Kagome Networks and Frustration

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Matrl 286G
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Emergent Phenomena

An entity exhibits properties its parts do not possess on their own
Reductionist Approach

Reductionist Approach

### Standard Model of Elementary Particles

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Mass</th>
<th>Charge</th>
<th>Spin</th>
<th>Leptons</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>~2.2 MeV/c^2</td>
<td>+1/3</td>
<td>0</td>
<td>e</td>
<td>~0.511 MeV/c^2</td>
</tr>
<tr>
<td>c</td>
<td>~1.28 GeV/c^2</td>
<td>+2/3</td>
<td>1/2</td>
<td>μ</td>
<td>~0.17 MeV/c^2</td>
</tr>
<tr>
<td>t</td>
<td>~173.1 GeV/c^2</td>
<td>+3/3</td>
<td>0</td>
<td>τ</td>
<td>~18.2 MeV/c^2</td>
</tr>
<tr>
<td>u̅</td>
<td>~2.2 MeV/c^2</td>
<td>-1/3</td>
<td>0</td>
<td>e^+</td>
<td>~2.2 eV/c^2</td>
</tr>
<tr>
<td>c̅</td>
<td>~1.28 GeV/c^2</td>
<td>-2/3</td>
<td>1/2</td>
<td>μ̅</td>
<td>~0.17 MeV/c^2</td>
</tr>
<tr>
<td>t̅</td>
<td>~173.1 GeV/c^2</td>
<td>-3/3</td>
<td>0</td>
<td>τ̅</td>
<td>~18.2 MeV/c^2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bosons</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>g</td>
<td>~124.97 GeV/c^2</td>
</tr>
<tr>
<td>H</td>
<td>~124.97 GeV/c^2</td>
</tr>
<tr>
<td>γ</td>
<td>~91.19 GeV/c^2</td>
</tr>
<tr>
<td>Z</td>
<td>~80.39 GeV/c^2</td>
</tr>
<tr>
<td>W^+</td>
<td>~80.39 GeV/c^2</td>
</tr>
<tr>
<td>W^-</td>
<td>~80.39 GeV/c^2</td>
</tr>
</tbody>
</table>

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Emergent Phenomena in Kagome Networks

- Fractional Quantum Hall Effect
- Quantum Spin Liquid States
- Spinons
- Majorana fermions

Kagome Networks

- Intersecting webs of “corner-sharing triangles”
- Named after patterned bamboo basket
  - Bamboo-basket (kago) woven pattern (me)

https://english.cas.cn/newsroom/research_news/phys/202112/t20211217_294587.shtml
Kagome Networks

- Lars Onsager (1944) paper on square lattice Ising model
- Kodi Husimi and Itiro Syôzi (1950) simplified Onsager's solutions and solved for honeycomb and triangular
- Syôzi (1951) studied Kagome lattice

Frustration in Kagome Network

\[ \vec{S}_A + \vec{S}_B + \vec{S}_C = \vec{0} \]

Resonant Valence Bond Theory

- Valence bonds are allowed to undergo quantum mechanical fluctuations
- GS is a superposition of different partitionings of spins into valence bonds

Figure 3: Valence-bond states of frustrated antiferromagnets.

First Kagome Candidate

On the Spin Arrangement in “Kagome” Lattice of Antiferromagnetic $\text{KFe}_3(\text{OH})_6(\text{SO}_4)_2$

Mikio Takano, Teruya Shinjo and Toshio Takada

Institute for Chemical Research, Kyoto University, Uji, Kyoto-fu
(Received August 18, 1970)

Experimental results showed that $\text{KFe}_3(\text{OH})_6(\text{SO}_4)_2$ is antiferromagnetic below 60°K and in each crystal c-plane, Fe ions form a compensated antiferromagnet. The crystal structure of Fe ions in the c-plane is a “kagome” lattice and it has been known that collinear antiferromagnetic spin arrangements are not stable in the kagome lattice. An estimation of the spin structure was attempted with the analysis of the Mössbauer spectrum and a kind of triangular configuration was suggested.

Jarosite

https://underthescopemineral.tumblr.com/post/178252086249/jarosite-kfe3-3so42oh6-localityla
Kagome System $\text{SrCr}_8\text{Ga}_4\text{O}_{19}$

μSR Muon Spin Relaxation Technique

Parity-violating collinear decay of a pion $\pi^-$ at rest into a muon $\mu^+$ and a muonic neutrino $\nu_\mu$.

Angular distribution of the positrons from the muon decay: $W(E,\theta) = 1 + a(E)\cos(\theta)$. When all positron energies $E$ are sampled with equal probability the asymmetry parameter has the

Kagome FeSn

ZnCu$_3$(OD)$_6$Cl$_2$ (herbertsmithite)

$\text{AV}_3\text{Sb}_5$ (A=K,Rb,Cs)

Ortiz, Brenden R., Gomes, Lidia C., Morey, Jennifer R., Winiarski, Michal, Bordelon, Mitchell, Mangum, John S., Oswald, Iain W. H., Rodriguez-Rivera, Jose A., Neilson, James R., Wilson, Stephen D., Ertekin, Elif, McQueen, Tyrel M., & Toberer, Eric S. (2019)
AV$_3$Sb$_5$ (A=K,Rb,Cs)

Thank You!