Next week last class fuck! (exam probably at end of this month)

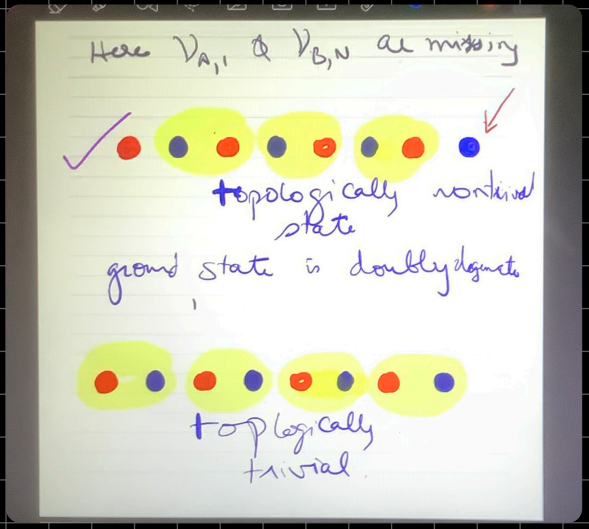
Topological Superconductivity

Majorana fermions in condensed matter

[Easiest realizat^{n} in a Quantum vortex in a $p_x + ip_y$ superconductor
↳ expt= 2/3 years earlier

Kitaev's toy model :- Spinless p-wave SC
↳ excitat^{n} on the boundary = linear combinat^{n} of fermionic operators.

Here $\gamma_{A,1}$ & $\gamma_{B,N}$ are missing



SOC + Superconductor
⇒ Primary → Qubits that have some topological protection.
↓
@ Microsoft, @ Google, @ IBM

Weyl Semi-metals :-

→ what are weyl "particles/excitations" from high en. physics?

→ "Bulk itself is conducting" → what are the interesting properties of weyl particles
- Chiral anomaly

References
RMP
Vanderbilt book

⇒ How does one realize a weyl Hamiltonian in cond matter systems

→ Role of symmetry → Dimensions = odd (1 or 3)

⇒ Berry Curvature hotspots ⇒ Surface states/ fermi arcs

↳ expt tests
→ ARPES
→ transport

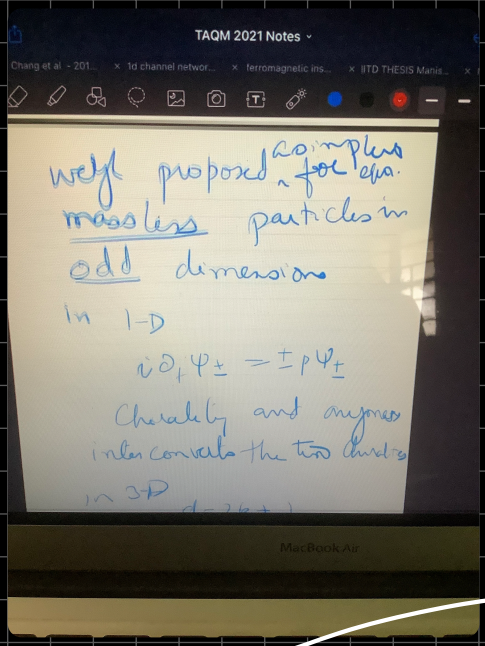
→ Majorana with Weyl

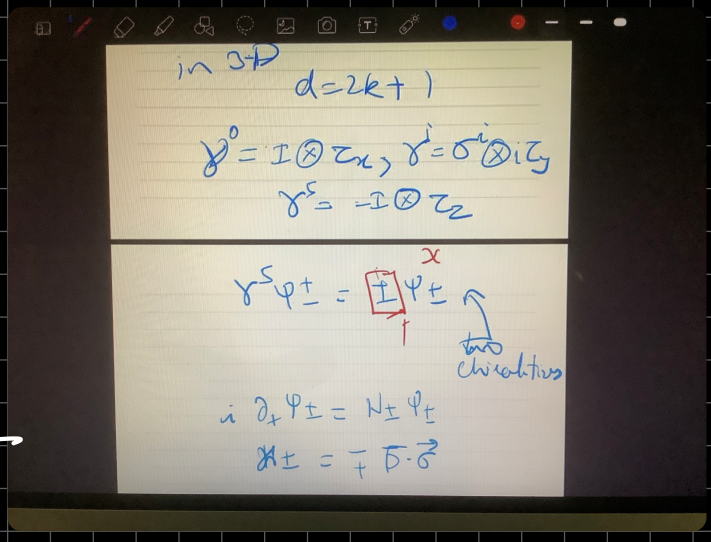
⇒ "Topological" weyl Superconductors

VANDERBILT

* Weyl from high en. physics.

dirac eqn ⇒ Chirality of the system in 3D





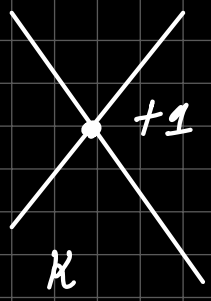
two chiralities → ± 1 $\quad \gamma^5 \psi_\pm = \pm \psi_\pm$

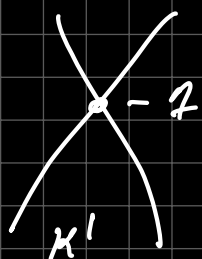
no real particles are identified as weyl fermions.

Weyl fermions propagate parallel or antiparallel to their spin.

Chirality

2 of them come in pairs ⇒ linear dispersion in 3 dimensions





⇒ might seem like Graphene

⇒ "effective low energy hamiltonian" → graphene (energy ~ 1eV

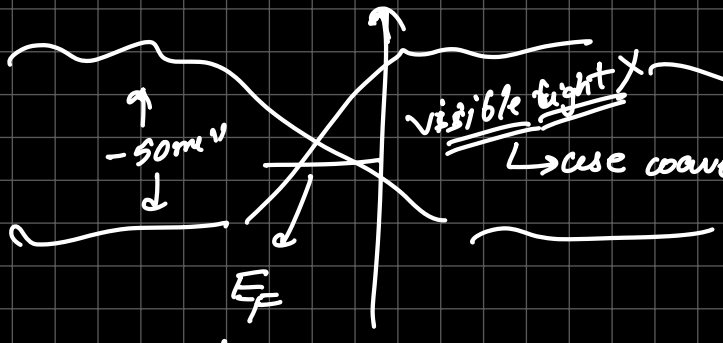
Chiral Anomaly

large en. scale

but for weyl, $\exists$ a smaller ($\sim$ 50 meV) over which it's linear.

"system specific"

- this physics can be/ can not be probed depending on
- $\exists$ an energy scale over which it's an accurate description of reality

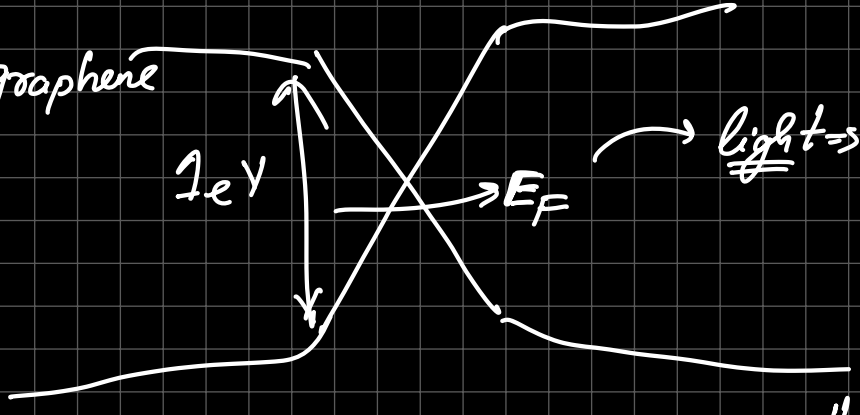


→ will easily probe the large en. physics

↳ use waves in THz

$\sim k_B T$ → low enough temperature

- graphene



→ light ⇒ scattering b/w e⊖ & photon

dirac

"not a description of all quasiparticles at all energies."

Quasiparticles ← "emergent excitation of a system."

Chiral Anomaly

$\partial_\mu j^\mu = 0$ & $\partial_\mu j^\mu_5 = 0$ → conversion b/w right handed to left handed

↳ independently # of left or right handed weyl fermions aren't conserved.

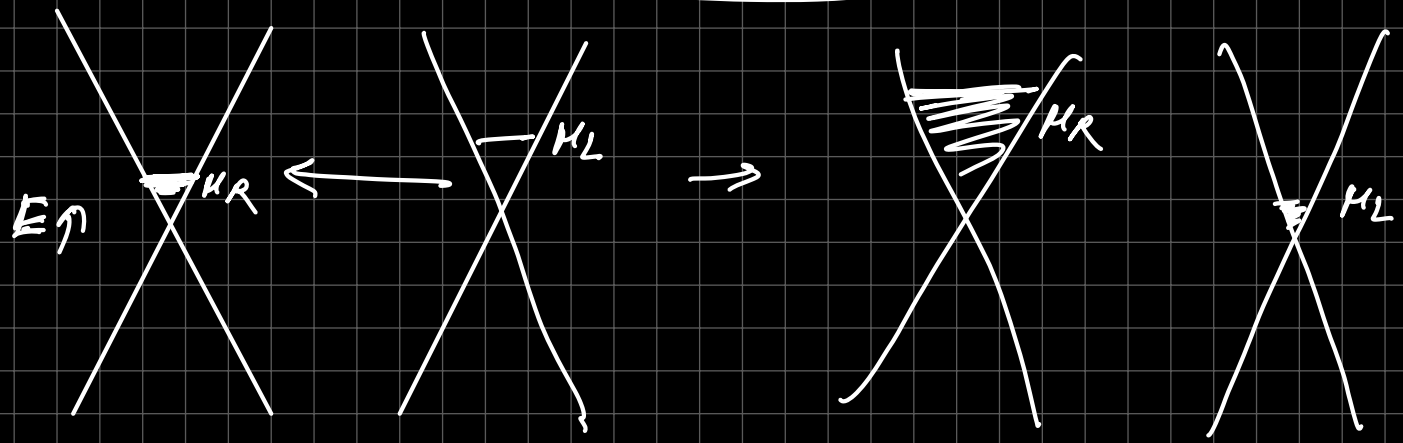
$\partial_\mu j^{\mu}_5 \neq 0$ ⟹ cons. of each species isn't possible

→ conv. b/w right handed to left handed weyl fermions.

"Total # of spin ↑ & spin ↓ is cons."

$$\partial_t (n_R + n_L) = 0$$

$$\partial_t (n_R - n_L) \neq 0$$



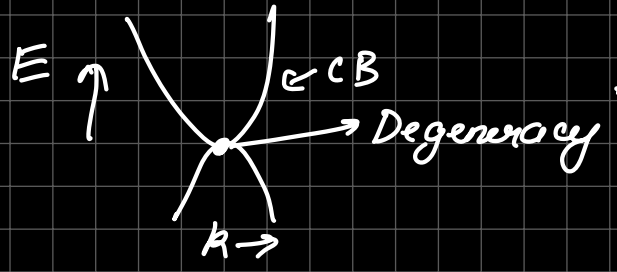
Total # is still conserved.

Smoking Gun confirmatn

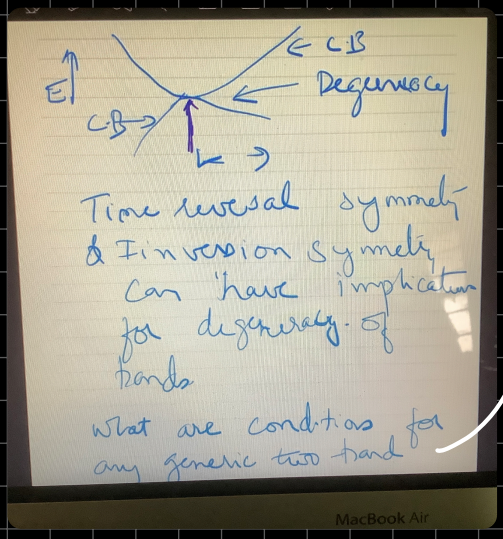
"Chiral anomaly"

→ ARPES :- Bandstructure

Condmat realization of Weyl hamiltonian.

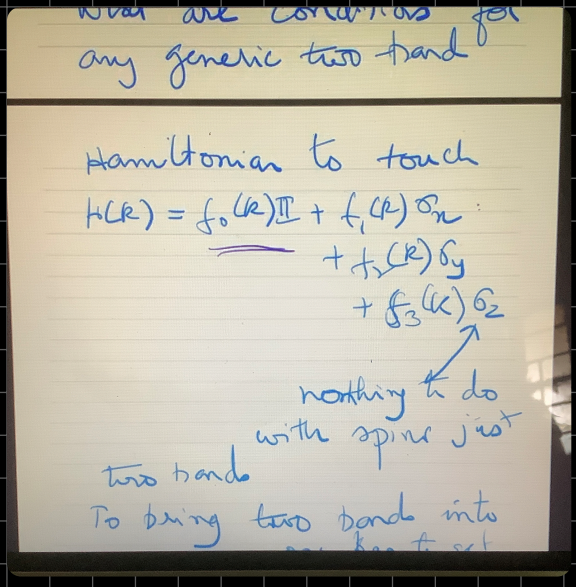


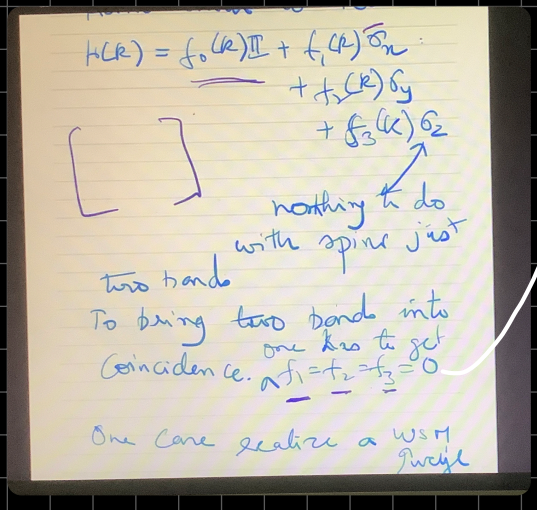
but now in 3D



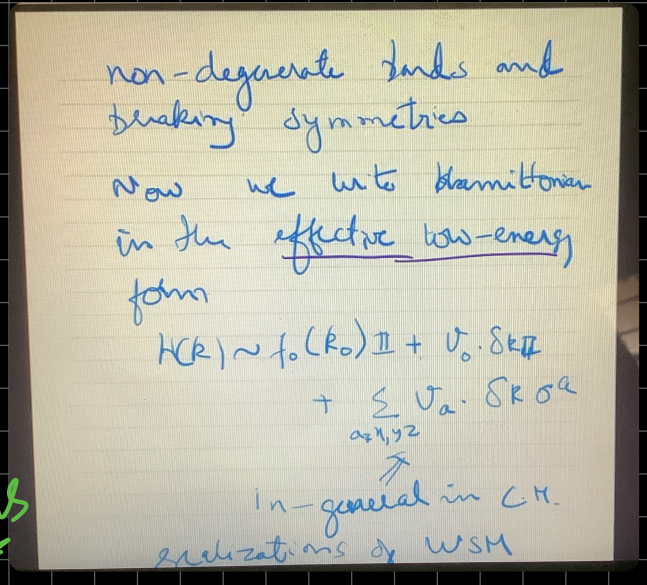
→ Hamiltonian to touch

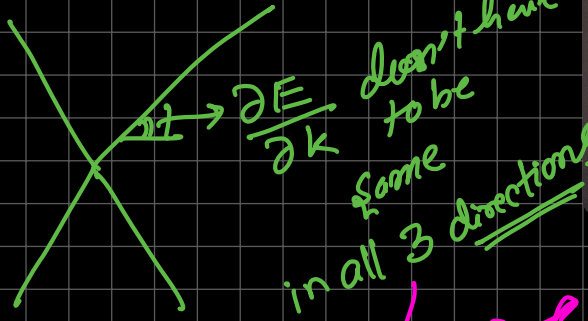
$H_0(k) =$



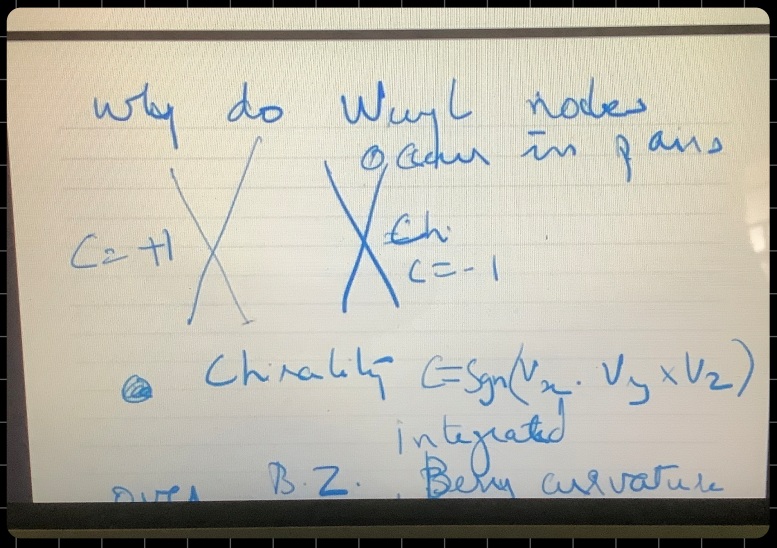


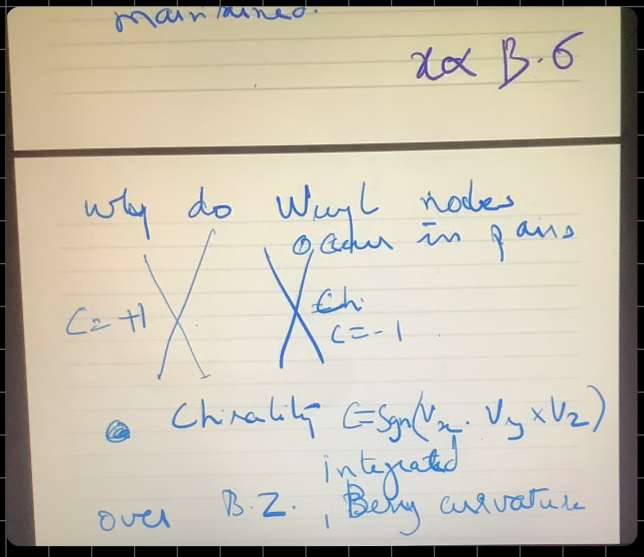
→ If at certain points in k-space, then we "get" a cone.

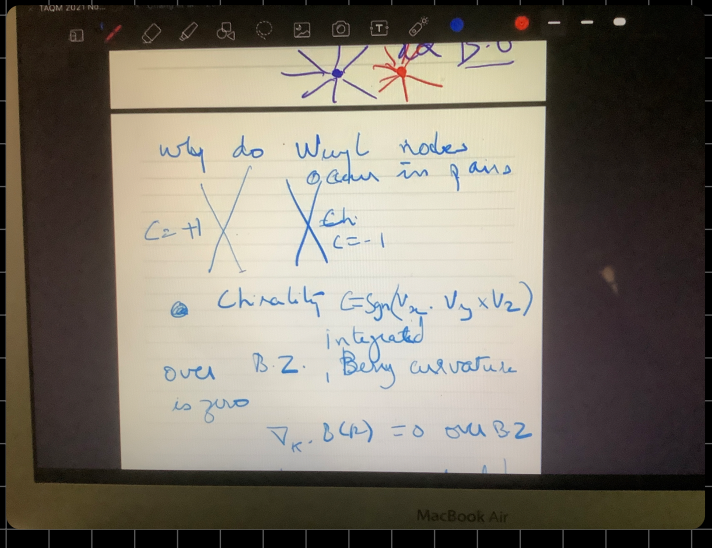




↳ Lorentz invariance may not be obtained







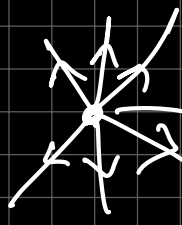
Another node → existence

↓

IR + TRS

$C_{net} BC = 0$

"physically justified way to argue for it is net Osum of B.C."

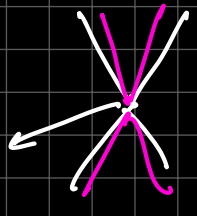


$H \propto \vec{B} \cdot \vec{\sigma}$ → a hotspot of BC of a particular sign

↳ if C=0, then ∃ another hotspot of opposite sense has to be here.

Two weyl nodes are sitting on top of each other.

↳ "Dirac semi-metals"

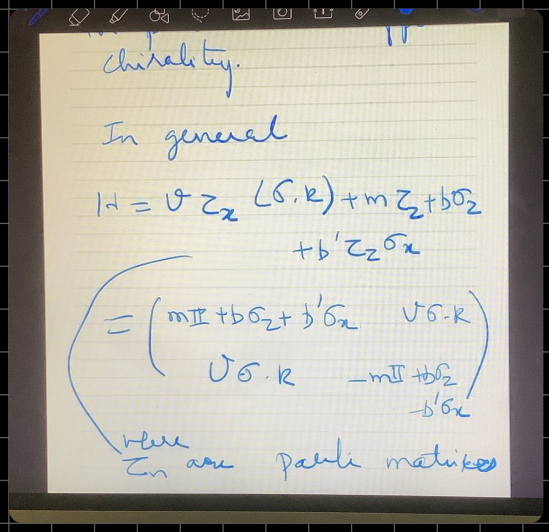


nodes → Chiral anomaly & other stuff doesn't happen.

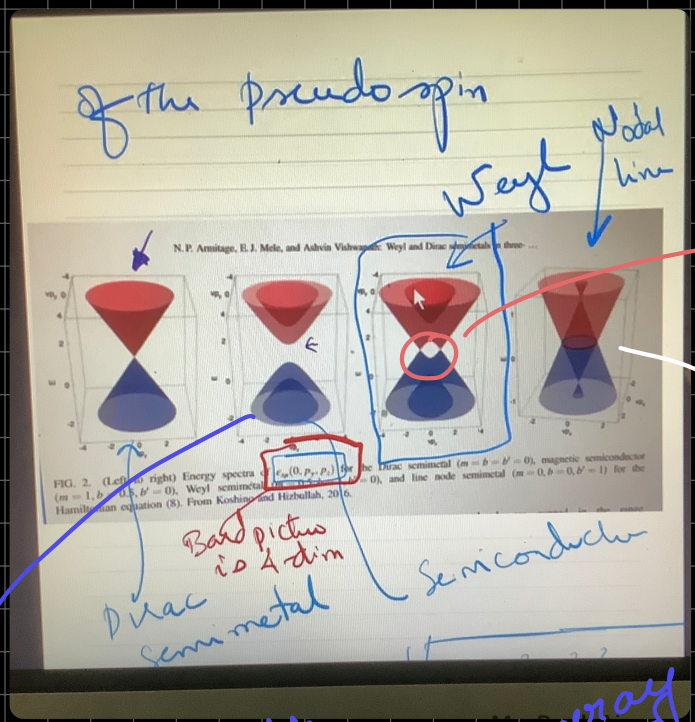
⇒ weyl nodes = must occur in "pairs"

↳ simple argument ⇒ $\int BC \, d\vec{\sigma} = 0$

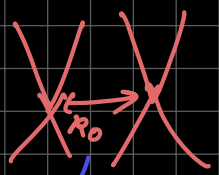
Lattice models of Weyl fermions



as b, b' are varied, → mimics all kinds of Band str.
↙
at some part ∃ weyl nodes



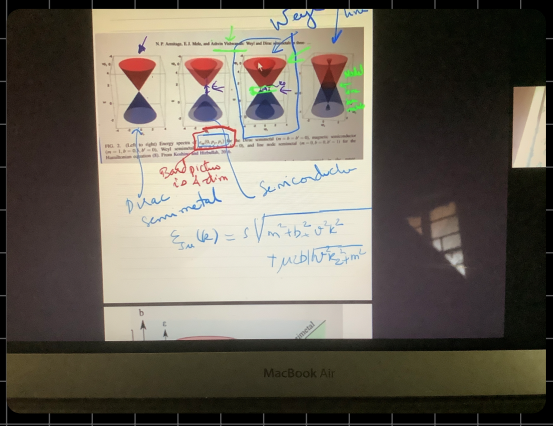
@ Armitage's paper



↳ weyl hamiltonian

touching pnt is a circle/ loop
↓
projected surface shown here
↓
"nodal line semimetals"

magnetic SC → ↑↓ degeneracy is lifted



Band touching are extremely common → what en. window is it a linear approximation good?

touching should not be buried under the fermi energy