An unification of light and electron

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Three turning points in my life

After 10 years closure, Deng Xiao-Ping reopened universities in 1977. I entered USTC that year.

After 30 years disconnection, TD Lee set up the CUSPEA program in 1980 to help Chinese students to come to US to study physics. I entered Princeton in 1982.

I switched from superstring theory to condensed matter theory in 1987. I have had a great fortune to work with world leading physicists in both fields.
What is CUSPEA program?
China-U.S. Physics Examination and Application
(1980 - 1988)

No GRE and no TOEFL in China that time.
After 30 years isolation, US universities cannot gauge Chinese students.

- TD persuaded Chinese government to organize a national exam to select physics students. (500-800/year participants and 100/year selected)
- TD persuaded near 100 universities to admit physics graduate students through this unusual channel.
- TD personally manage the application process to help all selected students to go to the schools of their choice.
What is the origin of photons and electrons?
Reductionist approach

A deeper understanding is gained by dividing things into smaller parts.
Emergence approach

Particle-wave duality $\rightarrow$
origin of particles = origin of waves

Three very famous wave equations

- Navier equation: $\partial_t^2 u^i - T^{i j k}_{m} \partial_j \partial_k u^m = 0$
  $\rightarrow$ sound waves in crystals.

- Euler equation: $\partial_t^2 \rho - v^2 \partial_i^2 \rho = 0$
  $\rightarrow$ density waves in (super) fluids.

- Maxwell equation: $\partial \times E + \partial_t B = \partial \times B - \partial_t E = 0$
  $\rightarrow$ electromagnetic waves and light.

What is the origin of those waves?
Principle of emergence

Different organizations (orders) of particles leads to different kinds of waves and wave equations.

- Crystal order $\rightarrow$ Navier equation $\rightarrow$ Transverse and longitudinal phonons
- Liquid order $\rightarrow$ Euler equation $\rightarrow$ Transverse and longitudinal phonons

$$|\Phi\rangle = \sum_{\text{all conf.}} |\text{ Boson state} \rangle \rightarrow \text{Boson condensed state}$$

Different organizations $\rightarrow$ different waves $\rightarrow$ different kinds of particles

Originate from organization $=$ principle of emergence
Reductionist approach does not apply to phonons

- A phonon has no smaller parts and is not formed by anything
- Phonons originate from the motions of organized particles that fill the whole space

**Should we understand photons in the same way?**

- May be all elementary particles originate this way, from the *things* that fill our vacuum
  - The simplest choice: the *things* = bosons/spins on some lattices
- The key is to find a particular organization of bosons whose collective waves are described by Maxwell equations $\rightarrow$ photons.
String-net condensation $\rightarrow$ Emergence of light

An organization of bosons that produces Maxwell eq. Levin & Wen 04

- bosons form strings (string-nets)
- string-nets form a quantum liquid

$|\Phi\rangle = \sum_{\text{all conf.}} |\ldots\rangle \rightarrow \text{String-net condensed state}$

- Waves in string-net liquid are described by Maxwell equations
  Light is the waving of condensed strings
What really are the photons in our world?

Fundamental building blocks or Collective motions of string-nets

- Is the ether really a string-net liquid?

**String-net picture also explains the origin of Fermi statistics**

- Strings are unobservable in string-net condensed state.
- Ends of strings behave like independent particles.

They are *charges* of the gauge field.
For string-net condensed state $|\Phi\rangle = \sum_{\text{all conf.}} |\rangle$

The end of strings are bosons.

For string-net condensed state $|\Phi\rangle = \sum_{\text{all conf.}} \pm |\rangle$

The end of strings are fermion.

*The different statistics of ends of strings is determined by the different kinds of string-net condensation.*

*String-net condensation provides a way to unify gauge interactions and Fermi statistics*
From lattice bosons/spins, how far can we go?

- Constructed a spin model whose string-net condensed state leads to $U(1) \times SU(3)$ gauge bosons, leptons and quarks. (2/3 of standard model)
- Can also have $SU(2)$, but the gauge coupling is not \textit{CHIRAL}!
  
  After many years hard work, we still do not know how to get gauged chiral fermions in a system with a finite cut-off.
  
  We do not know how to get the standard model from lattice bosons/spins.

After so many failed attempts,

\textit{we wish our world does not violate parity.}
Chiral fermion is one of deepest mysteries of nature

**Seven mysteries/wonders of universe:**

(1) Identical particles  
(2) Fermi statistics  
(3) Tiny masses of fermions (proton mass $\sim 10^{-20}$ Planck mass)  
(4) Chiral fermions  
(5) Gauge interactions  
(6) Lorentz invariance  
(7) Gravity

Starting from lattice bosons/spins, we can explain 4 of seven: Identical particles, Fermi statistics, Gauge interactions, Small masses, and, may be even Gravity.

Parity violation and chiral fermions carry a deep message, I believe, from the Planck scale. 50 years after its discovery, we still do not know how to decode it.

Parity violation and chiral fermions, like a light house in dark ocean, will guide us to sail into unknown territory.