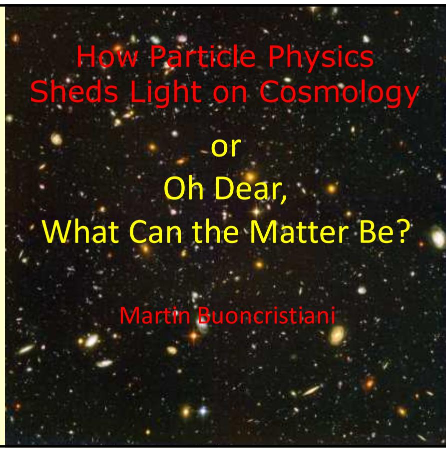


Agenda

- Universal Constants for length, time , mass, etc
- Three ages of Particle Physics
  - Birth — The Atomic Age (1900 – 1960)
  - Youth — The Quark Age (1960 – 1975)
  - Maturity — Asymptotic Freedom (from 1975)
- Implications for "Cosmology Chronology"

Three fundamental, long range forces of Classical Physics

Gravity — Electricity — Magnetism

Each of these forces has its own fundamental constant – a number which determines the strength of that force.

G — ε_0 — μ_0

These forces act the same way throughout the universe so their constants are Universal

and so are combinations of them.

For example, $\varepsilon_0 \mu_0 = \frac{1}{c^2}$

Gravity	$\vec{F}_{gravitation} = G \frac{m_1 m_2}{r^2} \hat{r}$	G = 6.673 10^{-11} m^3 kg^{-1} s^{-2}
Electric	$\vec{F}_{electric} = \frac{1}{4\pi \varepsilon_0} \frac{q_1 q_2}{r^2} \hat{r}$	$\mathcal{E}_0$ = 8.854 10^{-12} C^2 s^2 / (kg m^3)
Magnetic	$\frac{\vec{F}_{magnetic}}{[L]} = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{r} \hat{r}$	μ_0 = 4π×10^{-7} ≈ 1.257 10^{-6} kg m/C^2

Physics also deals with aggregates of particles – where it treats them statistically.

If a collection of particles is near equilibrium then, on average, their kinetic energy is distributed equally

$$Average\ Kinetic\ Energy\ of\ a\ particle = \frac{3}{2} k\, T$$

where T is the temperature of the collection and k is another Universal constant (Boltzmann's Constant).

Thus, we have four universal constants
G, ε_0, μ_0 and k

It is not possible to uses these constants to generate a universal constant for length, time, mass, etc.

However, we can if we add the fundamental constant of quantum mechanics
Planck's constant, h.

Fundamental Concepts and Their Units

Concept	Space	Time	Inertia	Electricity	Magnetism	Thermal
Dimension	Length, L	Duration, T	Mass, M	Charge, Q	Current, I	Temperature, Θ
SI Unit	Meter, m	Second, s	kilogram, kg	Coulomb, C	Ampere, A	Degree C or K
Elementary Unit	$l_P = \sqrt{\frac{\hbar G}{c^3}}$ Planck Length 1.616 10^{-35} m	$t_P = \sqrt{\frac{\hbar G}{c^5}}$ Planck Time 5.391 10^{-44} s	$m_P = \sqrt{\frac{\hbar c}{G}}$ Planck Mass 2.176 10^{-8} kg	$q_P = \sqrt{4\pi \varepsilon_0 \hbar c}$ Planck Charge 1.875 10^{-18} C	$\mu_M = \hbar \sqrt{G\varepsilon_0}$ Magnetic Moment 2.564×10^{-45} C m^2/s	$\Theta_P = \frac{m_P c^2}{k_B}$ Planck Temperature 1.417 10^{32} K

Birth of Particle Physics

Discovery of radio activity led to three unknown particles
alpha, beta and gamma rays

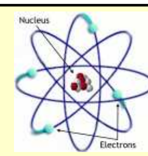
When all this was sorted out
the alpha particle was a Helium Nucleus (2 protons & 2 neutrons)
the beta particle was an electron
the gamma particle was a photon

With quantum mechanics, these particles explain ordinary matter an its interaction with light.

Later a fifth particle was discovered, the neutrino.

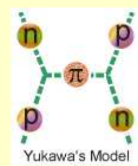
The resulting theory of Quantum Electrodynamics remains the most accurate theory Physics has produced with accuracy to one part in 10^{12}.

The force between electrons is "mediated" by photons.



The nucleus contains neutrons and protons and the protons repel each other electrically.

There must be an additional force which binds them together - the strong nuclear force - "mediated by mesons.



So the search began to find the mesons.

... and they were found in abundance!

$$\pi^+, \pi^0, \pi^+$$

$$K^+, K^0, \bar{K}^0, K^-$$

$$\eta, \eta^*$$

... and more nucleons, too!

$$n, p$$

$$\Sigma^+, \Sigma^0, \Sigma^-$$

$$\Lambda, \Xi^-, \Sigma^0$$

... but wait there's more!

The nucleon family also have excited states.

$$\Delta^-, \Delta^0, \Delta^+, \Delta^{++}$$

$$\Sigma^{*+}, \Sigma^{*0}, \Sigma^{*-}$$

$$\Xi^{*-}, \Sigma^{*0}$$

Neutrons, protons, neutrinos, mesons.
All those damn particles you can't see.
That's what drove me to drink.
But now I can see them!

How to deal with this growing alphabet?
Write down every possible combination and check which reactions actually occur ...

$$A + B \rightarrow C + D$$

$$A \rightarrow \overline{B} + C + D$$

For example, the reaction

$$p \rightarrow n + \pi^0$$

can't occur because charge is not conserved.

Slowly, some systematic symmetry was observed.

The masses of the neutron and proton are so close that n and p can be considered as the same particle distinguished by different values of a new quantity called Isotopic spin (I_3).

The heavier particles can be assigned another number, Baryon Number, B.

Finally, another strange quantity called Strangeness S, was uncovered.

Then when each particle was assigned a charge Q and a value for I_3, B and S

... only those reactions which conserved these four quantities were allowed.

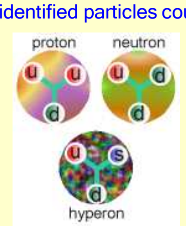
Furthermore, for any particle those four quantities are related

$$Q = I_3 + ½ (B + S)$$

which is the mathematical signature of a symmetry group called SU(3).

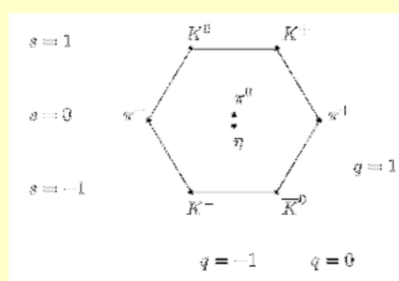
The mathematics also predicted a layer of particles below the mesons - quarks

... and all the identified particles could be built from these quarks.

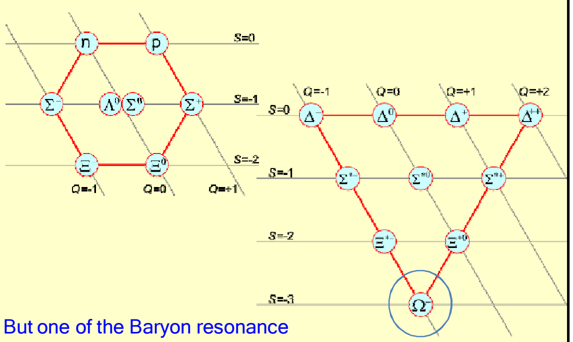


When this is done it produced patterns of the particles

Here is the pattern for the mesons.
All of these particles were known before SU(3).

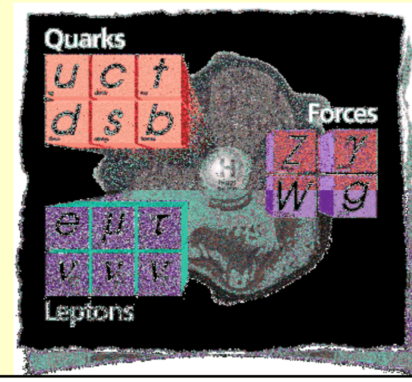


Here is the pattern for the baryons.
All of these particles were known before SU(3).



But one of the Baryon resonance patterns had a missing particle

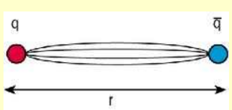
The Elementary Particles - (the new atoms)



Maturity - Asymptotic Freedom

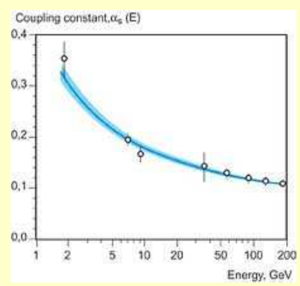
Once the particles of the standard model were identified theorists began to work out the details.

At first, they believed the quarks were bound together with super strong forces



Quark Confinement

However, when the theory was worked out it showed that as the energy increased the strength of the force got weaker ... asymptotic freedom.



Re-normalizable gauge theory with spontaneous symmetry breaking

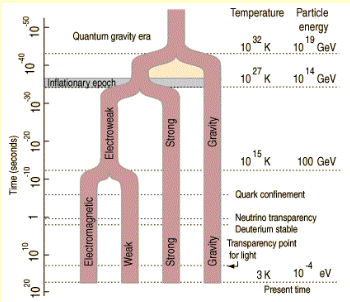
This meant that the universe is "a poor man's accelerator" (Yakov Zel'dovich).

Since the 1980's particle physicists and astronomers have pieced together a chronology of the universe from the big bang.

After the Big Bang
At very early moments four forces are unified

but over time the fundamental forces separate out

Gravity	10^{32} K	10^{19} GeV	10^{-43} sec	1 t_P
Strong	10^{27} K	10^{14} GeV	10^{-36} sec	10^{7} t_P
Electro-weak	10^{15} K	10^{2} GeV	10^{-12} sec	10^{31} t_P



After the Big Bang

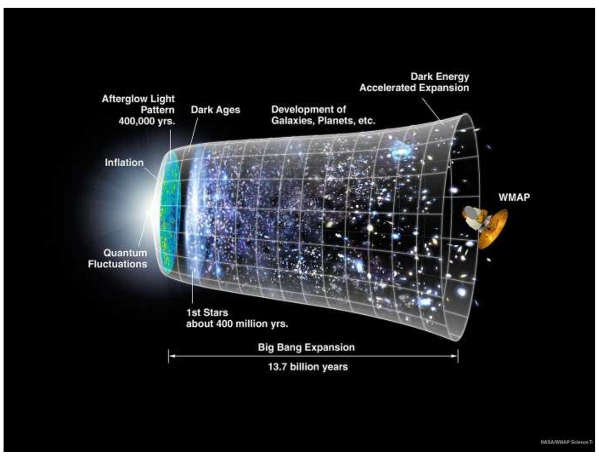
Quark Epoch (10^{-12} - 10^{-6} seconds)

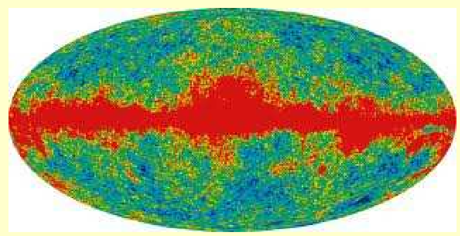
Hadron Epoch (10^{-6} - 1 seconds)

Lepton Epoch (1 - 10 seconds)

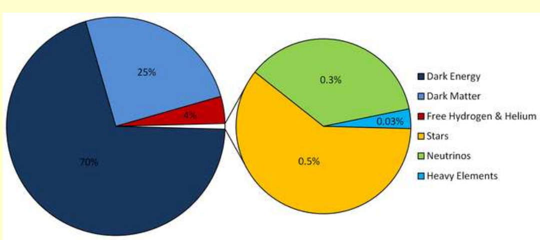
Photon Epoch (10 seconds - 380,000 years)
Nucleosynthesis (3 - 20 seconds)
Matter Domination (to 70,000 years)
Recombination (beginning 377,000 years)

After 10^{10} years “Living beings begin to analyze this process” (Steven Weinberg)





Wilkerson Microwave Anisotropy Probe



Experimental Particle Physicists turn their attention to Cosmological questions