Resumé

What is Science?

<u>Domain:</u> Science and the physical world
<u>Assumptions:</u> A rational, causal, and understandable universe
<u>Methodology:</u> "The Scientific Method"
Observation, Hypothesis, Prediction, Testing

The Copernican Revolution

Classical Cosmology: The Ptolemaic System
The Copernican Revolution: "The Earth Moves"
- Motivation and objectives
- Improvements: Kepler
- Tests: Galileo and Observational Astronomy

The Newtonian Revolution

Galileo: Experimental Physics
Newton's Mechanics: Fundamental "Laws of Nature"
Newton's Mathematical Physics
Newtonian Gravity

Matter and Energy

Einstein (1905)

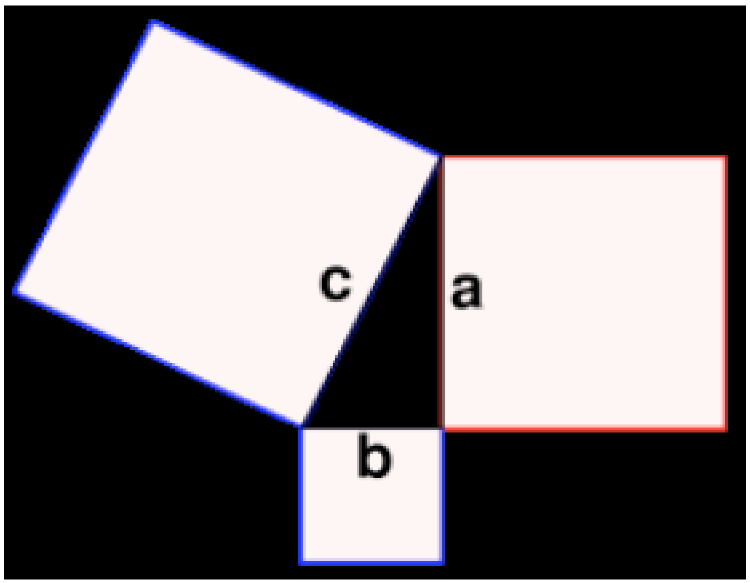
$$E = mc^2$$

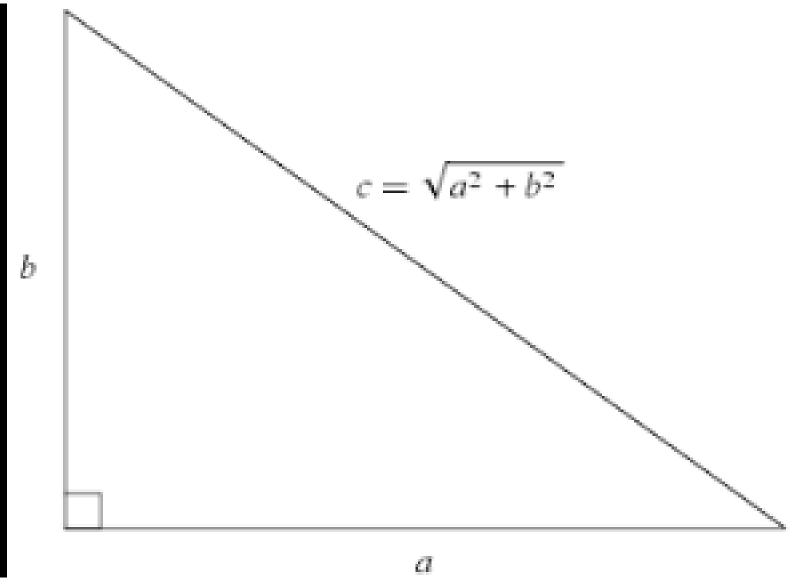
(Nagasaki: 9 August 1945)

Pythagoras (c. 569-475 BCE)

The Pythagorean Theorem:

$$a^2 + b^2 = c^2$$





Matter and Energy

Albert Einstein: The Special Theory of Relativity*
"On the Electrodynamics of Moving Bodies" (1905)

Motivation
Galileo's Principle of Relativity (1632)
and
Newtonian Relativity (1687)

Maxwell's Electromagnetism (1864)

The Michelson-Morley Experiment (1897)

One implication of Special Relativity is the equivalence of mass and energy

$$E = mc^2$$

where $\mathbf{c = 2.99792 \times 10^8\ m\ s^{-1}}$ is the speed of light in vacuum.
.......is a consequence/prediction of Special relativity - but what does it mean?

* Einstein's Doctoral Dissertation (1905) was on statistical molecular theory of liquids. He then provided an explanation for Brownian Motion (Brown 1828), showed that atoms and molecules were "real", and even provided a way to determine their dimensions.

Conservation Laws

Mass and Energy

<u>**Before 1905**</u>

• **"Matter can be neither created nor destroyed"**
(The total amount of mass within a closed system remains constant.)

• **"Energy can be neither created nor destroyed"**
(The total amount of energy within a closed system remains constant.)

<u>**After 1905**</u>

• **"Mass-Energy can be neither created nor destroyed"**
(The total amount of mass-energy within a closed system remains constant.)

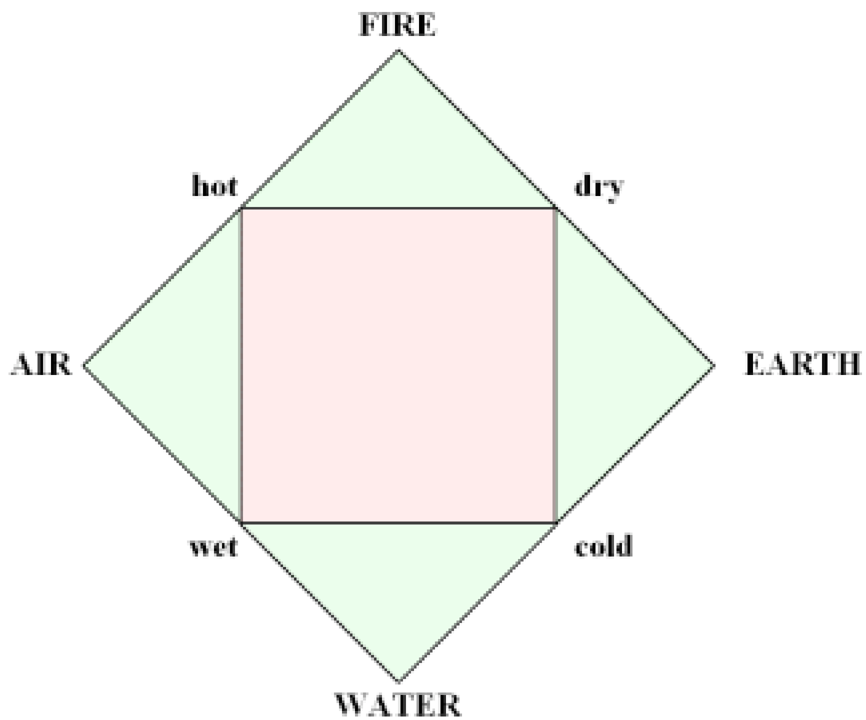
Digression: Empirical Conservation Laws in <u>isolated</u> systems

- **Mass-Energy** (Gravitational interaction)
- **Electrical Charge** (Electromagnetic interaction)
- **Linear and Angular Momenta** (Translation and Rotation)
- **Color Charge** (Strong interaction)
- **Flavor** (Weak interaction)

and "almost always" Baryon number, Lepton number, parity, CP symmetry, ...

The Nature of Matter: From Anaxagoras to Einstein

The Classical Elements
(Empedocles 484-424 BCE)
Earth - Water - Air - Fire



And the fifth element (*quintessence*): The **Aether.**
Aristotle (384-322 BCE)

Analogues of the "Classical Elements" in other traditions and disciplines

Digression: The Phases of Matter

The Classical Elements

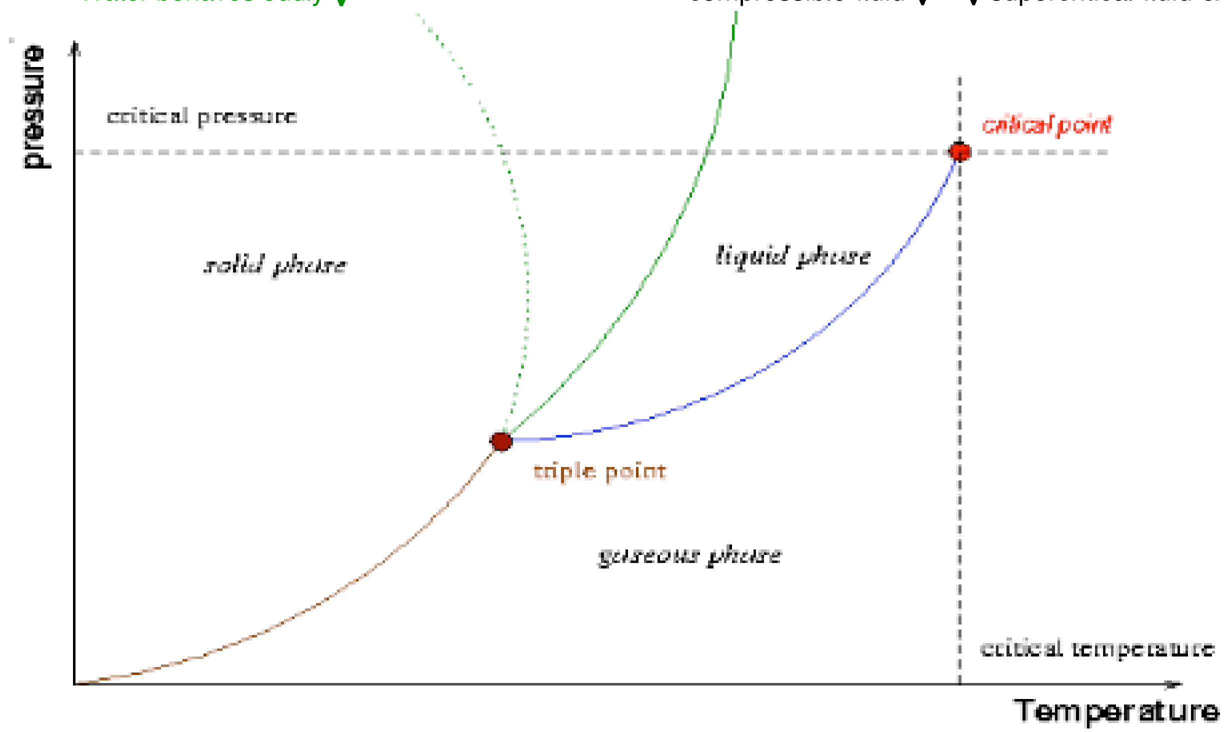
Earth - Water - Air - Fire

versus

The Phases of Matter

Solid - Liquid - Gas - Plasma

Water behaves oddly ↓ compressible fluid ↓ ↓ supercritical fluid & superheated vapor



The Fifth Element: Electromagnetic and Luminiferous Ethers? Quintessence?

The Structure of Matter: The Chemical Elements

Alchemy

Objectives: Transmutation of Base Metals into Gold

The *Panacea* and the Elixir of Life

Alchemy : Chemistry :: Astrology : Astronomy

Astrological-Alchemical Associations

(Gold↔Sun, Silver↔Moon, Mercury↔Mercury, Copper↔Venus, Iron↔Mars, Tin↔Jupiter, Lead↔Saturn)

Atoms and Chemistry

Anaxagoras (500 - 428 BCE) and Democritus (450 - 370 BCE)

A Causal Universe

Atoms and Atomism (and “Void”)

Atomic Shapes & Characteristics and Atomic Bonding

Empirical (Experimental) Gas Laws

Robert Boyle (1627 - 1691) *et al.*

PV = constant (at fixed Temperature, T)

Charles (1787) & Gay-Lussac (1802)

V/T = constant (at fixed Pressure, P)

Gas Law: PV/T = constant (at fixed number N = M/m)

Kinetic Theory of Gases

Newtonian Mechanics and the Ideal Gas Law: PV = NkT

Bernoulli (1700-1782). Here k is Boltzmann’s Constant.

The Chemical Elements

Antoine Lavoisier (1744 - 1794)

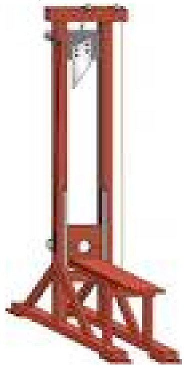
• Distinguished Elements (as atoms) from Molecules
• Composition of Air and Water: Hydrogen, Oxygen, Nitrogen
• Element Identification: H, N, O, P, Hg, Zn, S, ...
(...... including **light** and **caloric** as elements)
"Phlogiston" and "Calx" *versus* Lavoisier's "Caloric"
• Combustion CO_2 and Animal Metabolism, Metric System,

also

Principle: The Conservation of Mass

Principle: The Conservation of (Heat) Energy

but, alas



Guillotine (1792 Model)

The Chemical Elements

John Dalton (1766 - 1844)

Definition:

An atom of an element is the smallest unit which possesses the chemical properties of that element.

(cf. Democritus)

Observation:

In combinations (molecules) the ratios of elemental weights are ratios of integers.

Examples: CO = 12:16 CO_2 = 12:32 H_2O = 2:16 CH_4 = 12:4

(..implying relative atomic weights for H, C, and O of 1, 12, and 16, respectively.)

Michael Faraday (1791 - 1867)

Combining properties of atoms

Laws of Electrolysis: The Binding Forces in Molecules are Electrical!

Chemical bonds and integer Valences.

(H = +1, C = +4, O = -2, ..)

The Chemical Elements

Dimitri Mendeleev (1834 - 1907)

The Periodic Table of the Elements (1869)

<u>Chemical Properties and Atomic Weights</u>

Atomic Weights (Dalton's weight ratios)
Avogadro's Number, N*
A (and Z)
What does a particular element combine with - or not?
What are the combination ratios? (see: *Valence*)
How strong is the binding? (see: *Electrolysis*)

Periodicities in chemical properties
Trends with Atomic Weight
Atomic Number
Abundance trends
Predictions of "Elements to be Discovered" - and their properties
(Ge, Ga, Sc, ..)

* N = 6.022 x 10^{23} entities per mole; 1 mole = A grams of the entity

Cautionary digression on patterns: Planets and the "Law" of Titus-Bode
10a = n + 4 with n = 0, 3, 6 (Earth), 12, <u>24</u>, 48, 96, 192, <u>384</u>,....
(but Ceres didn't fit - nor do Neptune, Pluto, ..)

Periodic Table of the Elements

- hydrogen
- alkali metals
- alkali earth metals
- transition metals
- poor metals
- nonmetals
- noble gases
- rare earth metals

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
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
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
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Ti	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								

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
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

Note: There are 92 naturally occurring elements, These include numbers 1 through 94 except numbers 43 (Technetium) and 61 (Promethium). The others are "synthetic" short-lived radioactive species. Californium (98) is observed in stars but not found on Earth.

The Atomic View of Matter

An Historical Summary

Democritus (450-370 BCE) *and* Anaxagoras (500-428 BCE)
"Is matter discrete or continuous?"

Daniel Bernoulli (1700 -1782)
Boyle's Law, Pressure, and Temperature interpreted *via* Newtonian Mechanics

Antoine Lavoisier (1744-1794)
Identification of Elements & Molecules
Phlogiston Theory Disproved
Conservation of Mass and Energy (caloric)

John Dalton (1766 - 1844)
Definition of "Chemical Element"
Molecules and their Constituent Proportions by Weight
(CO, CO_2; H_2, O_2, H_2O; CH_4)

Humpry Davy (1778 - 1829)
Electrolysis
Proportions by Volume and by Weight
(Electrolysis of Water as an example)

The Atomic View of Matter

Dimitri Mendeleev (1834 - 1907)
The Periodic Table of the Chemical Elements
Atomic Numbers & Atomic Weights

Albert Einstein (1879 - 1955)
Explanation of **Brownian Motion** (Robert Brown 1827)
(Particles within in pollen grain vacuoles. Dust.)

Digression
Statistics and Statistical Processes in Nature
(See also the Kinetic Theory of Gases)

Note: Atoms first “directly observed” *via* X-Ray Diffraction by Crystals (1912)

Atoms and Energy: Special Relativity

Albert Einstein (1879 - 1955)

(Also: Brownian Motion,The Photoelectric Effect, General Theory of Relativity)

The Special Theory of Relativity

"On the Electrodynamics of Moving Bodies" (1905)

$$E = mc^2$$

Conclusions and clarifications regarding Mass and Energy (Einstein)

• The <u>total</u> energy of a moving mass is $E = mc^2$ or $E = \gamma m_o c^2$

where m_o is the <u>rest mass</u>,

$m = \gamma m_o$ is the <u>inertial mass</u> and

$\gamma = [1 - (v/c)^2]^{-1}$ is the <u>Lorentz Factor</u>

$E_o = m_o c^2$ is the <u>rest energy</u> (the energy if $v = 0$), and

$(E - E_o) = (\gamma - 1)m_o c^2$ is the <u>kinetic energy</u> associated with the motion

Newton: The <u>only</u> energy is the Kinetic Energy associated with the motion

i.e., $E = (1/2)mv^2$ ··· and $E = 0$ for $v = 0$

Special Relativity

Some Other (testable and much tested) Consequences*:

Inertial Mass: $m = \gamma\, m_o$

Newton: $m = m_o$

Fitzgerald-Lorentz Contraction: $L = L_o/\gamma$

Newton: $L = L_o$

Time Dilatation: $\Delta t = \gamma\, \Delta t_o$

Newton: $\Delta t = \Delta t_o$

Addition of Velocities: $v_{rel} = (u + v)/(1 + u\cdot v/c^2) \leq c$

Newton: $\mathbf{v_{rel} = u + v}$

Transverse Doppler Effect: $\nu/\nu_o = \gamma\, (1 - v_{radial}/c)$

Classical: $\nu/\nu_o = (1 - v_{radial}/c)$*

...as well as observing the conversion of mass to energy and vice versa.

Note that the precepts of Special Relativity apply only to inertial (unaccelerated) systems; gravitational "accelerations" were addressed in General Relativity (1915)

(Newtonian Mechanics was thought applicable to both inertial and accelerated systems)