“All these things being considered, it seems probable to me that **God in the beginning formed matter in solid, massy, hard, impenetrable, moveable particles** of such sizes and figures, and with such other properties, and in such proportion to space, as most conduced to the end for which he formed them; and that these primitive particles being solids, are incomparably harder than any porous bodies compounded of them; even so very hard, as never to wear or break in pieces; no ordinary power being able to divide what God himself made in the first creation. While the particles continue entire, they may compose bodies of one and the same nature and texture in all ages: but should they wear away, or break in pieces, the nature of things depending on them would be changed. Water and earth, composed of old worn particles and fragments of particles, would not be of the same nature and texture now, with water and earth composed of entire particles in the beginning. And there, that nature may be lasting, **the changes of corporal things are placed only in the various separations and new associations and motions of these permanent particles**.”

Isaac Newton - Optics

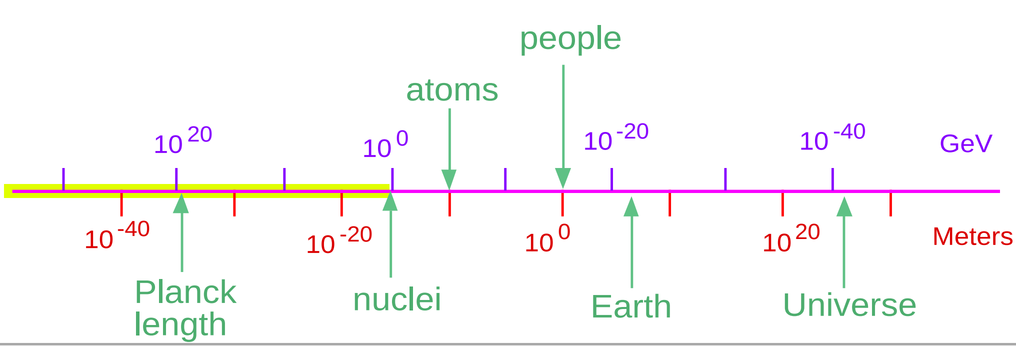
Nuclear and Particle Physics

Particle Physics is the discovery and measurement of the fundamental constituents and their basic interactions.

- Particle Physics is not all of physics.
  - ⇒ Complex systems require new concepts, e.g. Superconductivity
- Particle Physicists try to ignore multibody systems.

Nuclear Physics is the study of the simplest complex systems constructed from the fundamental constituents.

- Nuclear physics has some immediate direct practical relevance.



The Particle Physics Universe

Constituent point fermions

Quarks:

u	c	t
d	s	b

Leptons:

ν_e	ν_μ	ν_τ
e^-	μ^-	τ^-

interacting via forces mediated by vector bosons

photons (γ) - IVB (W^+, W^-, Z^0) - gluons (g)

as a consequence of gauge symmetries

$$U(1)_{em} \times SU(2)_{weak} \times SU(3)_{Colour(strong)}$$

Unresolved questions:

- The model breaks at energies above about 1 TeV.
- Why do particles have mass?
- What is most of the universe made of?

Nuclear physics

What can you make from quarks and leptons?

- protons & neutrons
- nuclei
  - How many elements?
- stars
- quark-gluon plasma
  - formation and properties?
- …

http://preprints.cern.ch/cgi-bin/setlink?base=PHO&categ=photo-ex&id=9600007

NA49 Pb on Pb

What happens when the things you make fall apart?

- alpha, beta, gamma radioactivity
- nuclear fission and fusion
  - safe and economical reactors?
- supernovae
- neutron stars and black holes
  - nuclear equation of state?

…

http://www.ncf.carleton.ca/~cz725/cnf_sectionJ.htm#images

CANDU Calandria

Conservation Laws

If nothing is conserved, then nothing can be described.

Conserved quantities, Symmetry Principles, Invariants

(Conserved quantities always correspond to some symmetry.
We usually try to formulate physics in terms of relativistic invariants.)

- **Always conserved (as far as we know)**

  Momentum (**p**⇔**x**) and Energy (E⇔t)

  { $q_\mu = [(E_f - E_i)/c, \mathbf{p}_f - \mathbf{p}_i]$ and $s = E^2 - \mathbf{p}^2$ }

  Angular momentum (**J**⇔**θ**)

  Electric charge (Q), colour (r,b,g), weak isospin (T_3)

  Baryon number (B), Lepton number (L)

  Lepton generation number (L_e, L_μ, L_τ)

  Spin-statistics relation, CPT,

  cross sections (σ),

  proper lifetimes (τ), decay widths (Γ), branching ratios (B.R.)

- **Sometimes conserved**

  Quark generation number (1,2,3), Isospin (I)

  Parity (P), Time reversal (T), Charge conjugation (C, CP)

  …

Units

The number of fundamental units and the dimensions of any physical quantity are arbitrary.

- There are, however, several common conventions.

  ⇒ SI: metre - kilogram - second – ampere (+ kelvin - mole - candela) — *e.g.* $F_{coulomb} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}$

  ⇒ Gaussian: centimetre - gram – second — *e.g.* $F_{coulomb} = \frac{q_1 q_2}{r^2}$

  ⇒ Natural units: $e=c=\hbar=1$ — *e.g.* $F_{coulomb} = \frac{q_1 q_2 \alpha}{r^2}$

  eV for Particle Physics (or second or metre or …)

  $\alpha = 1/137.03599976(61) = e^2/4\pi\varepsilon_0$

- We convert between units using conversion constants, *e.g.*

  24 hours/day, 2.54 cm/inch, 2.2 pounds/kg,

  299792458 esu/C, 1.602 176 462(63)×10^{-19} J/eV, …

  ⇒ 299 792 458 m/s (c)

  ⇒ 6.582 118 89(26)×10^{-16} eV/s^{-1} (ħ)

  ⇒ 1.602 176 462(63)×10^{-19} C (*e*)