imagined.