Lecture 8

Fundamentals of Physics

Phys 120, Fall 2015

Origin of Atoms

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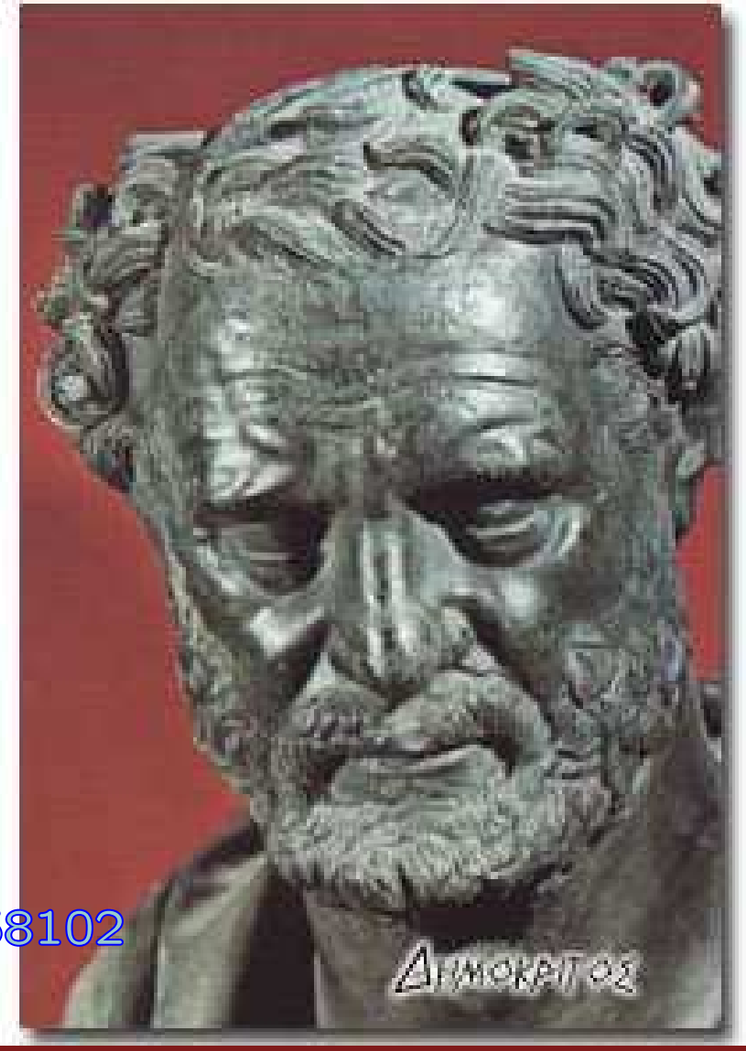


Postulating Atoms, then observing them

- What is the world made of?
- Empedocles
- Demecritus and Early Atomists
- Alchemy and Chemistry, the Periodic system of elements
- Brownian motion: strong evidence for atoms
- Explaining states of matter and temperature
- Powers of 10

What is the world made off?

We know many different substances:

iron, wood, water, ice, air, leaves, grass, cows, goats, etc.

We know that at least some of them can be created: grass gows, cows have calves, wood grows on trees.

Many can decompose: iron can rust, wood rots, cows die, etc.

Conservation of material

Little children delight in playing hide and seek, because the persistence of the world around them astounds and delights them. Initially babies don't appear to have any expectation that something that is out of their view still exists. The discovery that things persist is delightful.

Later, we are amazed by magicians that appear to be able to conjure up doves out of thin air or make a maiden (or themselves) vanish. This is exactly because we have learned to deeply that things do not simply appear or vanish. They have to go somewhere.

Greek notion of creation and destruction

Greeks held that no thing can be created out of nothing.

Conversely no thing can be made to vanish into nothingness.

Let us consider this: is this really true?

How about a fire that completely consumes the material it burns?

What about a puddle in the street that disappears by lunchtime?

What happens to wood that rots away?

Empedocles 495-435 BC

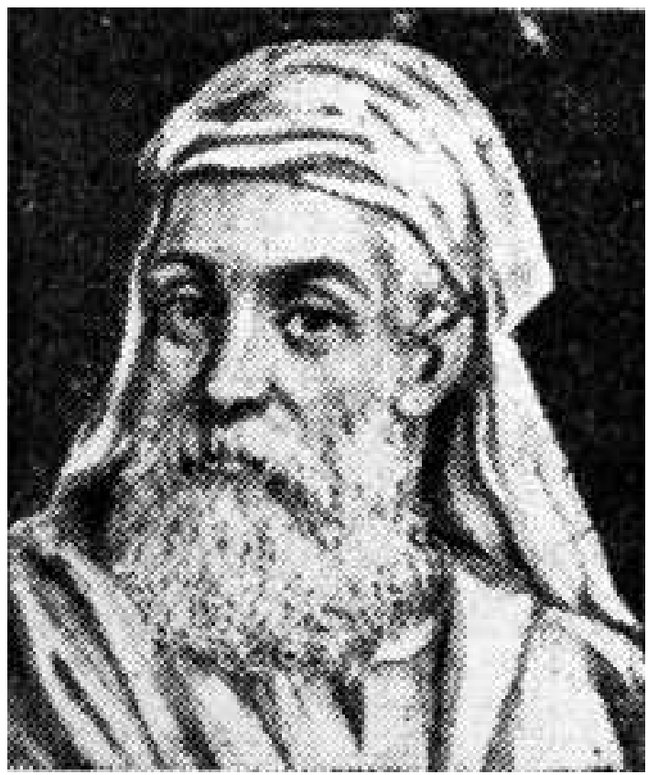
From Agrigentum (Greek City in Sicily)

Developed the cosmogenic theory of the four elements.

Earth, Water, Air, Fire

`http://plato.stanford.edu/entries/empedocles/`: Aristotle credits Empedocles with being the first to distinguish clearly these four elements, traditional in Greek physical theory (Aristotle, Met. A4, 985a313). These elements and forces are eternal and equally balanced, although the influence of Love and of Strife waxes and wanes (B6 and B17, lines 1420). Empedocles seems to have Parmenides' arguments in mind when he denies that these elements or forces come to be or pass away. Everything else comes to be and passes away because each is composed of elements that successively combine to form them and separate at their destruction (B 17.2635).

Established a democratic government of Agrigentum. May have died in mount Etna to be seen as more godlike.



Democritus 460-370 BC

Born in Abdera, Thrace

He developed the atomic theory of the universe.

Empedocles denied the existence of void.

Question: How can anything move if there is no void to move into?

Empedocles: things can just flow around the object

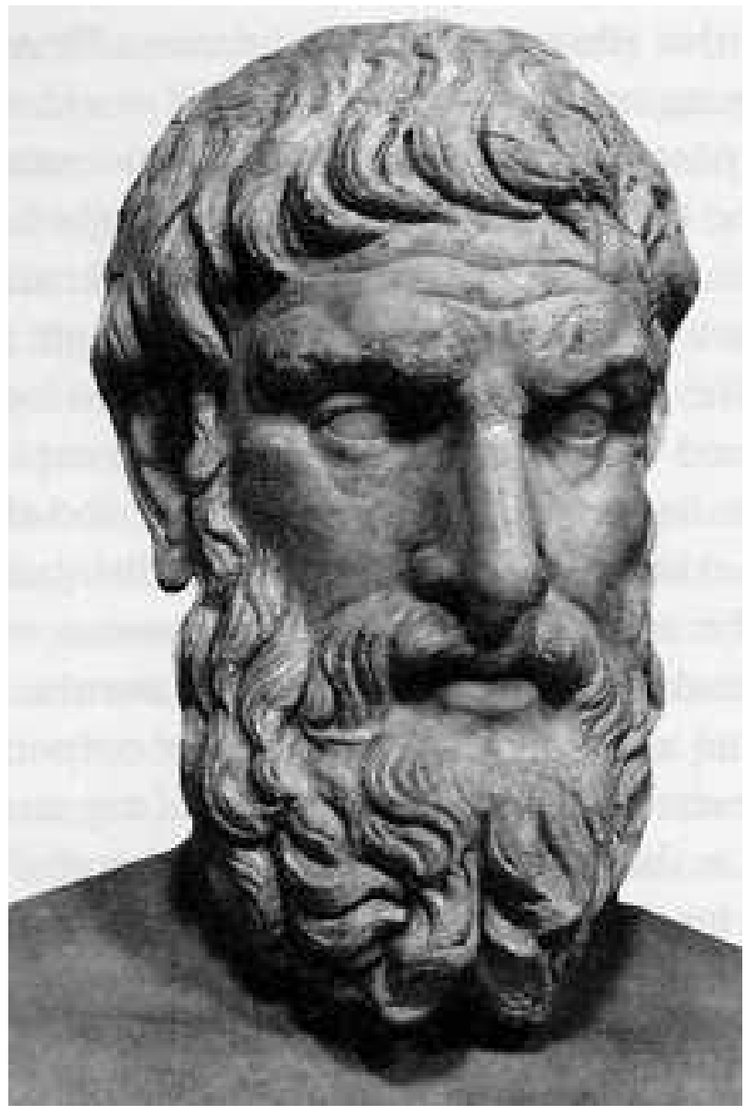
Democritus: it is impossible to move if there is no void

This (and other) arguments got Democritus to argue that if you continue to divide an object you will eventually arrive at a smallest indivisible particle or *Atom* which is surrounded by void. But these Atoms are too small to be seen.

Epicurus 341-270 BC

Originally from Samos, moved to Athens

Atomic theory was rejected by Plato and Aristotle. But Epicurus embraced it. He explained the world entirely in terms of atoms, claiming that there is no non-material component to the soul, and that gods do not influence our lives (although they may have initially set the world in motion). He argued that we can obtain knowledge of the world relying on our senses. The aim of ones lives is to achieve pleasure (tranquility) which is achieved by limiting ones desires and banishing the fear of death and fear of the gods.



Lucretius c.99c.55 BC

Titus Lucretius Carus) was a Roman poet.
Wrote *De Rerum Natura* (On the Nature of Things)

Why? Because I teach great truth, and set out to unknot
The mind from the tight strictures of religion, and I write
Of so darkling a subject in a poetry so bright,
Nor is my method to no purpose — doctors do as much;
Consider a physician with a child who will not sip
A disgusting dose of wormwood: first, he coats the goblet's lip
All round with honey's sweet blond stickiness, that way to lure
Gullible youth to taste it, and to drain the bitter cure,
The child's duped but not cheated — rather, put back in the pink-
That's what I do. Since those who've never tasted of it think
This philosophy's a bitter pill to swallow, and the throng
Recoils, I wished to coat this physic in melliflous song,
To kiss it, as it were, with the sweet honey of the Muse.

This treaty on Epicureanism is not the usual Roman way of teaching, rather it is a unique (and famous) bit of poetry/science teaching.

Lucretius on random motion of atoms*

If you should think these atoms have the power to stop and stay
At a standstill, and set new motions going in this way,
Then you have rambled far from reason and have gone astray.
Since atoms wander through a void, then they must either go
Carried along by their own weight or by a random blow
Into one another, they bounce apart after the clash
(And no surprise, since they are hard and solid, and they lack
Anything behind them to obstruct their moving back).

All bodies of matter are in motion. To understand this best,
Remember that the atoms do not have a place to rest,
And there's no bottom to the universe, since Space does not
Have limits, but is endless. . . .

*Lucretius, *The Nature of Things*, Penguin Classics, translated by A.E. Stallings

Descartes 1569 – 1650

Descart was a believer in atomism. He also built a philosophical foundation of matter, that he held that the essence of matter was extension, and had physical properties like motion and everything was to be derived from this: "*I do not use the qualities called heat, cold, moistness, and dryness, as the Philosophers do*" , Descartes claimed that he could explain these qualities themselves through matter in motion.

Other qualities like color or taste he attributed to spriritual effects generated by the observers mind.

Newton

Newton liked the idea of discrete building blocks in the spirit of Lucretius. He called these particles "corpuscles". If you assume that the world is made up of such small particles, and that they interact through forces, then you have a **theory of everything**.

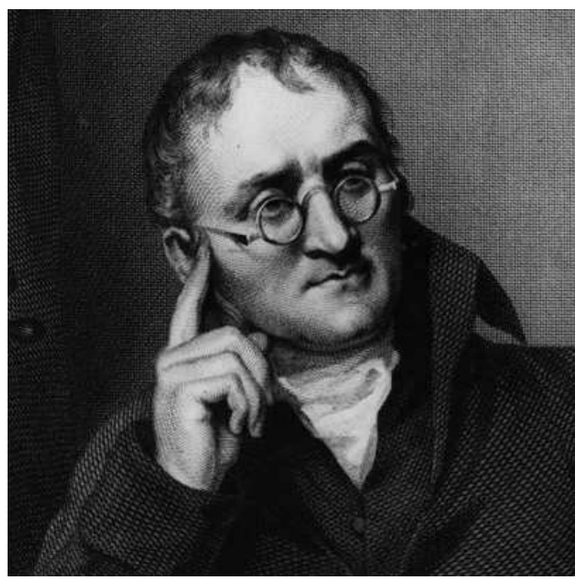
In fact he surmised that everything, matter, light, heat, etc. was made up of corpuscles.

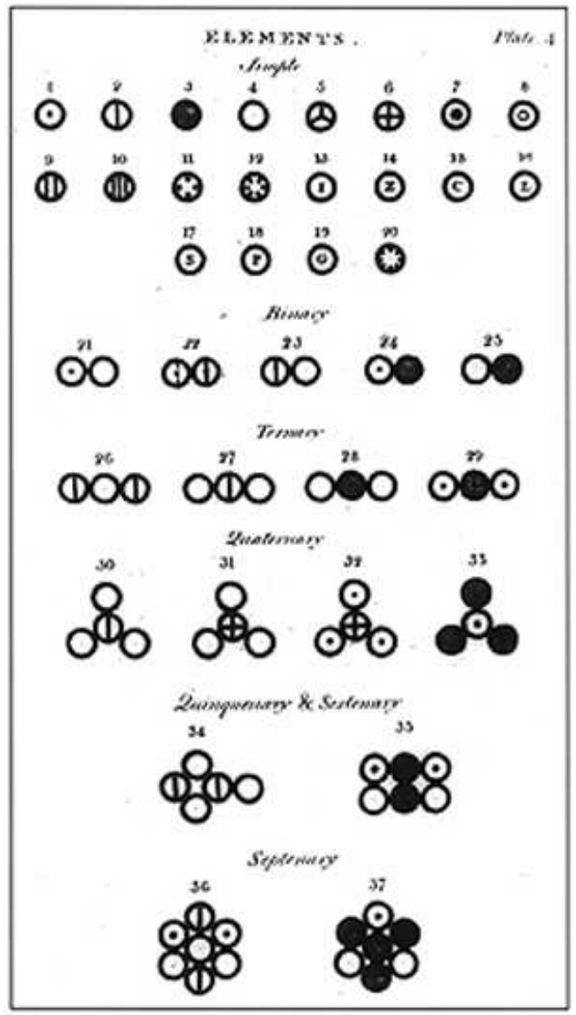
All that is needed to complete this program is to flesh out the details: what are these fundamental particles, and through what forces do they interact. Once you found this out you would be able to predict everything, at least in principle.

However, there still was no evidence that such corpuscles actually existed.

Revival of Atomic theory - Chemistry

John Dalton (1766 – 1844) discovered that chemical reactions always happen in exact ratios. This supported his believe in the Atomic theory.
If you dissociate water using an electric current, you get two gases, one at either contact. You get twice as much gas at the negative contact, but it weighs only 1/8th as much as the gas at the positive contact.



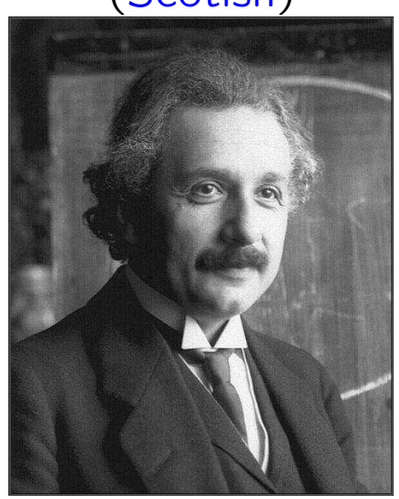


However, if you believed in a more Aristotelian view of matter mixed components you could still hold that the idea of Atoms was not necessary.

Brownian motion

Robert Brown discovered that under a microscope pollen grains in still water moved around erratically. He first thought that he had discovered the origin of life!
But he found that even inanimate dust particles show this strange form of motion. (Hence he disproved his hypothesis).
The explanation is that the pollen is bombarded by collisions with (still invisible) water molecules. Hence Lucretius' prediction was observed here! (see animation or experiment)
The motion of these particles was quantitatively predicted by the (still unknown) physicist Albert Einstein in 1905. He predicted how a group of such particles should spread out, which was then verified experimentally. Since Einstein's work on Brownian motion the atomic theory has not been questioned by scientists.

Robert Brown
1773 – 1858
(Scotish)



Albert Einstein
1879 – 1955

Atoms and Molecules

19th century Chemists (including Dalton) noted that they were able to decompose some substances but that other substances could not be decomposed. These fundamental materials are called **chemical elements**.

They hypothesized that each element is made up one kind of atom, so the **atom** would be the smallest particle of an element.

The elements can be arranged according to their atomic weight and chemical affinity, forming the periodic table. The weight corresponds to the **atomic number**, used to arrange the elements. Elements that are above each other in the table have similar chemical properties.

Periodic Table

1																	18
1 **H** 1.008	2											13	14	15	16	17	2 **He** 4.0026
3 **Li** 6.94	4 **Be** 9.0122											5 **B** 10.81	6 **C** 12.011	7 **N** 14.007	8 **O** 15.999	9 **F** 18.998	10 **Ne** 20.180
11 **Na** 22.990	12 **Mg** 24.305	3	4	5	6	7	8	9	10	11	12	13 **Al** 26.982	14 **Si** 28.085	15 **P** 30.974	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.948
19 **K** 39.098	20 **Ca** 40.078	21 **Sc** 44.956	22 **Ti** 47.867	23 **V** 50.942	24 **Cr** 51.996	25 **Mn** 54.938	26 **Fe** 55.845	27 **Co** 58.933	28 **Ni** 58.693	29 **Cu** 63.546	30 **Zn** 65.38	31 **Ga** 69.723	32 **Ge** 72.630	33 **As** 74.922	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
37 **Rb** 85.468	38 **Sr** 87.62	39 **Y** 88.906	40 **Zr** 91.224	41 **Nb** 92.906	42 **Mo** 95.96	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57-71 *****	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** (226)	89-103 **#**	104 **Rf** (265)	105 **Db** (268)	106 **Sg** (271)	107 **Bh** (270)	108 **Hs** (277)	109 **Mt** (276)	110 **Ds** (281)	111 **Rg** (280)	112 **Cn** (285)	113 **Uut** (284)	114 **Fl** (289)	115 **Uup** (288)	116 **Lv** (293)	117 **Uus** (294)	118 **Uuo** (294)

* Lanthanide series	57 **La** 138.91	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
# Actinide series	89 **Ac** (227)	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

Chemical compounds

Many other substances can be generated by combining different elements. A pure substance that is made up of more than one element (like water) is called a **chemical compound**.

We represent compounds by abbreviated formulas:
Water : H_2O
Oxygen gas: O_2
Hemoglobin: $C_{3023}H_{4816}O_{872}S_8Fe_4$.

The Atom's explanatory power

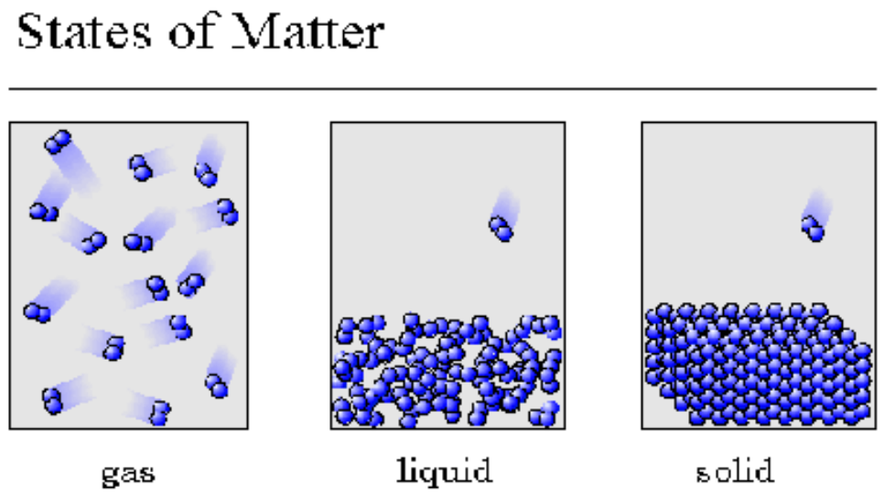
The atomic theory links human-scale or **macroscopic** phenomena to phenomena at the unseen **microscopic** level.

Smell - atoms move through air

Brownian motion

States of matter: solid, liquid, gas

Temperature $\Leftrightarrow$ microscopic motion of molecules



Metric distances and powers of 10

Basic metric distance unit is the meter (m). Derived units are kilometer (km=1000 m), centimeter (cm=0.01 m) and millimeter (mm=0.001 m).

For handling large and small numbers **powers of 10** are invaluable. We write $10^2 = 10 \times 10$ or $10^5 = 10 \times 10 \times 10 \times 10 \times 10$.

The solar systems diameter is

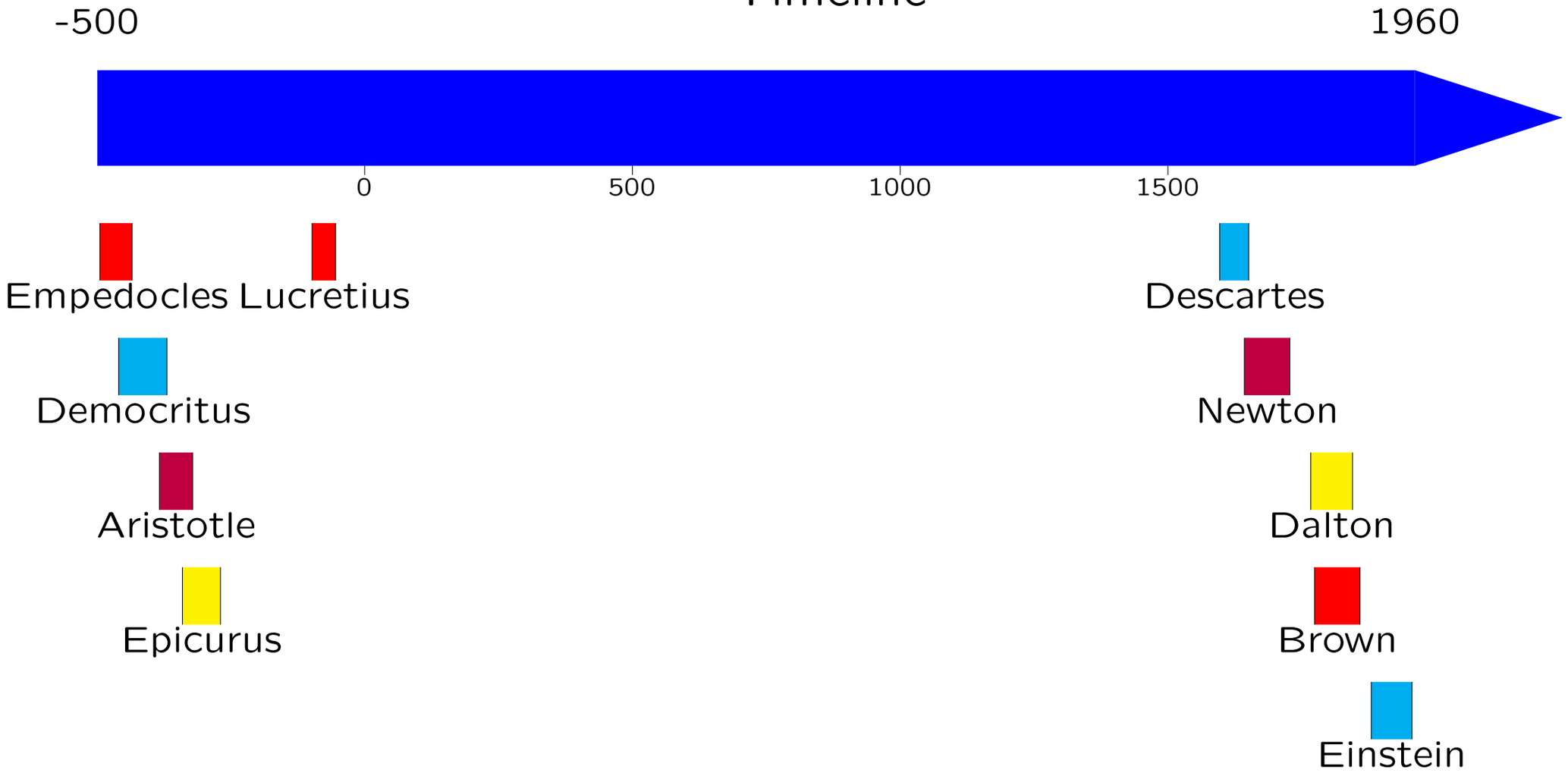
$$\begin{aligned} & 12,000,000,000,000m \\ =& 1.2 \times 10,000,000,000,000 \\ =& 1.2 \times 10^{13} \end{aligned}$$

Small distances are described as negative powers:

$$\begin{aligned} & 10^{-5} \\ =& \frac{1}{10^5} \\ =& 0.00001. \end{aligned}$$

Powers of 10 movie.

Timeline


-500
1960
0
500
1000
1500
Empedocles
Lucretius
Democritus
Aristotle
Epicurus
Descartes
Newton
Dalton
Brown
Einstein

Summary

- Democritus hypothesis of an "atom"
- Aristotle's rejection of this hypothesis
- The thread of Democritus' hypothesis through history
- Evidence for atoms at the end of the 19th century
- Elements and the periodic system
- States of matter