THE INFINITY PUZZLE

HOW THE HUNT TO UNDERSTAND THE UNIVERSE LED TO EXTRAORDINARY SCIENCE, HIGH POLITICS, AND THE LARGE HADRON COLLIDER

FRANK CLOSE

@closefrank

PETER HIGGS
The Economist:
“The Nobel Committee would be well advised to read Mr Close’s book before making their decision”
1964
1912: Rutherford and the nuclear atom
Person of the year 2012

Candidate

The Higgs Boson
Citation

Take a moment to thank this little particle for all the work it does, because

What's more

It was in the 1960s that Peter Higgs first posited the existence of a particle that

But it was not until last summer that a team of researchers at Europe's Large Hadron Collider —

at last sealed the deal and in so doing

The Higgs — as particles do — immediately
Take a moment to thank this little particle for all the work it does, because without it, you'd be just inchoate energy without so much as a bit of mass.

What's more, the same would be true for the entire universe.

It was in the 1960s that the physicist Peter Higgs first posited the existence of a particle that causes energy to make the jump to matter.

But it was not until last summer that a team of researchers at Europe's Large Hadron Collider — Rolf Heuer, Joseph Incandela and Fabiola Gianotti — at last sealed the deal and in so doing finally fully confirmed Einstein's general theory of relativity.

The Higgs — as particles don't immediately decayed to more-fundamental particles, but the scientists would surely be happy to collect any honors or awards in its stead.
Resolution of a 50 year old mystery
8 Oct 2013: Nobel Physics Prize

Francois Englert

Peter Higgs
For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles.....

..... and which was recently confirmed through the discovery of the predicted fundamental particle by ATLAS and CMS at CERN LHC
Tools needed to find Higgs Boson 2012
1912: Rutherford and the nuclear atom
Alpha particles from natural radioactivity

Gold leaf

Small scintillation screen

Rutherford: Nuclear Atom
Rutherford used energy conservation…)
...and long division
...and how Rutherford used them

\[
\frac{L}{t} = \frac{2 \times 1.5 \times 10^{17} \times 100 \times 4.05}{10^{10} \times 4.2 \times 10^{18}}
\]

\[
= \frac{6.6}{10^{12}}
\]

\[= \frac{6.6}{10^{12}} \text{ m/s.}\]

Ennus had by making accurate measurements of order 10^{-6} ern, it is found that distance followed by charged nuclei is very well accounted for with nuclear forces. The general it determines the region that at points where the deflecting forces mtlo and 1 deflects are large is very near central where the electric field is due almost entirely to central charge.

\[I = \frac{2NeE}{mv^2} \quad \therefore \quad v^2 = \frac{2I}{E} \quad \rho = \frac{NeE}{m}\]
Quarks in the proton

Electron beam = 3 km

Proton target (hydrogen)

Big electronic detector
Proton made of 3 quarks, gripped by gluons
To make proton and neutron requires two “flavours” of Quarks

**Up** and **down** Quarks
H atom
(not to scale!)

a miracle
of
neutrality

electron
balances

H atom (not to scale)

uud

hint of unification
Fundamental Forces

Gravity
Electromagnetic
Weak
Strong
QUANTUM ELECTRODYNAMICS
ELECTROMAGNETIC

 photon no mass

 W massive

 WEAK
The Gang of Six

- Brout
- Englert
- Guralnik
- Hagen
- Higgs
- Kibble
In truly empty space

**ELECTROMAGNETIC**

- photon **no mass**

- $W$ **no mass**

**WEAK**
Ionosphere ..... Plasma
Below Plasma Frequency

Emag wave

Above Plasma Frequency

Emag wave
Quantum: frequency = Energy

Minimum Energy = static particle with mass
“Plasmon”: excitation of the plasma
Need to know for this physics pedagogy:

- The vacuum is not nothing
- It's filled with “Higgs plasma”
- Excite this “Higgs plasma”
  - Plasmon => Higgson
In a recent note\(^1\) it was shown that the Goldstone theorem,\(^2\) that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson\(^3\) has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal, acoustic waves when the coupling to the electromagnetic field is turned off.
ELECTROMAGNETIC

\textbf{photon no mass}

\textbf{W massive}

WEAK
ELECTROMAGNETIC

photon no mass

W massive

WEAK
Why structure?

electron $\rightarrow$ atom size

Quark $\rightarrow$ compact nuclei

W massive: slow beta decay

Sun burns hydrogen for Byr
1912: Rutherford

2012: Higgs Englert and the nuclear atom
First to publish mass mechanism 1964

Massive boson that proves theory 1964/66

1967: Real world: photon massless; W massive
=> marriage of weak and electromag possible
Theory => 2013 Nobel Prize

for
Theory => 2013 Nobel Prize for CHEMISTRY
8 Oct 2013: Nobel Physics Prize

For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles.....

Francois Englert

..... and which was recently confirmed through the discovery of the predicted fundamental particle by ATLAS and CMS at CERN LHC

Peter Higgs
8 Oct 2013: Nobel Physics Prize

For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles.....

Robert Brout + Francois Englert

..... and which was recently confirmed through the discovery of the predicted fundamental particle by ATLAS and CMS at CERN LHC

Peter Higgs
THE INFINITY PUZZLE
HOW THE HUNT TO UNDERSTAND THE UNIVERSE LED TO EXTRAORDINARY SCIENCE, HIGH POLITICS, AND THE LARGE HADRON COLLIDER
FRANK CLOSE

@closefrank

PETER HIGGS
Resolution of a 50 year old mystery

HALF-LIFE

THE DIVIDED LIFE OF
BRUNO PONTECORVO,
PHYSICIST
OR SPY

FRANK CLOSE