Best of All Possible Worlds

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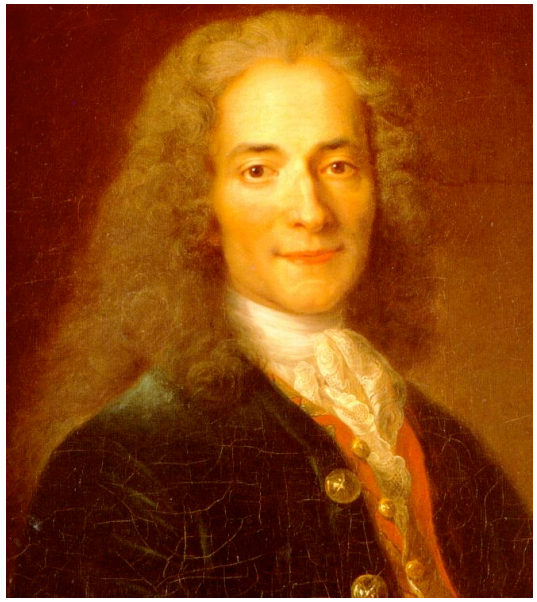
Dec. 15, 2009



Voltaire

Pangloss enseignait la métaphysico-théologo -cosmolonigologie. Il prouvait admirablement qu'il n'y a point d'effet sans cause, et que, dans ce meilleur des mondes possibles, le château de monseigneur le baron était le plus beau des châteaux et madame la meilleure des baronnes possibles.

18 Parameters of the Standard Model in Your Everyday Life

Began as polemic, disputing claims that particle physics was divorced from everyday experience.

Expanded by 50% with discovery of neutrino oscillations.

Seized by landscapists.

A Muonic World

$$m_e \rightarrow m_\mu$$

What happens?

Matter shrinks: $$a_{Bohr} = \frac{1}{\alpha\, m}$$

Light becomes soft x rays.

No. Remember muonic atoms.

$$\mu^- Z_A \rightarrow \nu_\mu (Z-1)_A$$

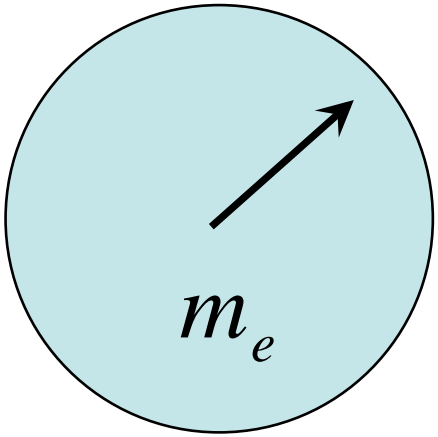
"Muon" would be stable, but "hydrogen" isn't:

$$\mu^- p \rightarrow \nu_\mu n$$

Universe = neutrons and neutrinos!

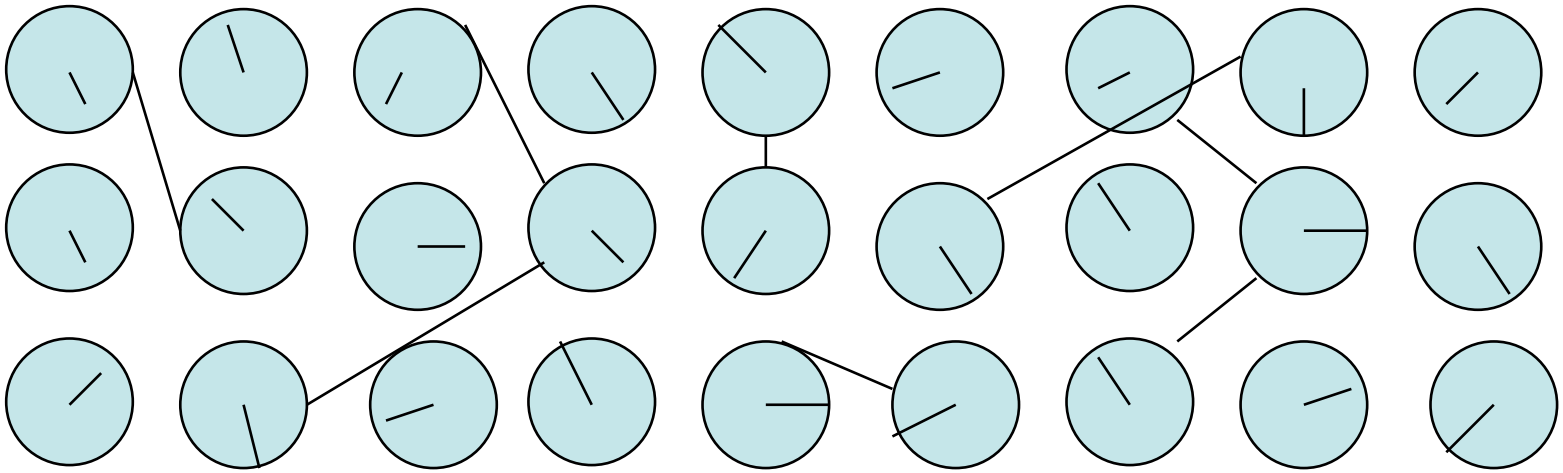
Today's theory has 27 (+1) dials.

One is m_e .



The dials appear to be independent, arbitrarily set.

Probably they are linked.



Increase u-quark mass by 0.8 MeV

$$e\,p \rightarrow \nu_e\,n$$

hydrogen disappears

by only 0.16 MeV and nitrogen disappears:

$$^{14}N \rightarrow ^{14}C$$

Other worlds

As long as the masses of the quarks and leptons appear arbitrary, there are plausible alternative worlds.

As long as we don't understand why there are three generations, we can imagine other possibilities.

Suppose we had only the second generation:

$$(c, s) \quad (\nu_\mu, \mu^-)$$

Only one quark survives:

$$c \rightarrow s \mu^+ \nu_\mu$$

No isotopes.

A Strange World

One stable baryon: $\Omega^- = sss$

No nuclei? Lightest meson is $\phi = s\bar{s}$

Probably too heavy to bind Ω^- to Ω^-

A single atom: $\Omega^- \mu^+$

Original 18 Parameters

Quark masses: $m_u, m_d, m_s, m_c, m_b, m_t$

Charged lepton masses: m_e, m_μ, m_τ

Coupling strengths: $\alpha_{em}, \alpha_{weak}, \alpha_{strong}$

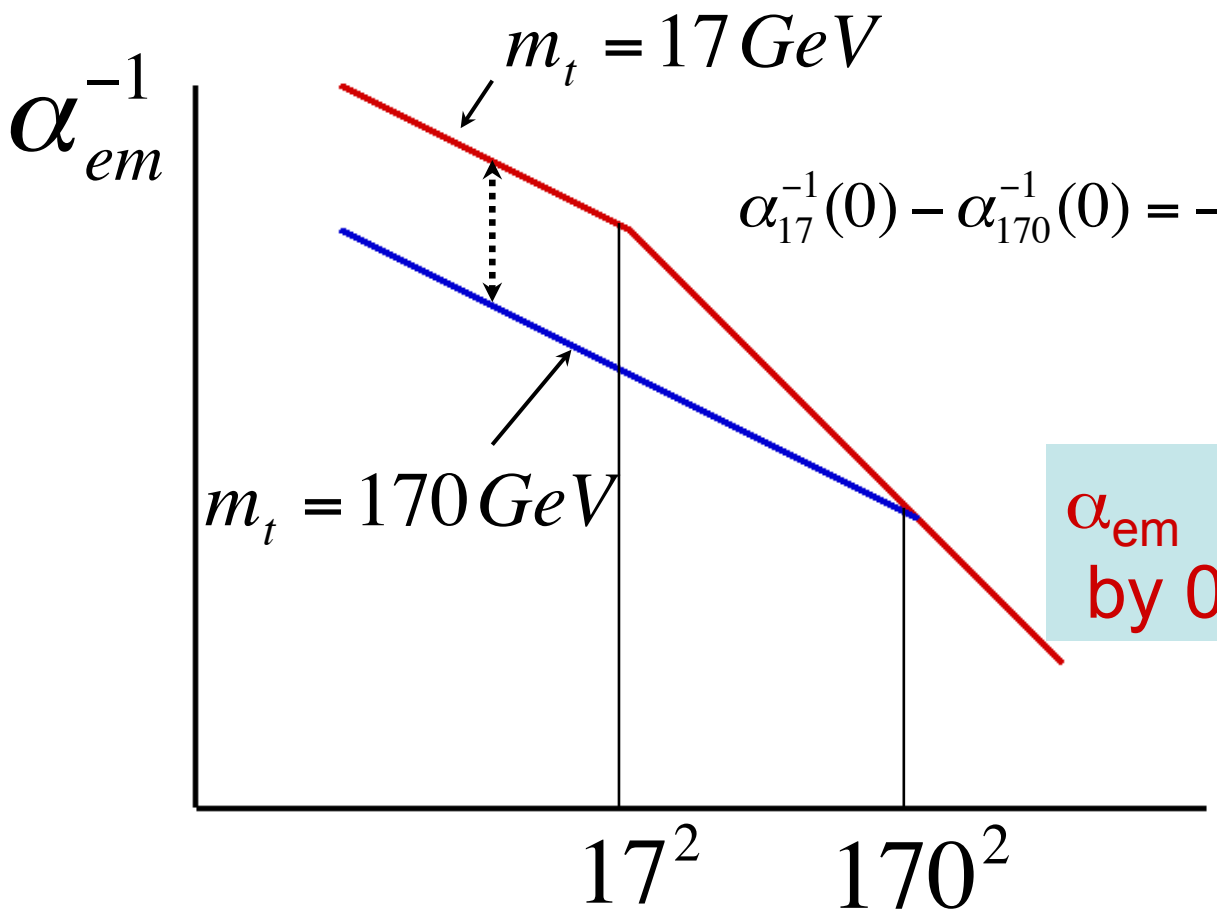
Quark mixing: $A, \lambda, \rho, \eta = V_{ud}, V_{us}, \ldots$

Electroweak Symmetry Breaking: v, m_H

Unification Philosophy

- High-energy values fixed.
- Low-energy values of couplings:
  - "evolve" (even in Kansas)
  - not fundamental
  - depend on fermion masses

If the *t* quark mass were 17 GeV



$$\alpha_{17}^{-1}(0) - \alpha_{170}^{-1}(0) = -\frac{4}{9\pi}\ell n\left(\frac{17}{170}\right)^2 = 0.65$$

α_{em} would decrease by 0.5%

m_t and the proton's mass

$$\Lambda_3 \propto m_t^{2/27}$$

Proton's mass determined by Λ_3 not quark masses.

(*u* and *d* quark masses are about 1% of a proton's)

If top quark mass were 10 times smaller,

proton's mass would be reduced by factor 0.84.

CP Violation and Baryon-Antibaryon Asymmetry

Andrei Sakharov (1967):

Why we're here:

Baryon number violation.

Non-equilibrium.

CP violation.

Is there CP violation in leptons?

- Neutrinos have mass.
- Neutrinos mix as quarks do.
- Neutrinos can be their own antiparticles.
- 18→27
  - 3 neutrino masses
  - 4 mixing parameters
  - 2 extra phases if “Majorana neutrinos”

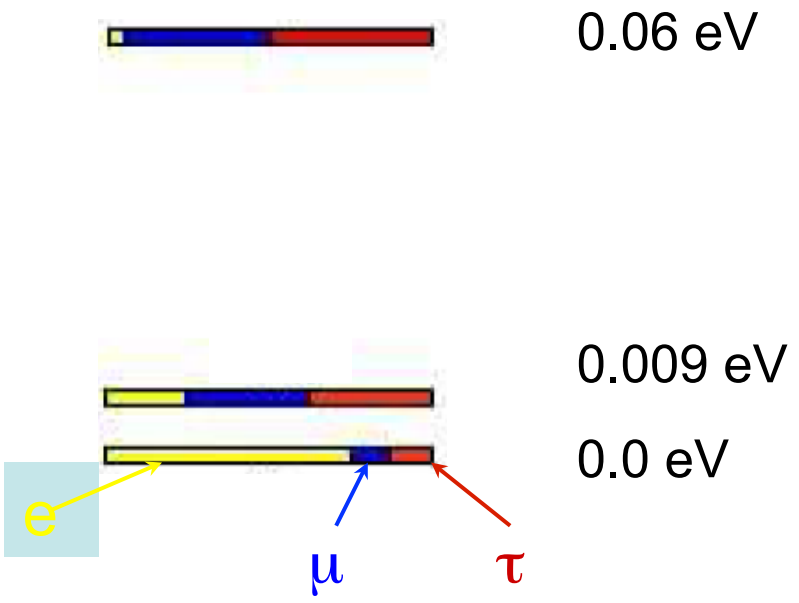
Neutrino Masses and Mixing

- Oscillations: “atmospheric” and “solar” neutrinos:

$$\Delta m^2_{solar} = 8 \times 10^{-5} eV^2$$

$$\Delta m^2_{atmos} = 3 \times 10^{-3} eV^2$$

$$\begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$



Majorana Neutrinos

- Electron has four degrees of freedom:

$$e_L^-, e_L^+, e_R^-, e_R^+$$

- Massive particle needs L and R.
- Can't have just e_L^-, e_L^+ : $CPT\, e_L^- = e_R^+$
- Can't use e_L^-, e_R^+
- For neutrinos can use $\nu_L, \overline{\nu}_R$ (Majorana)

Which CP violation makes us happen?

- Quarks? No. Too small.
- Light neutrinos? No. Too small.
- Heavy neutrinos? Maybe!
  - Need more parameters. CP violation for light neutrinos would be hint.

Electroweak Symmetry Breaking

Weak isospin: $\begin{pmatrix} \nu \\ e^- \end{pmatrix}_L \quad e_R^-$

Breaking this symmetry gives mass to fermions, *W*, and *Z.*

G_F in your everyday life.

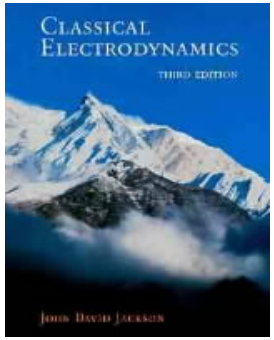
$\Gamma(pp \to de^+\nu) \propto G_F^2$ drives the sun.

Increasing v increases m_W and decreases G_F.

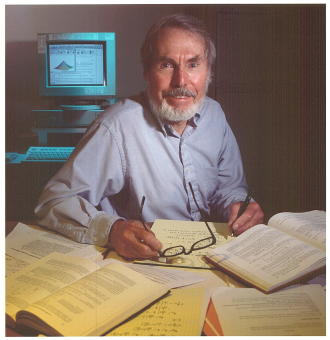
Decreases heat at center of sun. Sun contracts.

Problem 13.9

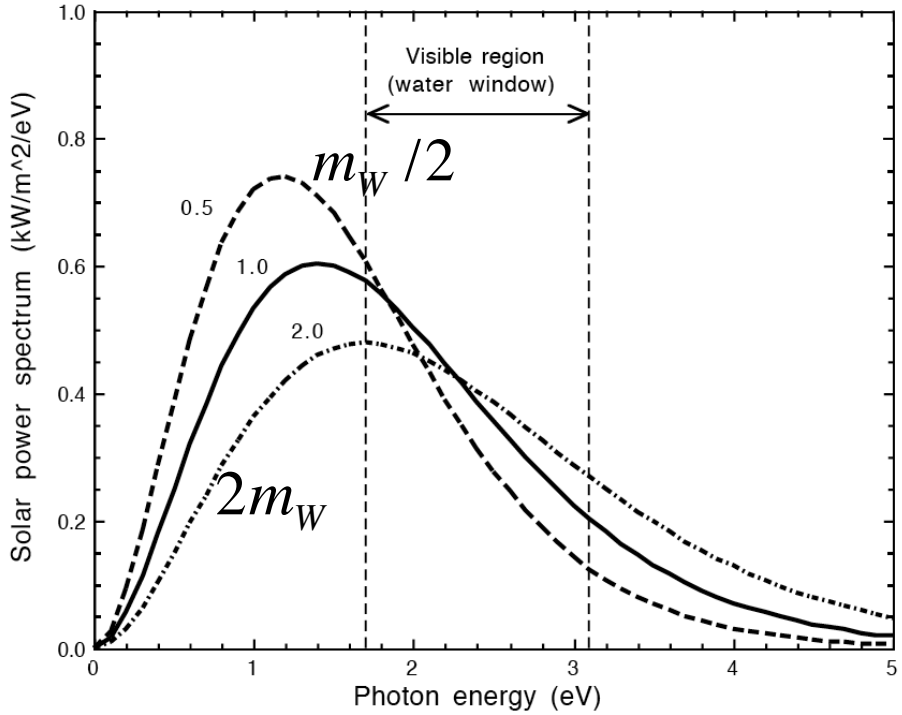
- Calculate what the sun's spectrum would be if the mass of the W boson were decreased by a factor of two and what it would be if the mass of the W boson were increased by a factor of two.



Solution by J.D.Jackson



Doubling m_W would cause the radius to shrink by 33% and increase the surface temperature by 22%.



Be sure to use sunblock!

Changing V_{ud}

$$A(pp \to de^{+}\nu) \propto V_{ud}\,\frac{1}{m_W^2}$$

V_{ud} can only decrease. Reducing it to 0.25 is equivalent to doubling m_W .

What about Higgs boson mass?

- Doesn't affect much. That's why its so hard to find!
- There could be several Higgs bosons, as in supersymmetry.

Why should we believe in supersymmetry? (with apologies to Pierre Fayet)

"Supersymmetry has withstood the test of time, although there is no evidence to support it."

From an introduction for Bruno Zumino as colloquium speaker at Berkeley.

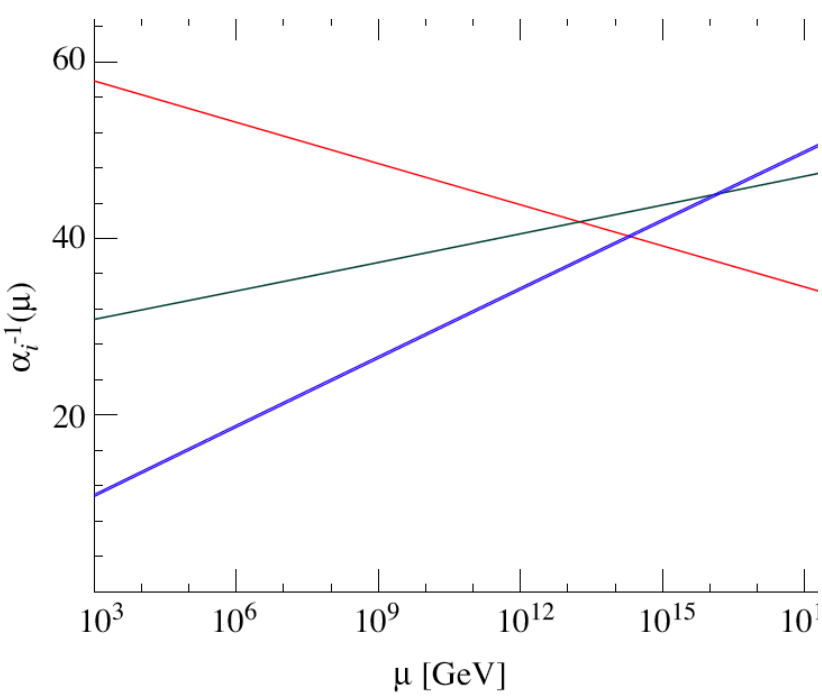
Theoretical esthetics.

Half the particles required by supersymmetry have been found.

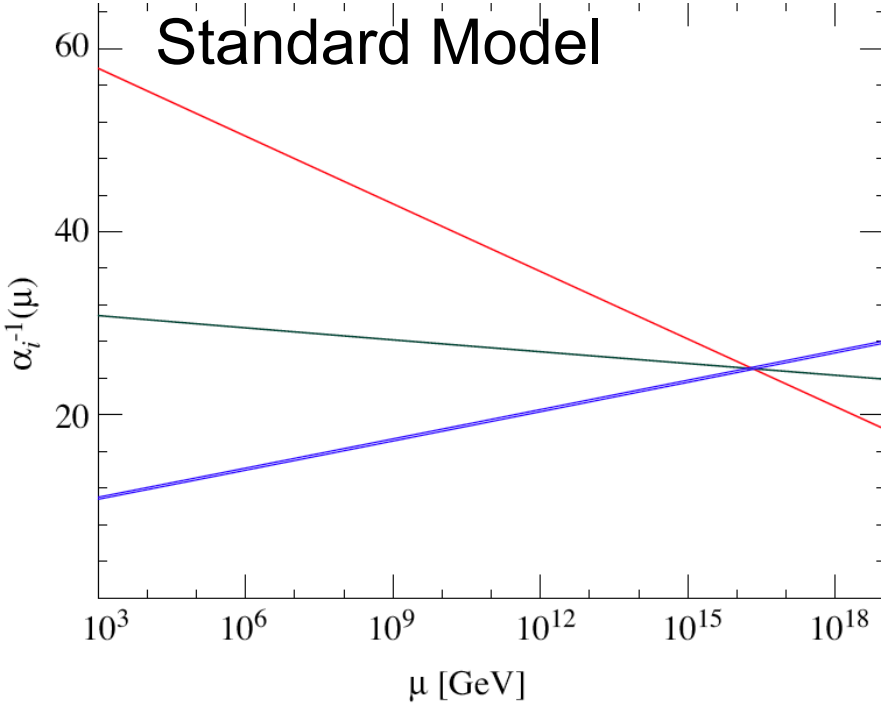
Grand unification works with supersymmetry, but not without it.

Grand Unification or Not?

Standard Model



Minimal Supersymmetric Standard Model



What if the lightest particles were selectrons, that is, bosons?

- Atoms would lose their individuality.
- Molecules would lose their integrity.
- Matter would fuse into an undifferentiated blob.

Binding energy of matter

- For ordinary matter with N atoms

$$\Delta E \propto -N$$

- For bosonic atoms (F. J. Dyson, 1967)

$$\Delta E \propto -N^{7/5}$$

- Watch out!

- The greatness of the Standard Model is not the questions it answers but the questions it lets us ask.

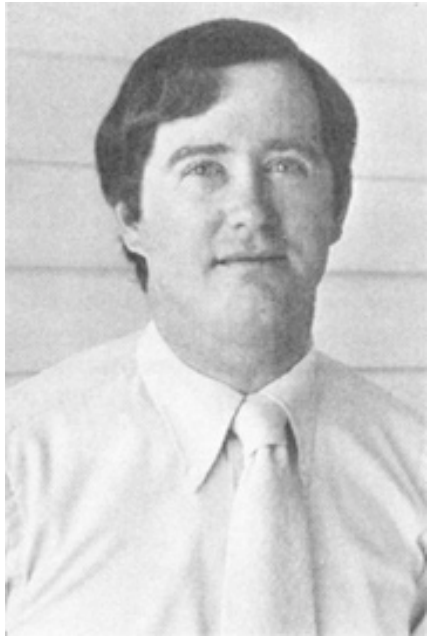
- It teaches us how much we actually have to explain about the world.

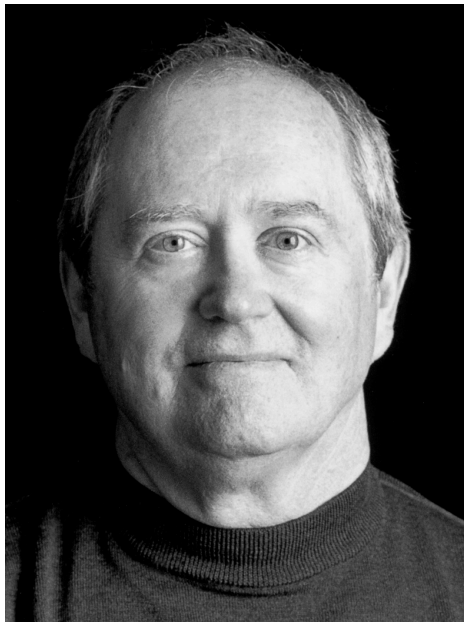
- It demands that we learn how our world was chosen (by symmetry breaking) from many equally plausible and quite different alternatives.

Without addressing the fundamental questions of particle physics we cannot fully explain the world of atoms and molecules, or even why there are atoms and molecules.

Chris has always insisted on the nobility of our work. We aren't doing all this for amusement or even to satisfy our own curiosity, but rather as surrogates for curious people everywhere who want to understand Nature.

Test of Time
Translation Invariance





Good enough approximation for a theorist.

Je te souhaite
le meilleur des anniversaires
possibles.