



मौलिक विज्ञान प्रकर्ष केन्द्र

Unlocking Room-temperature Quantum Spin Entanglement

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Institute Public Lecture, IIT Indore, April 13, 2026




Indian Institute of Technology Indore


VIMARSH
INSTITUTE PUBLIC LECTURE

**Unlocking Room-
temperature Quantum
Spin Entanglement**

Distinguished Speaker
Prof. S. M. Yusuf
FNASc, FNA, FASc, FNAE, FTWAS
J C Bose National Fellow,
Vigyan Shri



 April 13, 2026
(Monday)

 4:30 PM IST

 POD 1D – 105

Contact:
outreach@iiti.ac.in

All Are Welcome!

National Quantum Mission

The Union Cabinet, chaired by the Hon'ble Prime Minister Shri Narendra Modi, today approved the **National Quantum Mission (NQM) at a total cost of Rs.6003.65 crore** from 2023-24 to 2030-31, aiming to seed, nurture and scale up scientific and industrial R&D and create a vibrant & innovative ecosystem in Quantum Technology (QT)

April 19, 2023

National Quantum Mission (NQM) at a total cost of Rs.6003.65 crore from 2023-24 to 2030-31

Four T-Hubs:

I: IISc Bengaluru

II: IIT Madras

III: IIT Bombay

IV: IIT Delhi

Announcement on Sept 30, 2024

National Quantum Mission

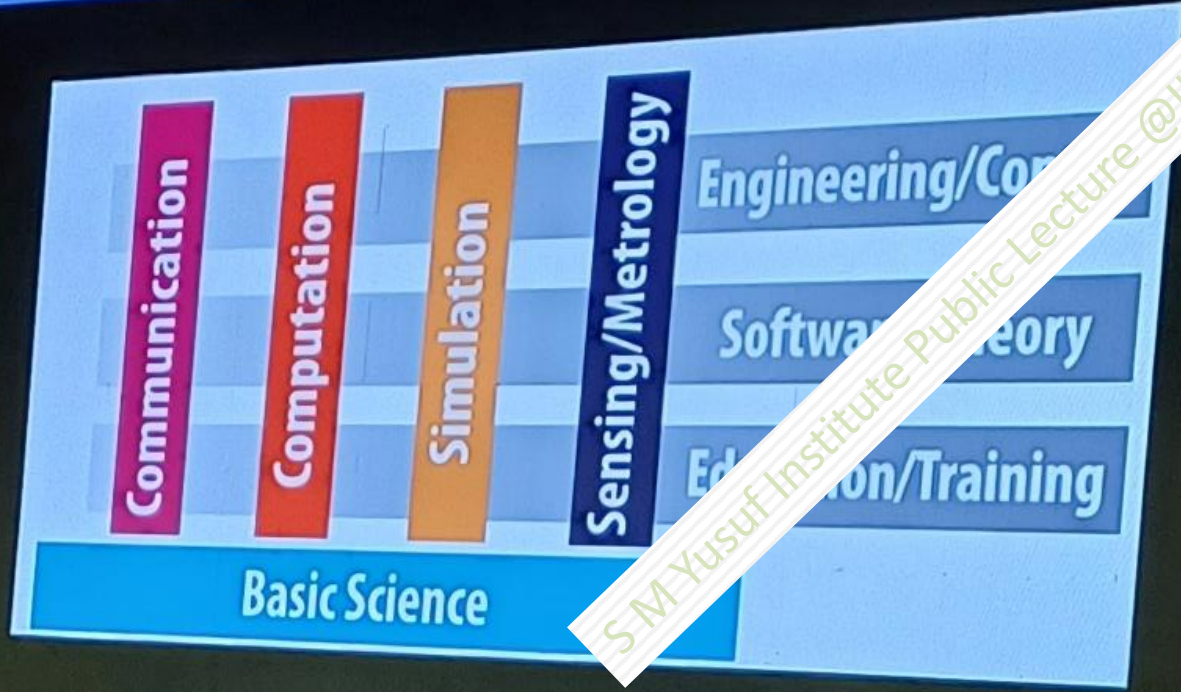
- I. Quantum Computing**
- II. Quantum Communication**
- III. Quantum Sensing & Metrology**
- IV. Quantum Materials & Devices**

Each T-Hub will operate under the Hub-Spoke-Spike Model

Spokes: Cluster based network of Research Projects

Spikes: Individual Research Groups

ROADMAP FOR QUANTUM TECHNOLOGIES



S.M. Yusuf Institute Public Lecture @IIT Indore

There are various platforms for the qubit design:

1. **Superconducting qubit (TRANSMON):** Josephson junction of superconductors
2. **Hybrid qubit, Superconductor-Topological Insulator-Superconductor (S-TI-S) Josephson junctions**
3. **Trapped-ion qubit:** (Individual ions e.g., Ytterbium, Calcium)
4. **Quantum dot:** Nanoscale semiconductor structure
5. **Spin qubit : Use the intrinsic spin of electrons** or holes confined in semiconductor quantum dots. **in silicon**
6. **Nitrogen vacancy-defect diamond-based qubit**
7. **Topological nano-wire qubit-Majorana qubit**

Among all these, **Transmon** is the most widely used qubits platform as on today, because of its advantages like **good coherence, easy coupling, and readout** etc.

In addition, research on discovering new materials such as spin chain oxides (**dimer and trimmer chains**), superconductors, **topological insulators** having robust **correlated quantum entangled state**

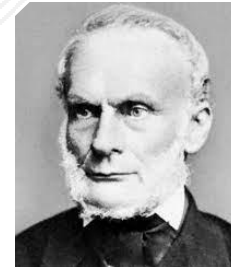
Classical concept



Sir Isaac Newton
(1642-1727)



James Clerk Maxwell
(1831-1879)



Rudolf Clausius
(1822-1888)

Two distinct categories :

1. Material body (**particle**): Newton's laws of motion

$$F = m.a$$

Position and velocity (momentum) are precisely measurable **simultaneously**

2. Electromagnetic field (**wave**): Maxwell's equation

$$\nabla \cdot \mathbf{D} = \rho_v \quad | \quad \nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad | \quad \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}$$

3. Additionally Laws of thermodynamics

$$E = kT$$

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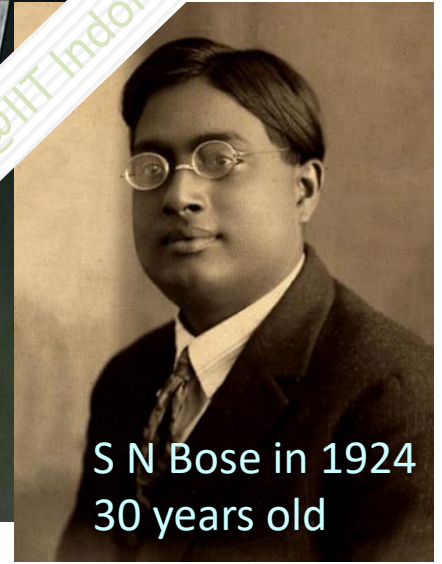
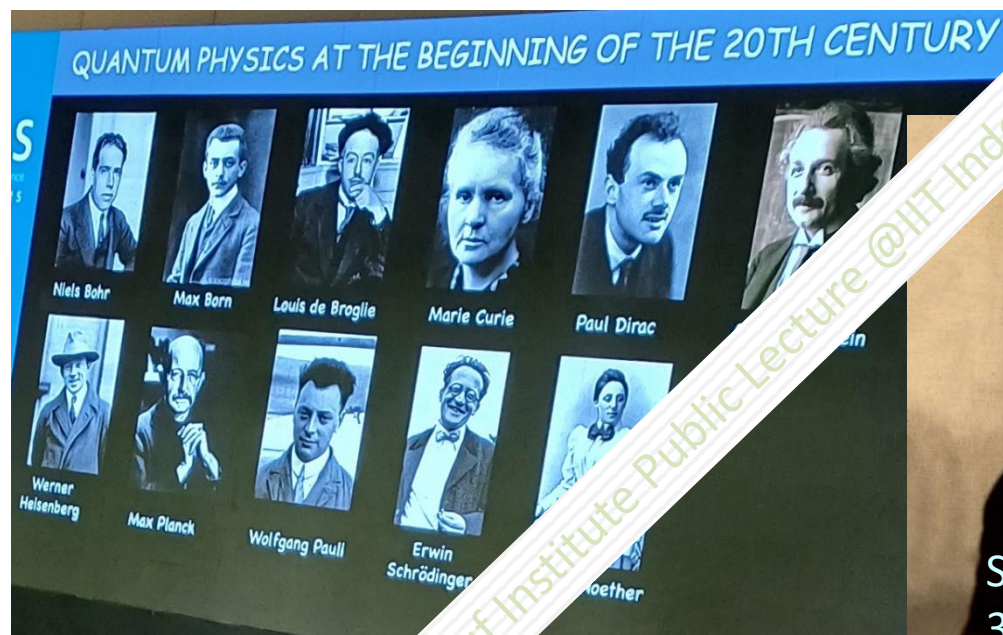
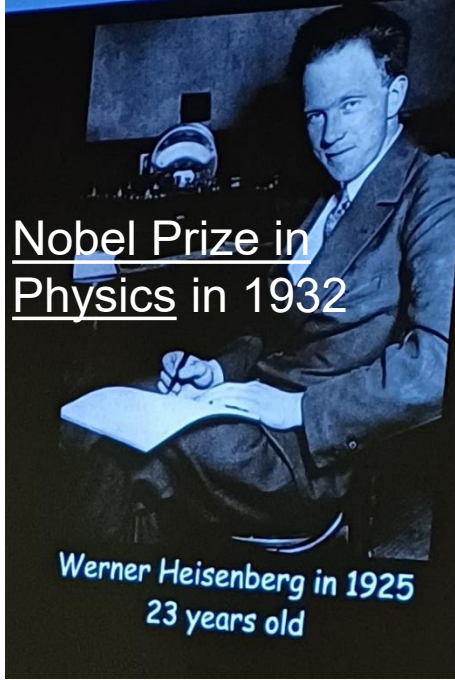
Classical concepts never allow to think that

1. Wave may also behave like a particle
(**Planck's hypothesis: Photon Quanta**)
2. Particle may behave like wave
(**de Broglie hypothesis: $\lambda = h/p$**)
3. Position and momentum of a particle **cannot** be measured accurately **simultaneously**
(**Heisenberg uncertainty principle: $\Delta x \cdot \Delta p \geq \hbar$**)
4. Energy of wave is related with frequency, & quantized
 $E = nh\nu$



Max Planck
(1858-1947)

These new concepts are basically quantum mechanical concepts



S N Bose (1924), "Plancks Gesetz und Lichtquanten-hypothese", *Zeitschrift für Physik* (in German), **26**: 178–181

Planck's Law and the Hypothesis of Light Quanta (Quantum statistics)

Pauli Exclusion Principle (1925): 25 years old

Zeitschrift für Physik in July 1925

Observable parameters, parameters that could be measured in scientific experiments, such as **transition probabilities** or **frequencies**

Heisenberg's **uncertainty principle** *Zeitschrift für Physik* in March 1927

Solvay Conference 1927 *.....too much intelligence!*

Founded by industrialist Ernest Solvay



Picard

Henriot

Ehrenfest

Herzen

de Donder

Schrödinger

Verschaaffelt

Pauli

Heisenberg

Fowler

Brillouin

Debye

Knudsen

Bragg

Kramers

Dirac

Compton

de Broglie

Born

Bohr

Langmuir

Planck

Curie

Lorentz

Einstein

Langevin

Guye

Wilson

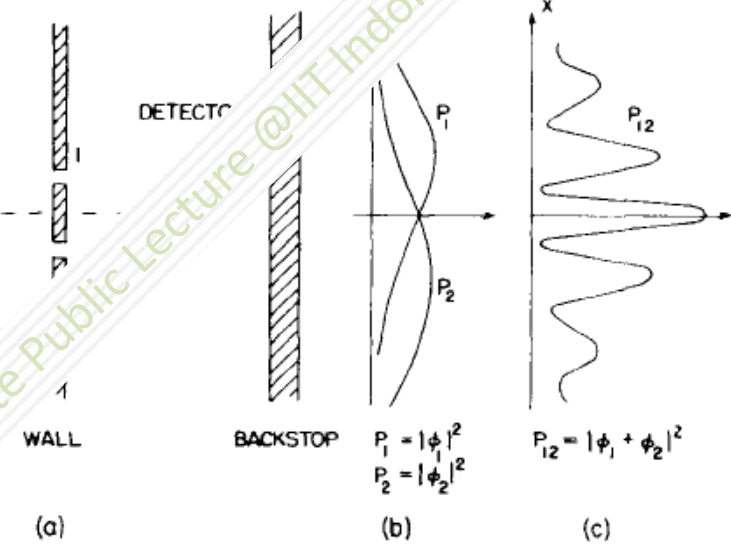
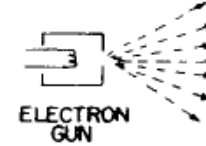
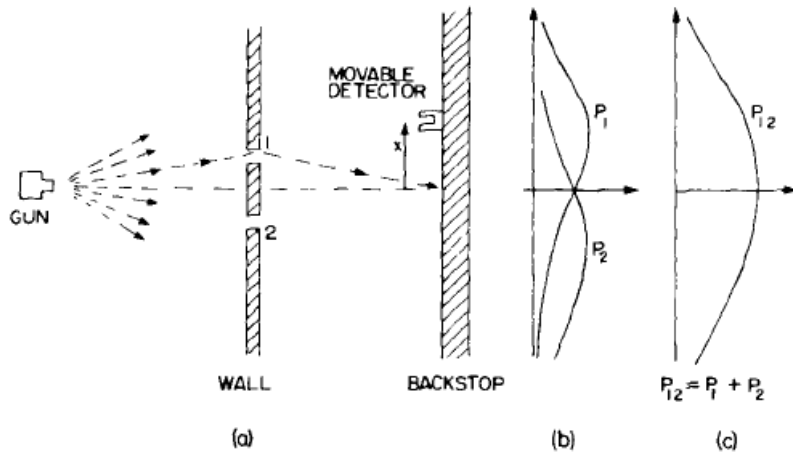
Richardson

Young's Double Slit Experiment (using particles):



Quantum

Classical



Bullets cannot interfere

$$P_{12} = P_1 + P_2$$

$$P_{12} = ||\Phi_1\rangle + |\Phi_2\rangle|^2$$

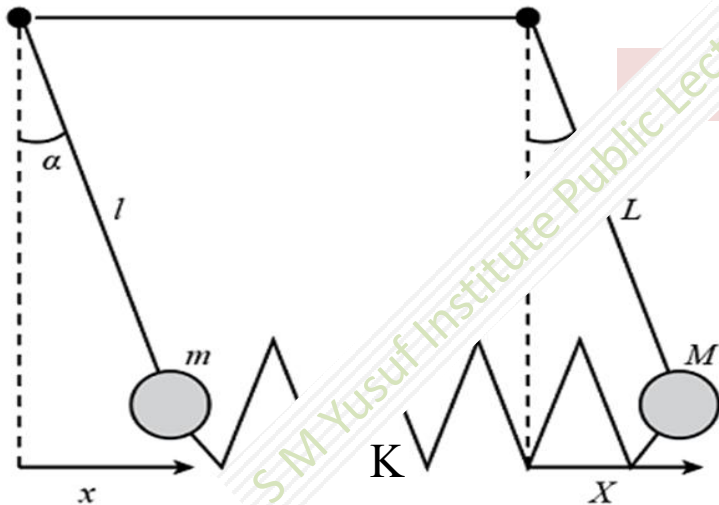
$|\Phi_1\rangle$ represents the state with the electron in the slit 1
 $|\Phi_2\rangle$ represents the state with the electron in the slit 2

Quantum Entanglement of two Oscillators

Hamiltonian: $H = T_1 + T_2 + V(x, X)$

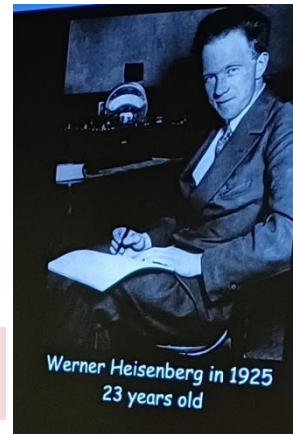
General Solution

$$Y(x, X, t) = y_1(x, t) \cdot y_2(X, t)$$



Quantum mechanical state

$$\Psi_{S/A}(x, X, t) = |\Phi_1(x, t), \Phi_2(X, t)\rangle \pm |\Phi_1(X, t), \Phi_2(x, t)\rangle$$



Two ions in same laser trap act as a coupled pendula oscillator

Quantum Spin Entangled States

$$\frac{1}{\sqrt{2}} \left(\begin{array}{c} \uparrow \\ \downarrow \end{array} \begin{array}{c} \downarrow \\ \uparrow \end{array} \pm \begin{array}{c} \downarrow \\ \uparrow \end{array} \begin{array}{c} \uparrow \\ \downarrow \end{array} \right)$$

A natural building block for non-magnetic states

Quantum Spin States

Qubit: Fundamental unit of quantum computing

$$|\uparrow\rangle \quad |\uparrow\rangle$$

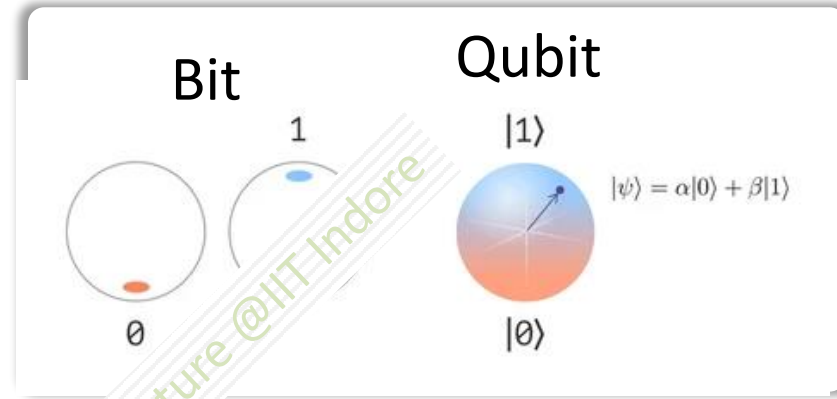
$$\psi = |\uparrow, \uparrow\rangle, \text{ Un-Entangled states:}$$
$$= |\downarrow, \downarrow\rangle,$$

$$= \frac{1}{\sqrt{2}} (|\uparrow, \downarrow\rangle + |\downarrow, \uparrow\rangle),$$
$$= \frac{1}{\sqrt{2}} (|\uparrow, \downarrow\rangle - |\downarrow, \uparrow\rangle)$$

Entangled states

General states of two entangled qubits

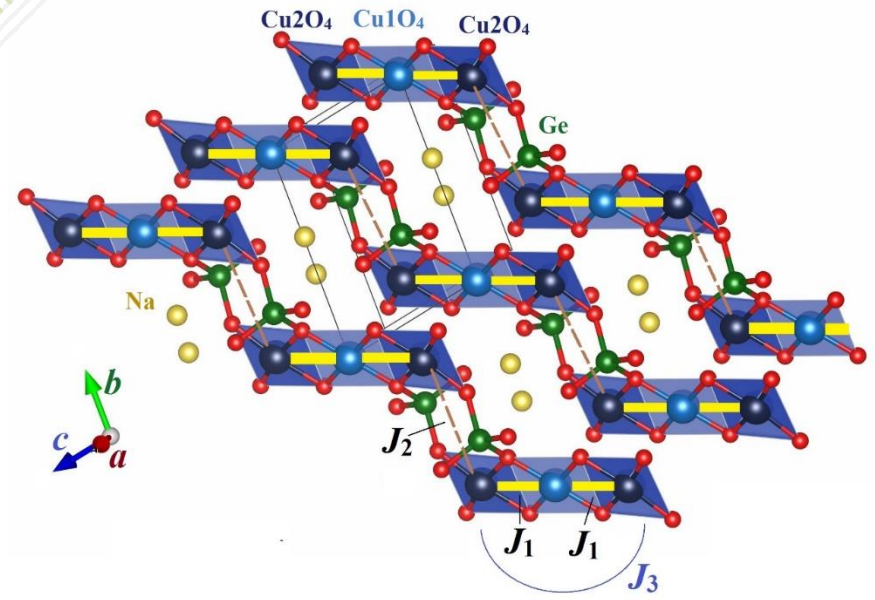
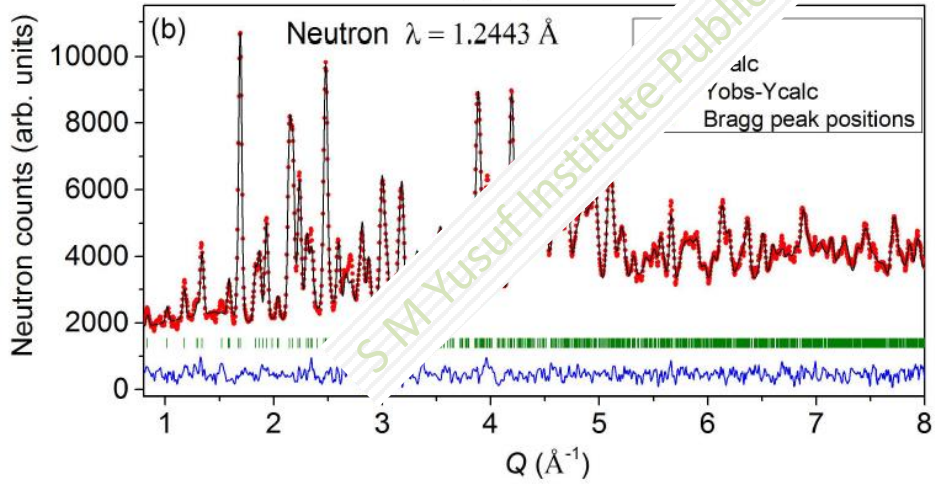
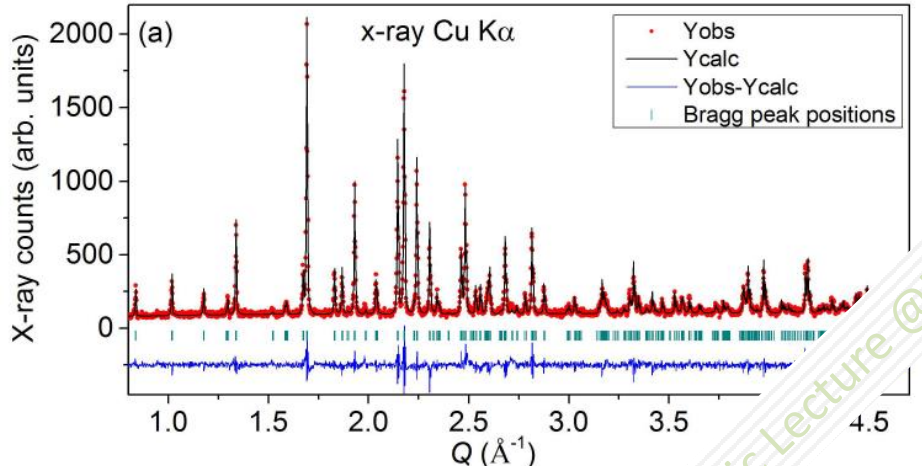
$$\psi = (a|\uparrow, \downarrow\rangle \pm b|\downarrow, \uparrow\rangle)$$



Access and control these quantum properties with better coherence, scalability, measurements access

$\text{Na}_2\text{Cu}_3\text{Ge}_4\text{O}_{12}$

Cu^{2+} in CuO_4 square planes



Triclinic, $P-1$

Dhruva Research Reactor @ BARC, Mumbai

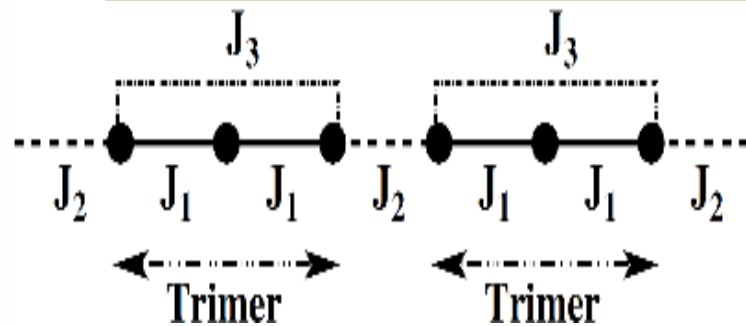
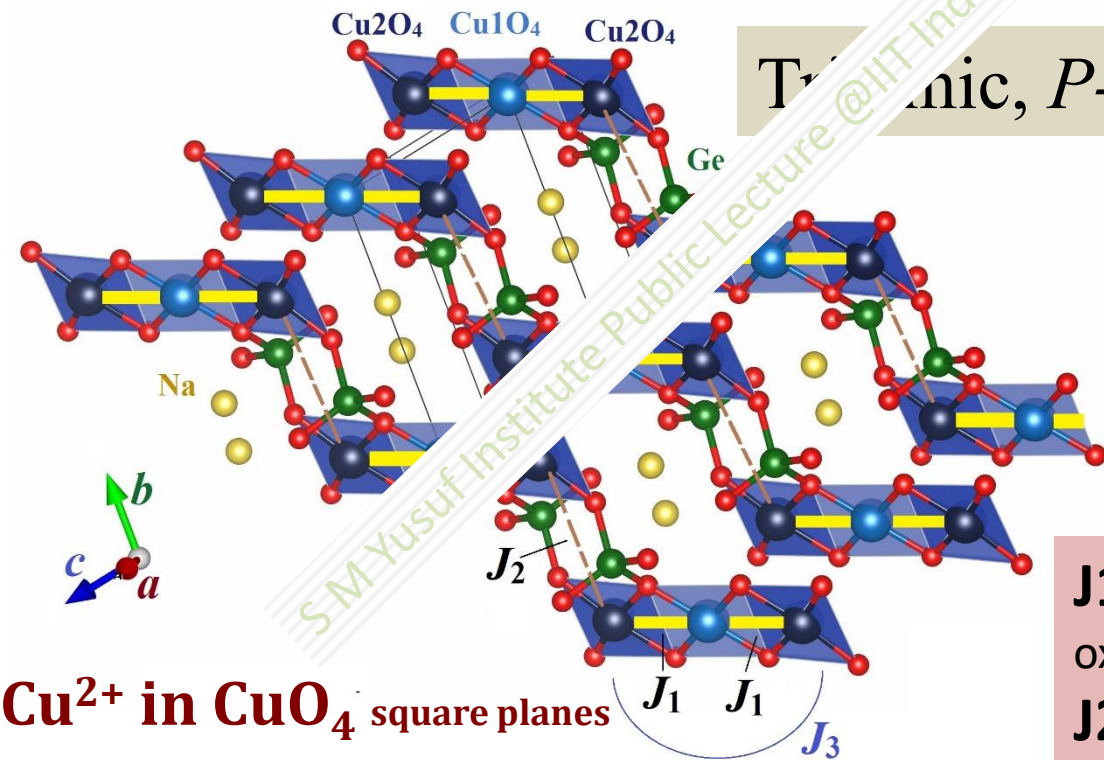


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Interacting spin-1/2 trimer chain in $\text{Na}_2\text{Cu}_3\text{Ge}_4\text{O}_{12}$

Trimeric, $P-1$

Composed of Cu_3O_8 trimers formed by edge-sharing 3 CuO_4 square planes in a linear fashion



Cu^{2+} in CuO_4 square planes

$\alpha = J_2/J_1 = 0$: Isolated Trimers

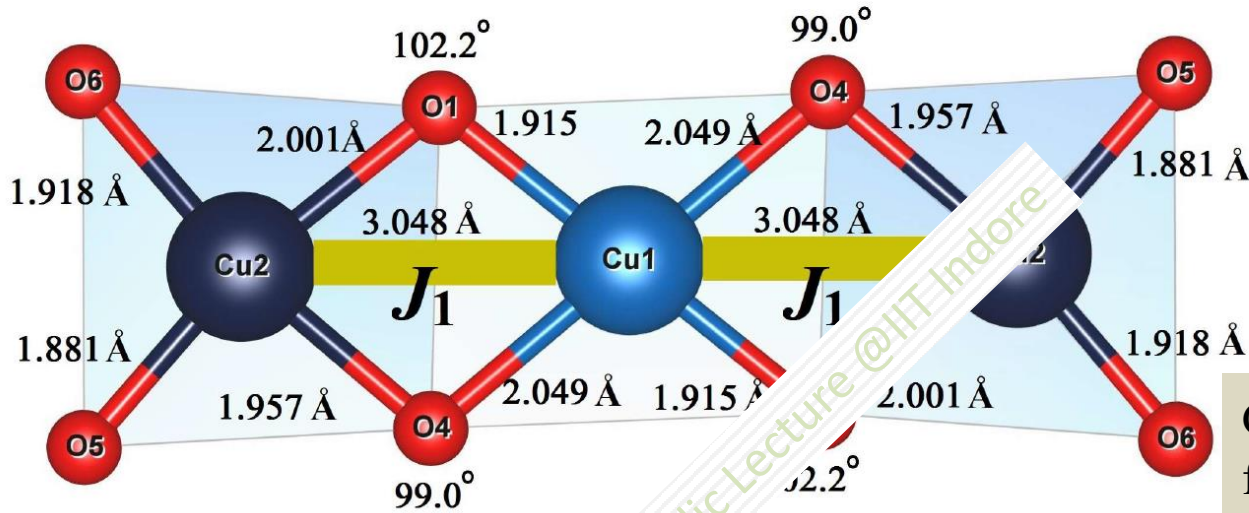
$\alpha = 1$ and $J_3 = 0$: Isotropic Bethe-ansatz solvable
1D $S = \frac{1}{2}$ Heisenberg AF chain (HAC) system

J_1 : nn intra trimer Super-exchange via oxygen ions

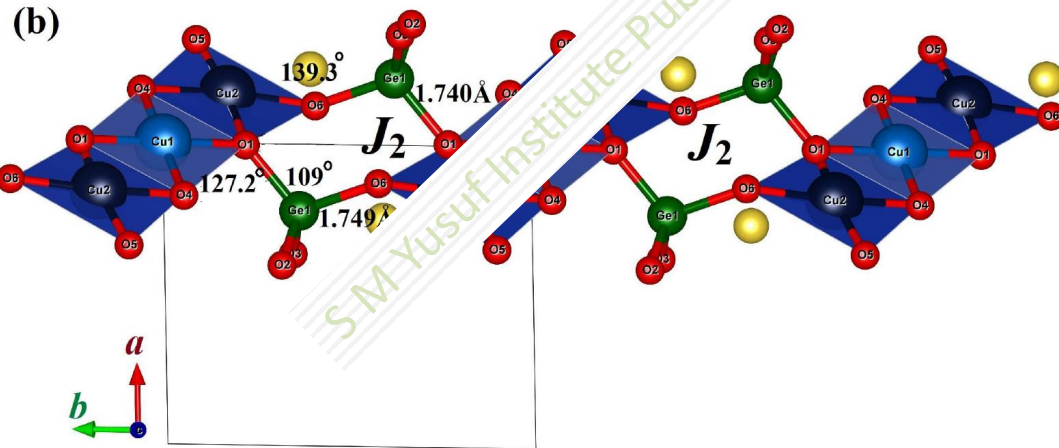
$J_2 (= \alpha J_1)$: inter trimer Super-exchange via O, Ge, and O

$J_3 (= \beta J_1)$: nnn intratrimer super-exchange via O-O ions.

Interacting spin-1/2 trimer chain in $\text{Na}_2\text{Cu}_3\text{Ge}_4\text{O}_{12}$

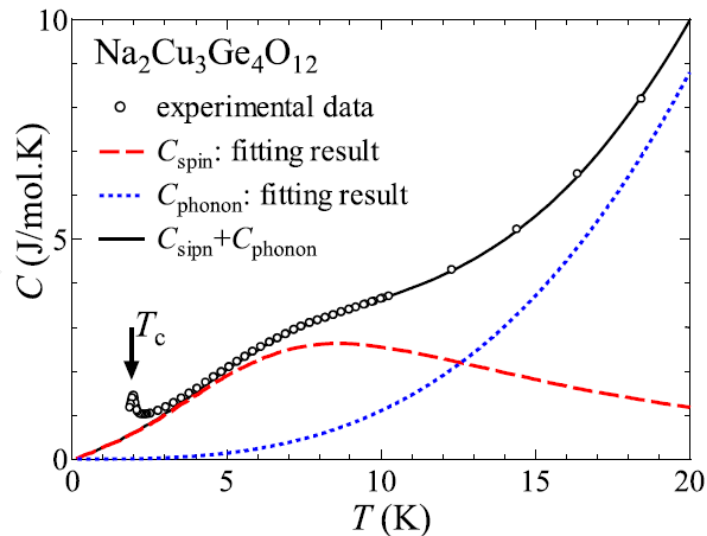
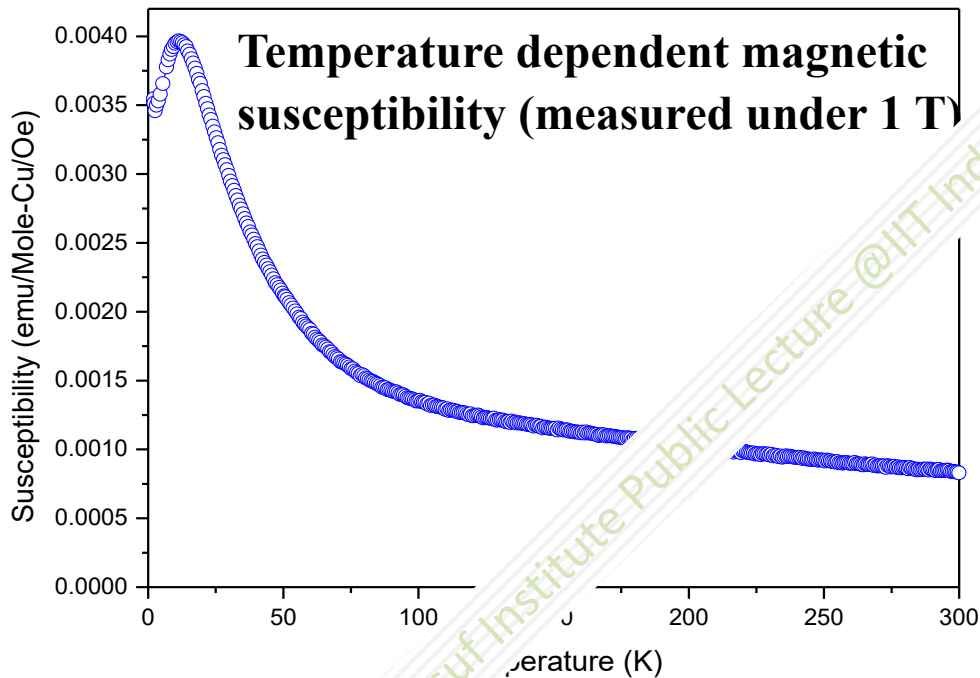


Composed of Cu_3O_8 trimers formed by edge-sharing 3 CuO_4 square planes in a linear fashion

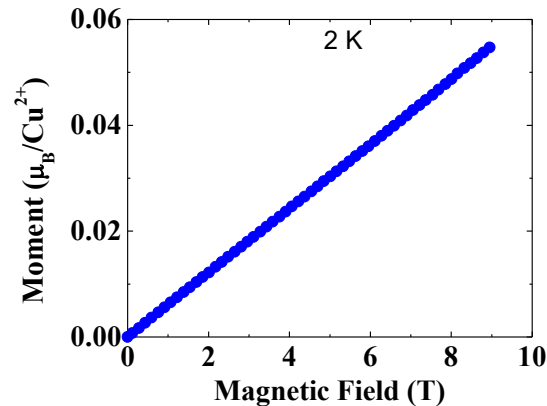


Dresden High Magnetic Field Lab.
 $M(H)$ up to 59 T, & ESR

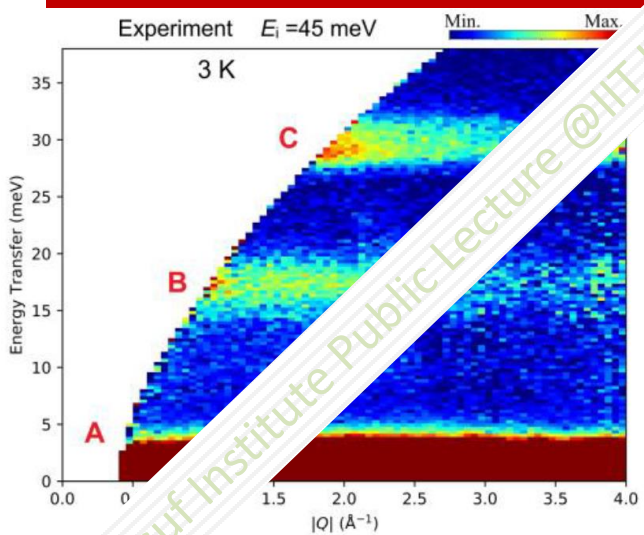
Sudip K. Saha, Manoranjan Kumar, S N Bose
Density Matrix Renormalization Group
(DMRG) Calculation



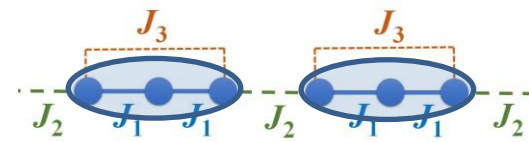
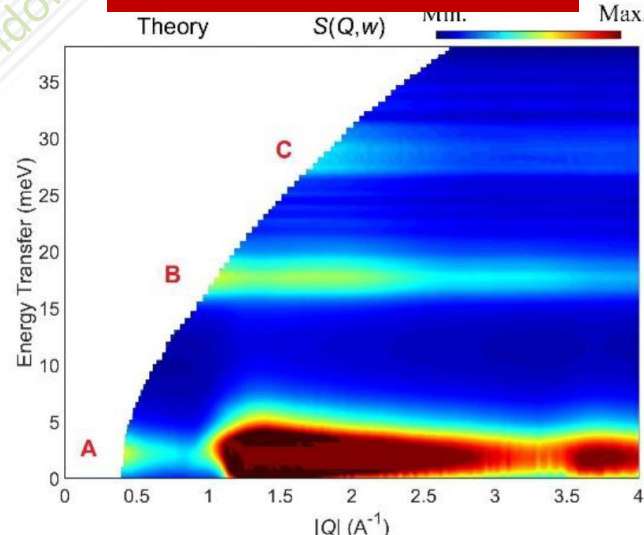
Temperature dependent zero-field specific heat (Ref: Yasui et al. J. Appl. Phys. 115, 17E125 2014))



Inelastic neutron scattering



DMRG -calculations



quarton

doublon

spinon

Manoranjan Kumar, S N Bose Density Matrix Renormalization Group Calculation

A. K. Bera, S. M. Yusuf* *et al.* Nature Commun. (2022)

Dynamical Density Matrix Renormalization Group (DMRG)

$J_1 = 235$ K

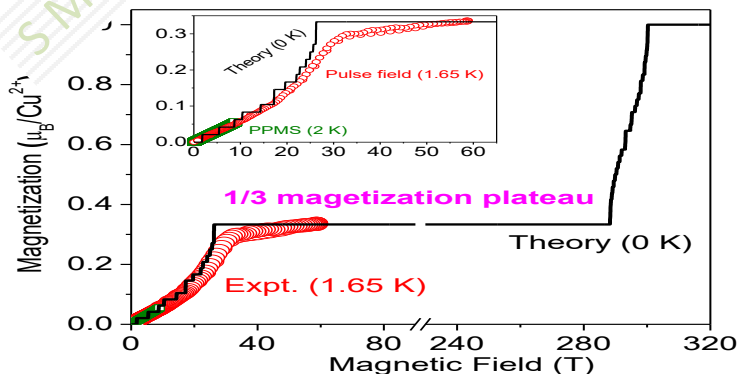
$\alpha (J_2/J_1) = 0.18$

$\beta (J_3/J_1) = 0.18$

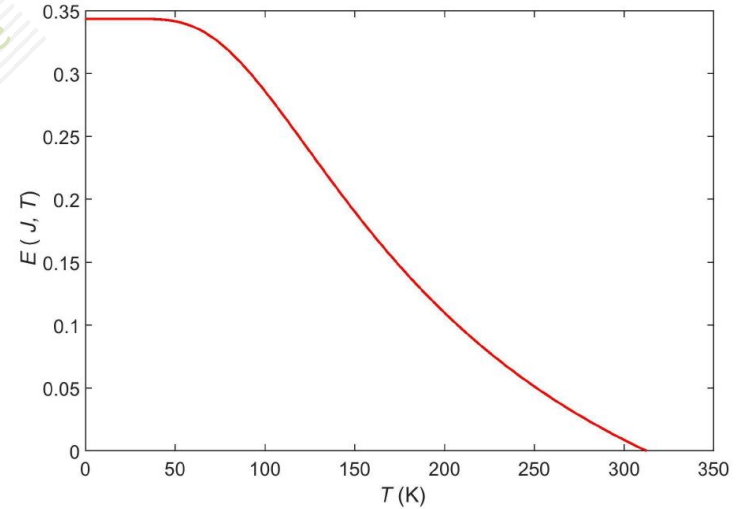
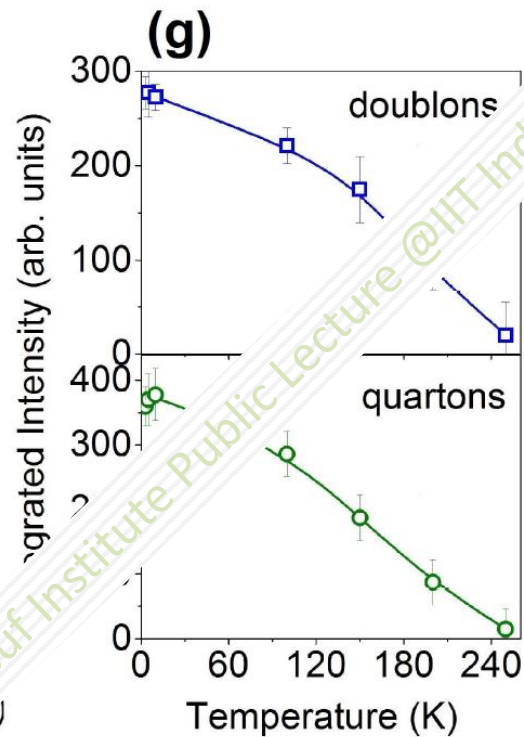
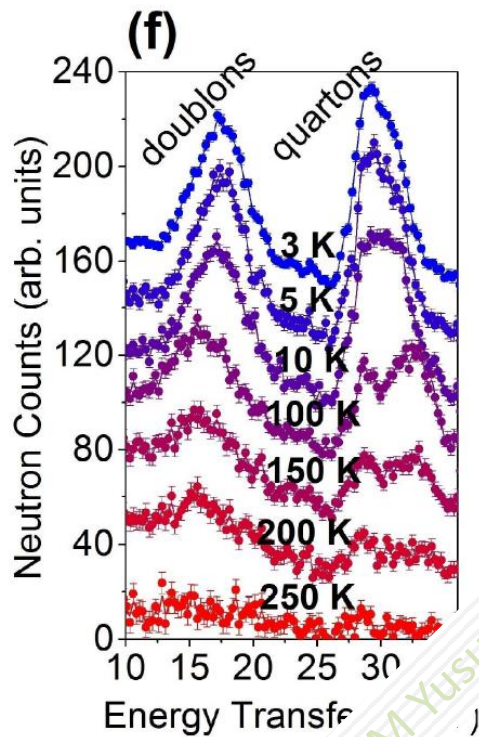
$\mu_0 H c_1 = 28$ Tesla (J_2)

$\mu_0 H c_2 = 252.5$ Tesla

$\mu_0 H c_3 = 256.8$ Tesla



Dresden High Magnetic Field Lab. $M(H)$ up to 59 T, & ESR



Quantification of Quantum Entanglement

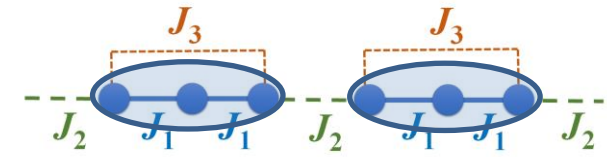
First experimental finding of near room temperature quantum spin entanglement (Doublons, Quartons)

A. K. Bera, S. M. Yusuf* *et al.*
Nature Communications 13, 6888 (2022)

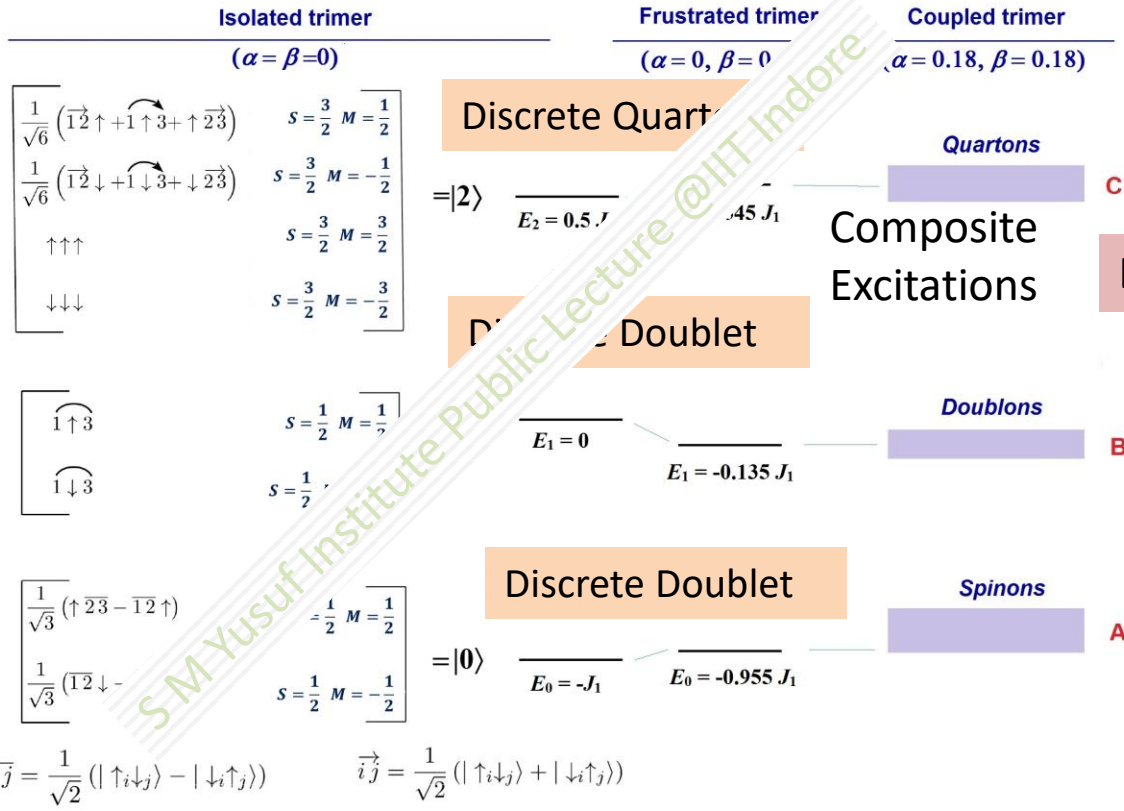
Spin-1/2 AFM Heisenberg trimer chain

Na2Cu3Ge4O12

Energy state and wave functions



$J_2 (= \alpha J_1)$ $J_3 (= \beta J_1)$



Entanglement

$\alpha (= J_2/J_1) < 0.4$

First experimental realization of the many-body composite excitations of doublon and quarton

Strong quantum entanglement: promising for quantum information

$$\vec{i,j} = \frac{1}{\sqrt{2}} (|\uparrow_i\downarrow_j\rangle - |\downarrow_i\uparrow_j\rangle)$$

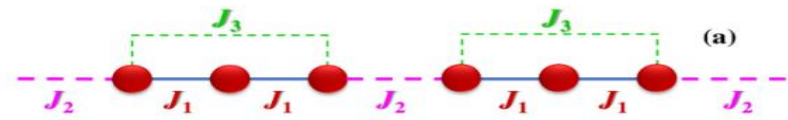
$$\vec{i,j} = \frac{1}{\sqrt{2}} (|\uparrow_i\downarrow_j\rangle + |\downarrow_i\uparrow_j\rangle)$$

Extending the Investigations on $\text{Na}_2\text{Cu}_3\text{Ge}_4\text{O}_{12}$

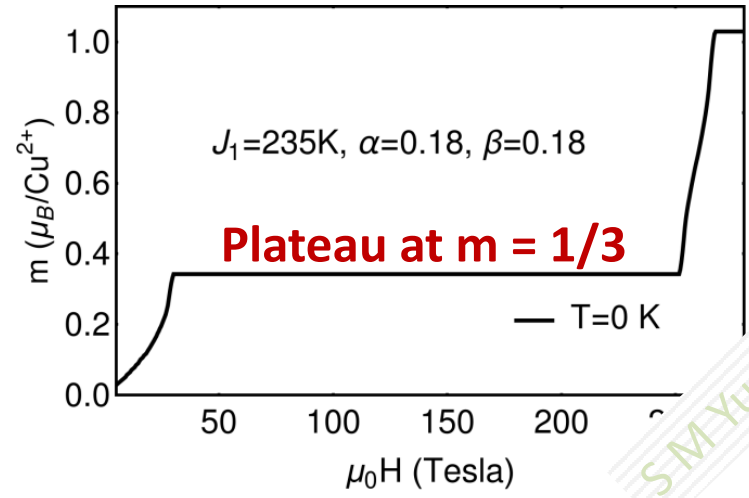
- **Finite Temperature Effect on 1/3 Magnetization Plateau**
- **Raman Study**
- **Neutron Diffraction Study**

S.M. Yusuf Institute Public Lecture @ IIT Indore

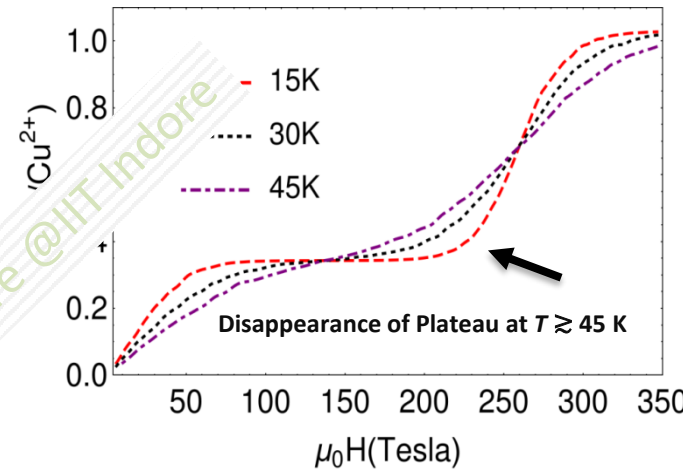
Experimental and Theoretical Understanding of $1/3$ Magnetization Plateau in $S = 1/2$ Antiferromagnetic Spin Trimer Chain compound $\text{Na}_2\text{Cu}_3\text{Ge}_4\text{O}_{12}$ for $J_2/J_1 = 0.18$, $J_3/J_1 = 0.18$ and $J_1 = 235$ K



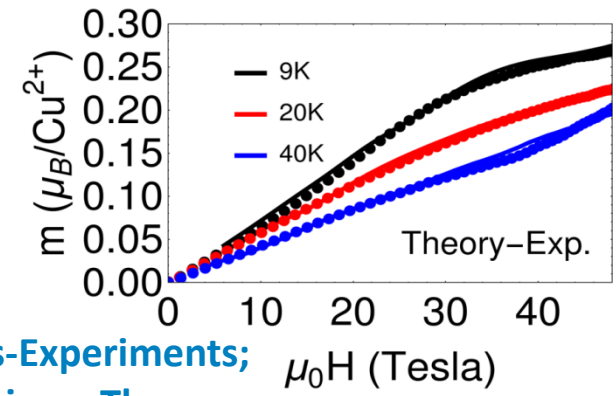
Frustrated Trimer Spin Chain Model:



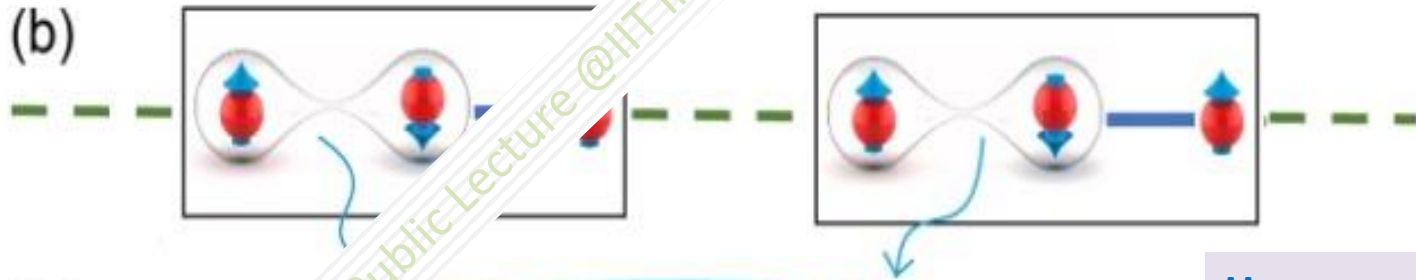
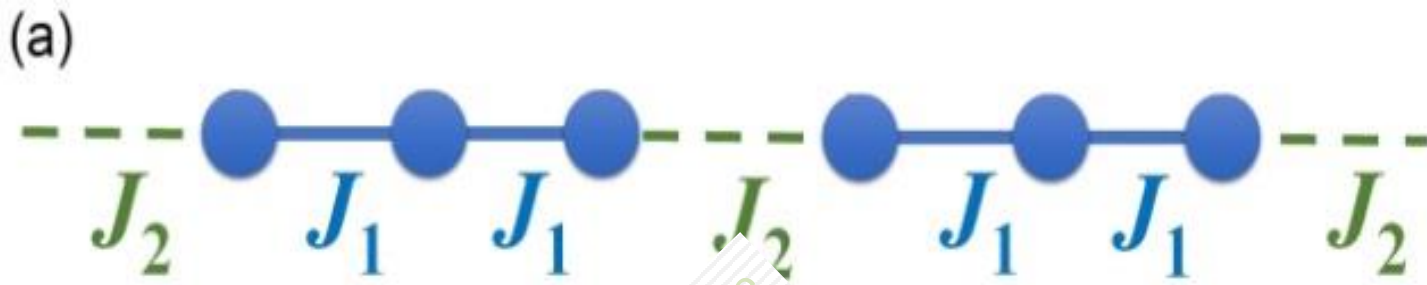
Finite T Magnetization Curves



Comparison of Theoretical Results with Experimental data



Circles-Experiments;
Solid Lines- Theory



(c)

$$|e_j\rangle = \frac{1}{\sqrt{2}} (|\uparrow_i \downarrow_j\rangle - |\downarrow_i \uparrow_j\rangle)$$

However, quantum correlations becomes extremely fragile against thermal fluctuation

First experimental finding of near room temperature quantum spin entanglement

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ENTANGLEMENT – Schrödinger 1935

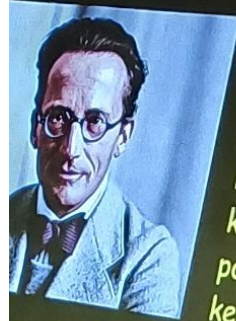


Correlations between particles that go beyond the predictions of classical physics

The individual state of each system cannot be known – only the global state as a whole!

Schrödinger on Entanglement

Naturwissenschaften 23, 807 (1935)



■ "This is the reason that knowledge of the individual systems can decline to the scantiest, even zero, while that of the combined system remains continually maximal. Best possible knowledge of a whole does not include best possible knowledge of its parts - and that is what keeps coming back to haunt us."

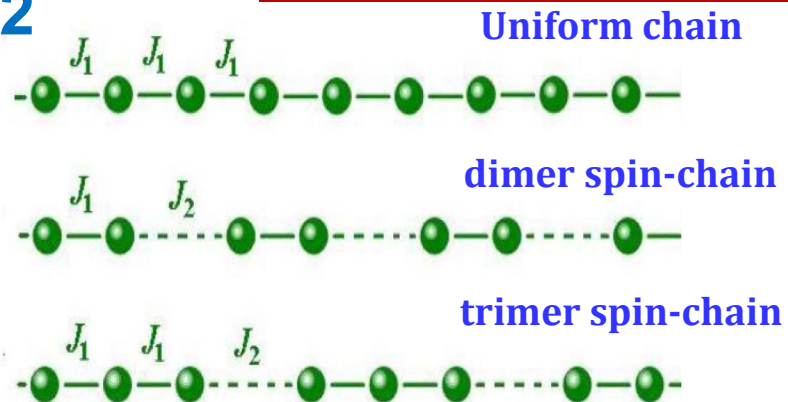
Exploring Beyond $\text{Na}_2\text{Cu}_3\text{Ge}_4\text{O}_{12}$

Observed Quantum Entangled Spins: Accidental?

Ingredient for Strong Quantum Fluctuations:

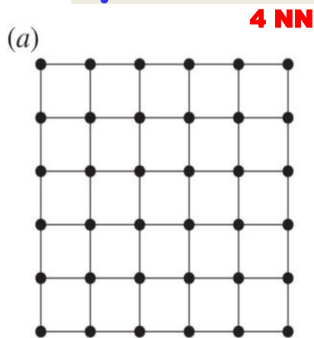
- Small spin value, preferably $S=1/2$
- Low dimensionality
- Geometrical frustration

1D lattice:

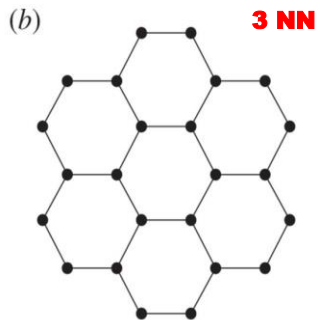


2D lattices: $k: z = 0$

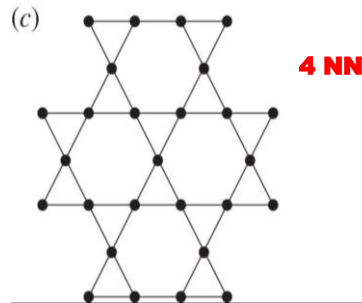
Square



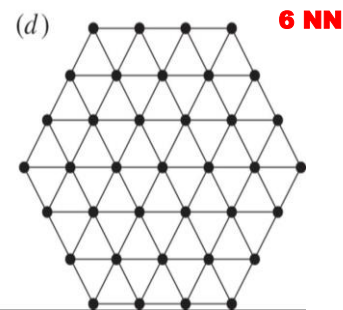
Honeycomb



Kagome

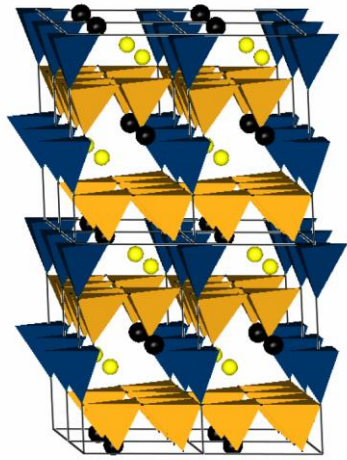


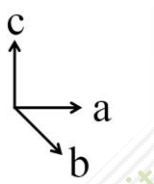
Triangular



Layered YBaCo_4O_7

Co1: Triangular Layer

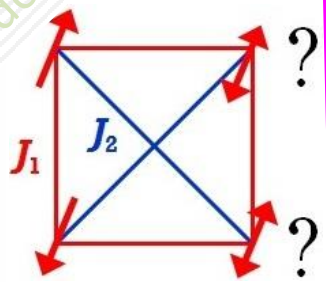
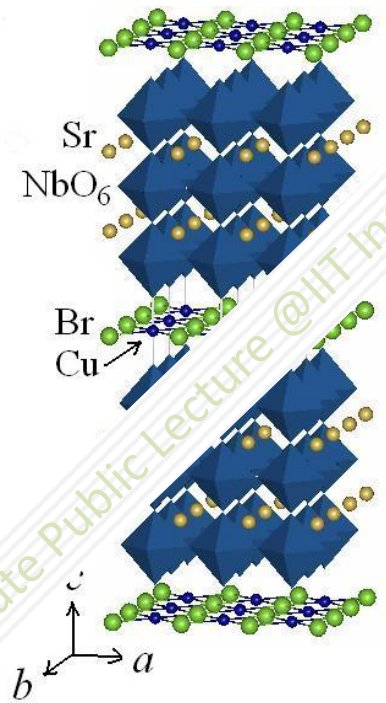


- Y
 - Ba
 - Co(2)O₄
 - Co(1)O₄
- 

Co2: Kagome Lattice

A K Bera, S M Yusuf, S Banerjee, *Solid State Sc.* 16, 57 (2013)

$(\text{CuBr})\text{Sr}_2\text{Nb}_3\text{O}_{10}$



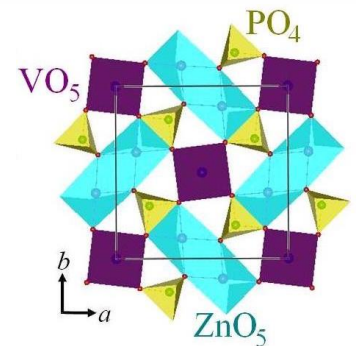
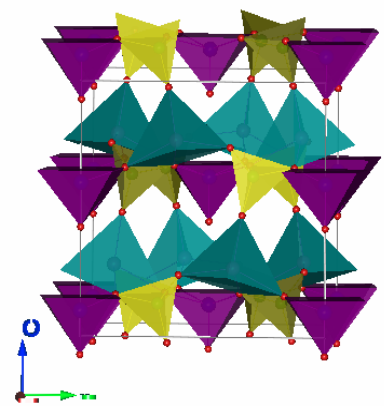
$a = 3.888(1) \text{ \AA}$
 $c = 15.947(1) \text{ \AA}$

S. M. Yusuf, A. K. Bera, et al.
Phys. Rev. B 84, 064407 (2011)

C Ritter, S M Yusuf, et al.
Phys. Rev. B 88, 104401 (2013)

$\text{Zn}_2\text{VO}(\text{PO}_4)_2$

Square Lattice



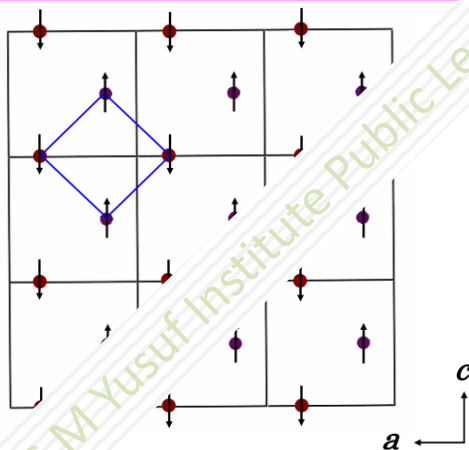
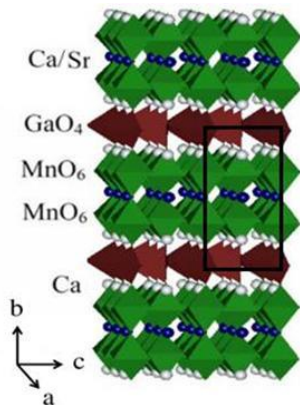
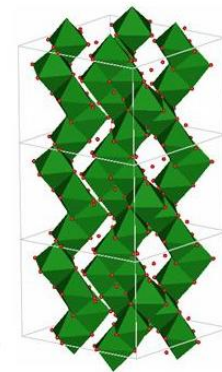
S M Yusuf et al. *Phys. Rev. B* 82, 094412(2010)

Quantum phase transition from a spin-liquid state to a spin-glass state in the quasi-one-dimensional spin-1 system $\text{Sr}_{1-x}\text{Ca}_x\text{Ni}_2\text{V}_2\text{O}_8$

A. K. Bera and S. M. Yusuf*

Solid State Physics Division, Bhabha Atomic Research Centre, Mumbai
(Received 21 September 2011; revised manuscript received 16 June 2012)

Indore, India
(Accepted 9 July 2012)



Layered Material
 $\text{Ca}_{2.5-x}\text{La}_x\text{Sr}_{0.5}\text{GaMn}_2\text{O}_8$

$a \sim 5.436 \text{ \AA}$

$b \sim 11.352 \text{ \AA}$

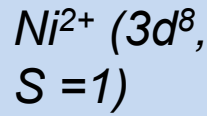
$c \sim 5.301 \text{ \AA}$

Orthorhombic

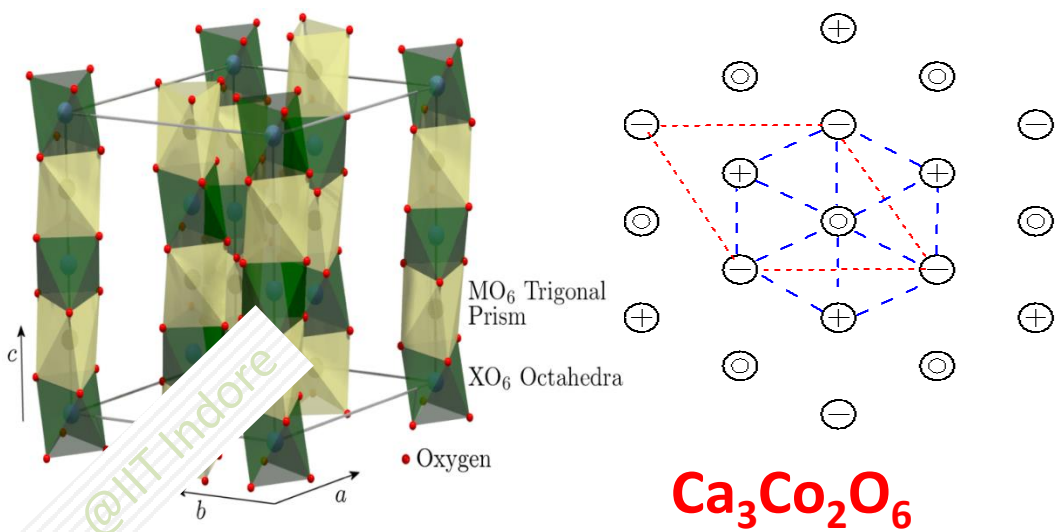
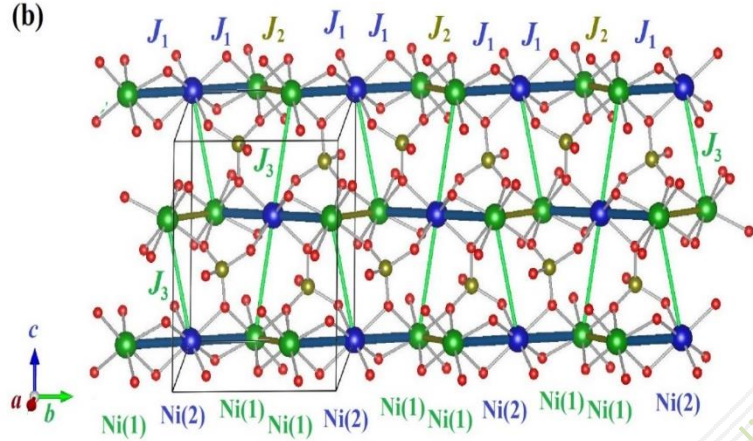
S. M. Yusuf et al. **Phys. Rev. B** 74, 184409 (2006)

A. K. Bera and S. M. Yusuf, **J. Appl. Phys.** 107, 013911 (2010)

A K Bera, S M Yusuf, I Mirebeau, **J. Phys. Con. Mat** 23, 426005 (2011)



S = 1 trimmer chain



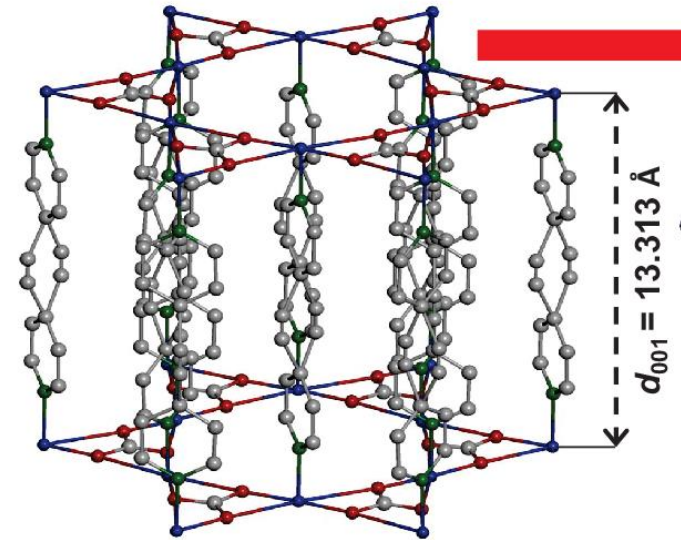
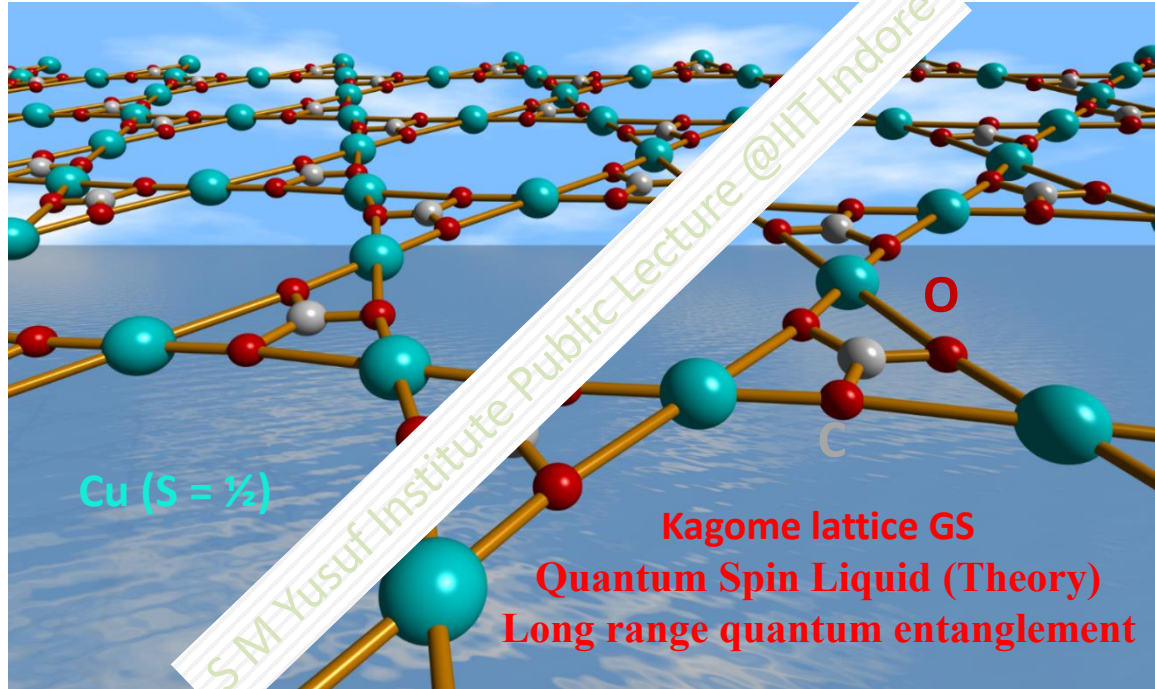
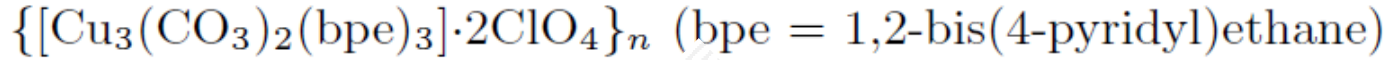
- S. M. Yusuf, A. Jain et al, Phys. Rev. B 107, 184406 (2023)
 S. M. Yusuf, A. Jain, ..S M Yusuf, B. Keimer, D S Inosov, Phys. Rev. B 88, 224403 (2013).
 A Jain, SM Yusuf, S Singh, C Ritter, Phys. Rev.B 87, 094411 (2013)
 S M Yusuf, A Jain, L. Keller, J. Phys. Cond. Matt. 25, 146001 (2013)
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 A. Jain, S. M. Yusuf et al., Phys. Rev. B 79, 184428 (2009).
 I Nowik, A Jain, SM Yusuf , JV Yakhmi, Phys.Rev.B77, 054403 (2008)
 A. Jain, S. Singh, S. M. Yusuf, Phys. Rev. B 74, 174419 (2006).

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Phys. Rev. B 93, 184409 (2016)

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Phys. Rev. B 97, 200403 (2018)

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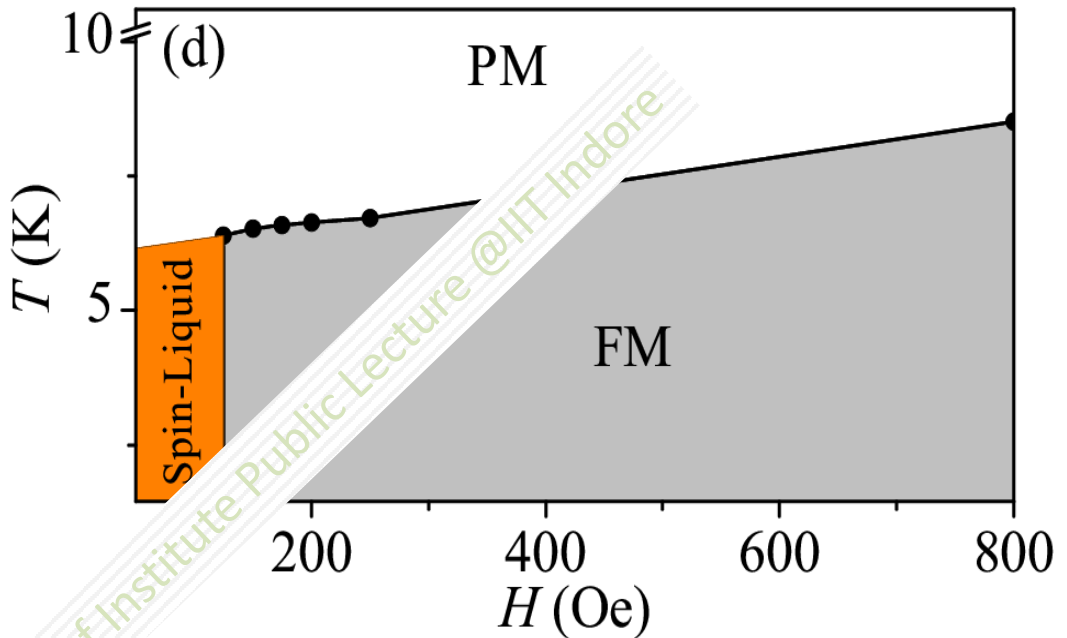
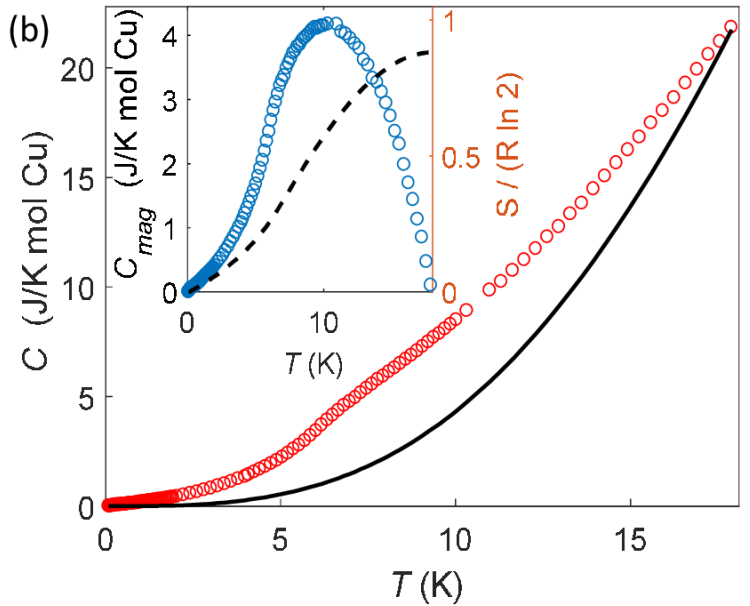
Exotic Quantum Phases in spin- $\frac{1}{2}$ kagome frustrated magnets



Kagomé Layers Pillared by “bpe” Ligand

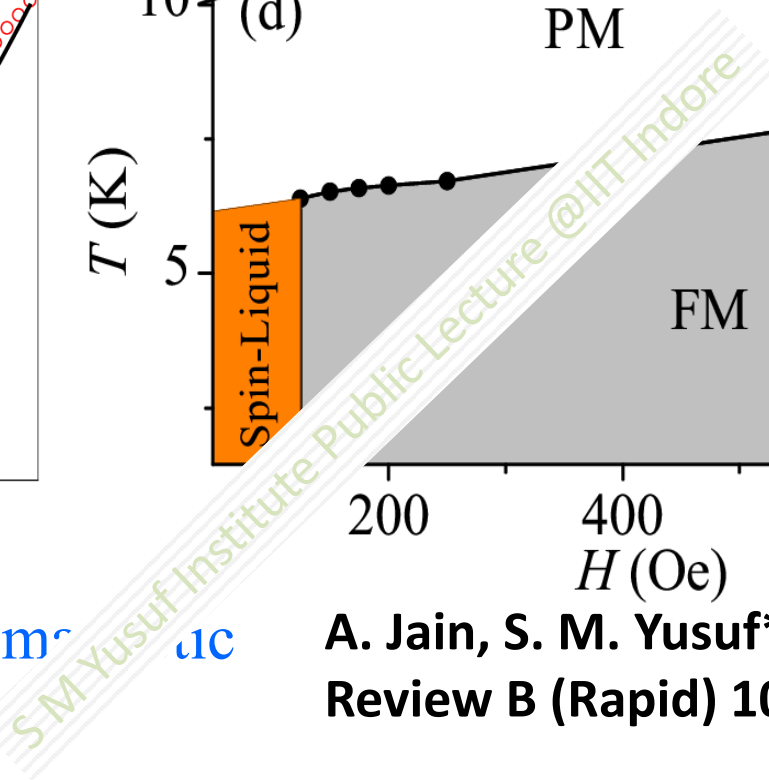
Magnetic Specific Heat Data down to 86 mK

Phase Diagram



88% of the total entropy (Rln2 per mol of Cu spin) is released With no magnetic ordering

A. Jain, S. M. Yusuf*, *et al.* Physical Review B (Rapid) 101,140413(2020)



2D Honeycomb compound $\text{Na}_2\text{Co}_2\text{TeO}_6$

Co1, Co2:
 $\text{Co}^{2+}(3d^7,$
 $S = 3/2)$

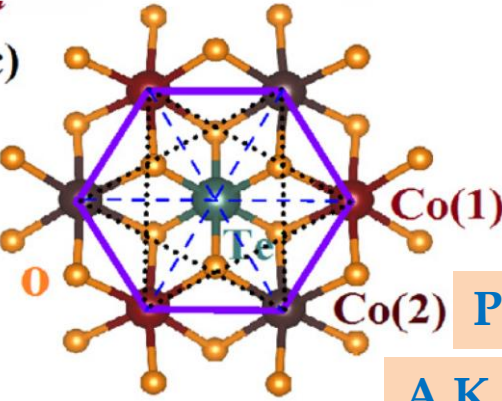
A K Bera, S M Yusuf*, A. Kumar *et al.*
Phys. Rev. B 95, 094424 (2017)

A K Bera, and SM Yusuf*
J. Physical Chem. C 124, 11470 (2020)

Plich, Peedu, Bera, Yusuf *et al.* *Phys. Rev B(Lett)*(2023)

A K Bera, SM Yusuf* *et al.* *Phys. Rev. B* 108 214419((2023)

***Kitaev
Phase***



Magnetism of 2d Honeycomb layered $\text{Na}_2\text{Ni}_2\text{TeO}_6$

A K Bera, S M Yusuf*, *et al.*
Phys Rev. B 105, 014410 (2022)

B. Saha, AK Bera, S. S. Ghosh, S. Ghosh, SM Yusuf*
Phys. Rev. Mat. 7, 085001 (2023)

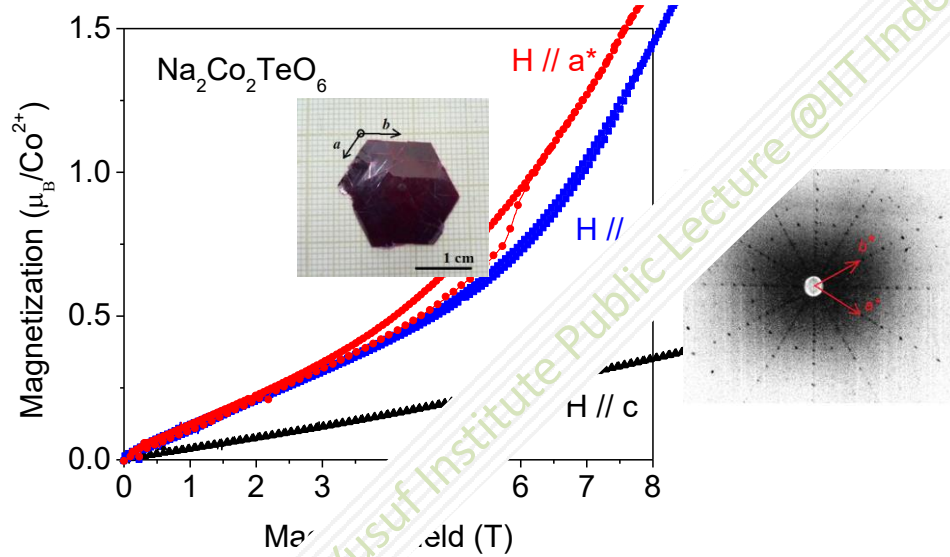
2-d Short-range Spin Spin Correlations in Layered Spin $\frac{1}{2}$ Maple Leaf Lattice

Antiferromagnet $\text{Na}_2\text{Mn}_3\text{O}_7$

B Saha, AK Bera, SM Yusuf*, A Hoser
Phys Rev. B 105, 014410(2022)

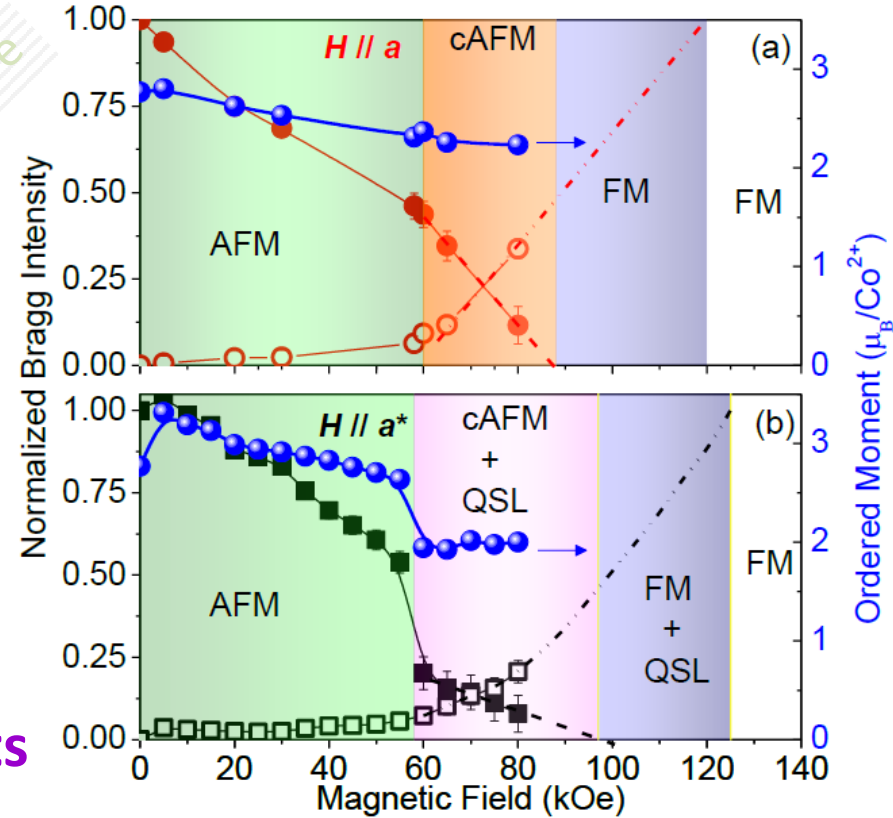
Kitaev spin systems

$\text{Na}_2\text{Co}_2\text{TeO}_6$



$\text{Co}^{2+}: 3d^7$

spin-orbit entangled $j = 1/2$ moments



Patrick Pilch,¹ Laur Peedu,² Anup Kumar Bera,^{3,4} S. M. Yusuf,^{3,4} Urmaz Nagel,² Toomas Rõõm,² and Zhe Wang^{1,*}

¹Department of Physics, TU Dortmund University, 44227 Dortmund, Germany

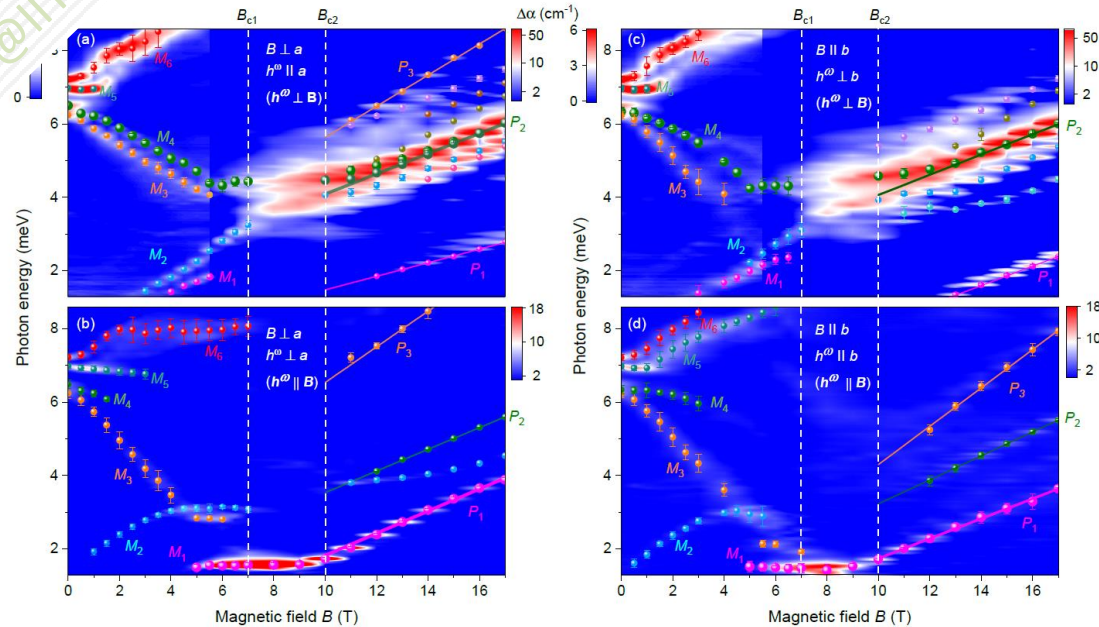
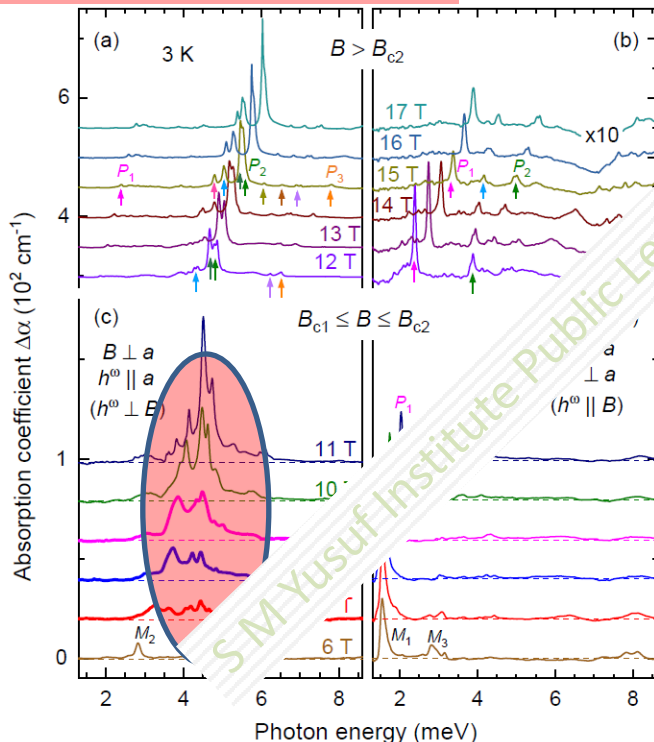
²National Institute of Chemical Physics and Biophysics, 12618 Tallinn, Estonia

³Solid State Physics Division, Bhabha Atomic Research Centre, Mumbai 400 085, India

⁴Homi Bhabha National Institute, Trambhambur, Maharashtra, Mumbai 400 094, India

Continuum
scattering

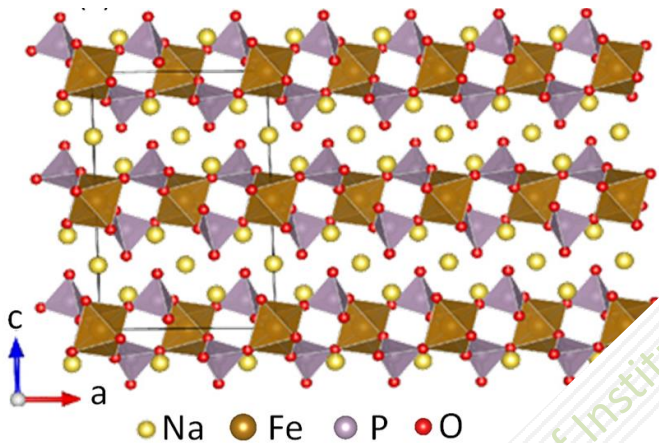
High field THz Spectroscopy



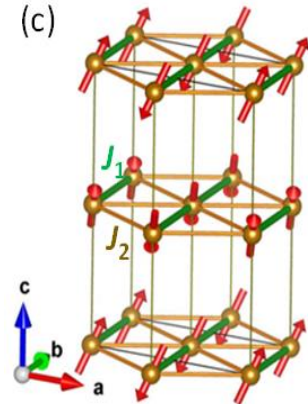
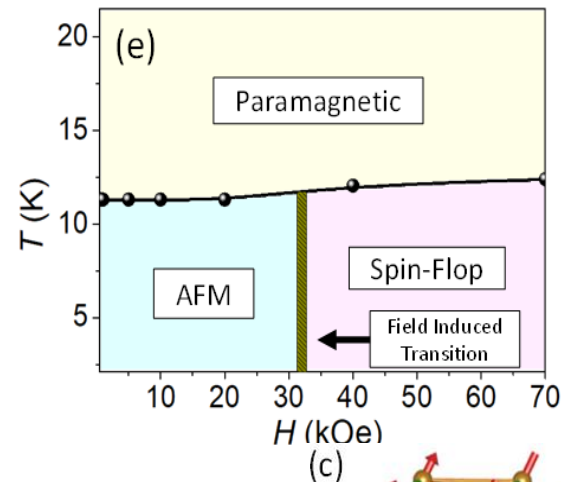
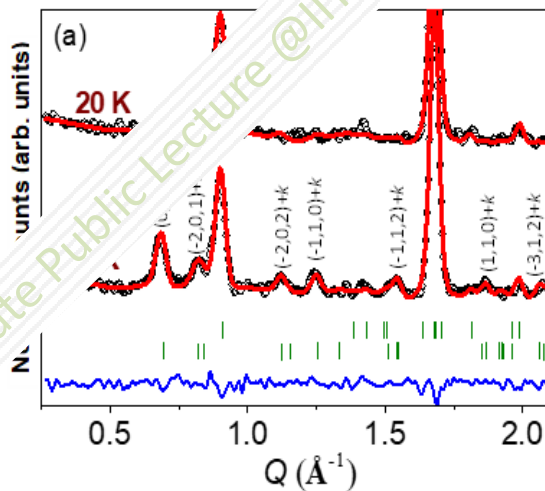


Quasi-2D Antiferromagnets

Triangular lattice



Neutron Diffraction: magnetic ground state



J_1 (meV)	J_2 (meV)	J_3 (meV)	D (meV)
0.31(1) (FM)	0.15(1) (AFM)	0.00003(1) (AFM)	0.02(2)

Saha, Bera, Yusuf* *et al.*, Phys. Rev B 110, 094421 (2024)

Ingredient for Strong Quantum Fluctuations:

- Small spin value, preferably $S=1/2$
- Low dimensionality
- Geometrical frustration

$$\frac{1}{\sqrt{2}} \left(\begin{array}{c} \uparrow \\ \bullet \\ \downarrow \end{array} + \begin{array}{c} \downarrow \\ \bullet \\ \uparrow \end{array} \right)$$

Entanglement of Spins

Every spin of the lattice is coupled to a partner

A natural building block for non-magnetic states

Quantum Technology Development in India

Looking Beyond.....



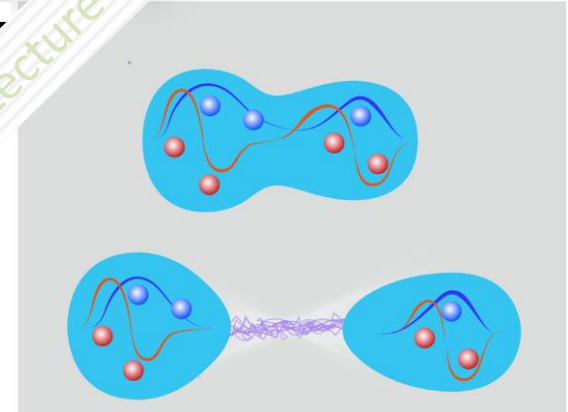
Contents lists available at ScienceDirect

Physics Letters B

journal homepage: www.elsevier.com/locate/physletb



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Letter

Quantum entanglement in nuclear fission

Yu Qiang^a, Junchen Pei^{a,b,*}, Kyle Godbey^c


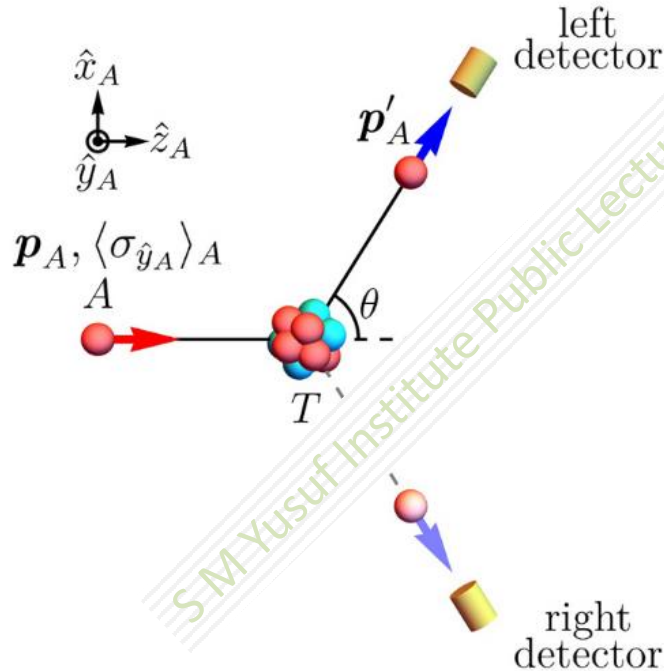
The sharing of particles and energies in fission:

This statistical sharing mechanism in low energy fission is **not a complete** description as light fragments generally have less excitation energies than heavy fragments

Conclusion: The entanglement is mainly caused by the non-localization of wave functions in two parts

Estimated the quantum entanglement magnitude between two fission fragments

Toward experimental determination of spin entanglement of nucleon pairs

 Dong Bai *


determining the transverse spin polarization $\langle \sigma_{\hat{y}_A} \rangle_A$ by the left-right asymmetry measurement and the concurrence written as

$$C(|\Psi_{AB}^{\text{spin}}\rangle) = \sqrt{1 - \langle \sigma_{\hat{x}_A} \rangle_A^2 - \langle \sigma_{\hat{y}_A} \rangle_A^2 - \langle \sigma_{\hat{z}_A} \rangle_A^2},$$

- Spin entanglement of an entangled nucleon pair is measurable in nuclear experiments at least in principle



Regular Article - Theoretical Physics

Quantum entanglement patterns in the structure of atomic nuclei within the nuclear shell model

A. Pérez-Obiol^{1,a}, S. Masot-Lloma^{1,b}, J. Romero^{2,3,c}, J. Menéndez^{2,3,d}, A. Rios^{2,3,e},
A. García-Sáez^{1,4,f}, B. Juliá-Díaz^{1,4,g}

- Proton and neutron orbitals are weakly entangled

Observation of quantum entanglement with top quarks at the ATLAS detector

The ATLAS Collaboration* 542 | Nature | Volume 633 | 19 Sept 2024

In proton–proton (pp) collision events recorded at the LHC with a centre-of-mass energy of 13 TeV

- The spin correlation between the top quark and antitop quark is used to probe the effects of quantum entanglement

- Entanglement is observed $> 5\sigma$ for the first time in pairs of quarks

Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems

Gregory S. Engel^{1,2}, Tessa R. Calhoun^{1,2}, Elizabeth L. Read^{1,2}, Tae-Kyu Ahn^{1,2}, Anindya Ghose^{1,2}, Isaac Mančal^{1,2}†, Yuan-Chung Cheng^{1,2}, Robert E. Blankenship^{3,4} & Graham R. Fleming^{1,2}

PNAS

Long-lived quantum coherence in photosynthetic complexes at physiological temperature

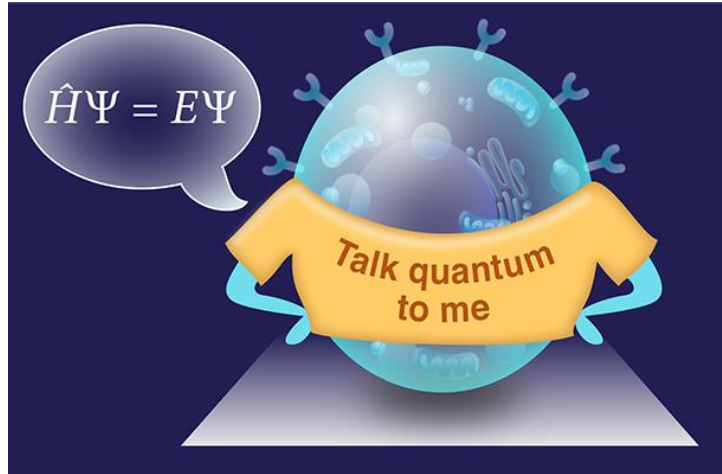
Gitt Panitchayangkoon^a, Dugan Hayes^a, Kelly E. Johnson^a, Jiahua Cao^a, Anindya Ghose^a, Justin R. Caram^a, Elad Harel^a, Jianzhong Wen^b, Robert E. Blankenship^b, and Gregory S. Engel^a

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<https://physics.aps.org/articles/v16/79>

“It’s Time to Take Quantum Biology Research Seriously”

• [Clarice Aiello](#), University of California **May 10, 2023** • *Physics* **16, 79**



Understanding the possible quantum-driven behaviors of biological systems could aid in preventing injuries or in developing cures for diseases

Fisher, M. P. (2015). *Quantum cognition: The possibility of processing with nuclear spins in the brain*
Annals of Physics, 362, 593-602

Impact of ionizing radiation on superconducting qubit coherence

<https://doi.org/10.1038/s41586-020-2619-8>

Received: 25 January 2020

Accepted: 5 June 2020

Published online: 26 August 2020



Check for updates

Antti P. Vepsäläinen¹✉, Amir H. Karamlou¹, John L. ... Akshunna S. Dogra^{1,4}, Ben Loer²,
Francisca Vasconcelos¹, David K. Kim³, Alexandr ... ille³, Bethany M. Niedzielski³,
Jonilyn L. Yoder³, Simon Gustavsson¹, Josep ... aggio¹, Brent A. VanDevender² &
William D. Oliver^{1,3}

Technologies that rely on quantum bits (qubits) require long coherence times and high-fidelity operations¹. Superconducting qubits are one of the leading platforms for achieving these objectives². However, the coherence of superconducting qubits is affected by the breaking of Cooper pairs of electrons^{4–6}. The experimentally observed density of the broken Cooper pairs, referred to as quasiparticles, is orders of magnitude higher than the value predicted at equilibrium by the Bardeen–Cooper–Schrieffer theory of superconductivity^{7–9}. Previous work^{10–12} has shown that infrared photons considerably increase the quasiparticle density, yet even in the best-isolated

QUANTUM COMMUNICATION

RESEARCH ARTICLE

QUANTUM OPTICS Yin et al., *Science* 356, 1140–1144 (2017) 16 June 2017

Satellite-based entanglement distribution over 1200 kilometers

Jian Yin,^{1,2} Yuan Cao,^{3,4} Yu-Huai Li,^{1,2} Sheng-Kai Liao,^{1,2} Liang Zhang,^{1,2} Ji-Gang Ren,^{1,2} Wei-Qi Cai,^{1,2} Wei-Yue Liu,^{1,2} Bo Li,^{1,2} Hui Dai,^{1,2} Guang-Bing Li,^{1,2} Qi-Ming Lu,^{1,2} Yun-Hong Gong,^{1,2} Yu Xin,^{1,2} Shuang-Lin Li,^{1,2} Peng-Zhi Li,^{1,2} Yu-Yun Yin,^{1,2} Zi-Qiang Jiang,¹ Ming Li,¹ Jian-Jun Jin,¹ Ge Ren,¹ Dong He,¹ Yi-Lin Zhou,¹ Xiao-Xiang Zhang,¹ Na Wang,¹ Xiang Chang,¹ Zhen-Cai Zhu,¹ Nai-Le Liu,^{1,2} Yu-Ao Chen,^{1,2} Chao-Yang Lu,^{1,2} Rong Shu,^{1,2} Cheng-Zhi Peng,^{1,2,3} Jian-Yu Wang,^{1,2,3} Jian-Wei Pan^{1,2,3}



Jian-Wei Pan



SCIENTIFIC AMERICAN

China Reaches New Milestone in Space-Based Quantum Communications

The nation's Micius satellite successfully established an ultrasecure link between two ground stations separated by more than 1,000 kilometers

By Karen Kaplan on June 25, 2020

IBM currently operates quantum computers with 100+ qubits.

The chips operate at approximately 10 – 100 millikelvins

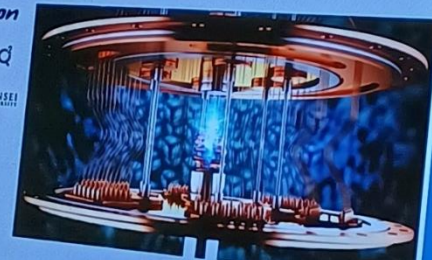
IBM Quantum Made a Quantum Computing Breakthrough

HSBC=The Hong Kong and Shanghai Banking Corporation

by Timothy Green – Sep 26, 2025 at 7:20AM

KEY POINTS

- HSBC used IBM's quantum computers to improve a process involved in algorithm bond trading.
- The collaboration demonstrated that pairing quantum computers with classical techniques can provide real-world benefits.



IBM uses superconducting transmon qubits



Quantum Computing Market Map

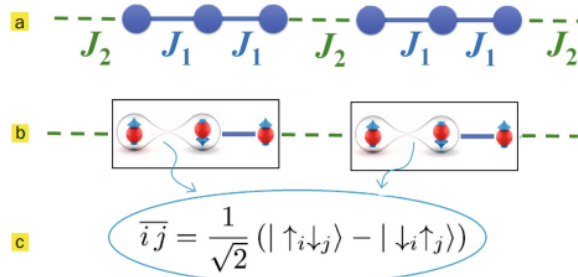


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¹ Software offerings can be further classified into SDKs, frameworks, and full stack services (e.g. cloud access to QPUs, simulators, etc.). Many QPU providers are offering full stack services (e.g. AWS Braket, Azure Quantum, Google Cloud Quantum).
² QPUs are categorized by technology (e.g. superconducting, neutral atoms, silicon, photonics, etc.) but many companies are offering a mixture across the stack. Quantum was originally COC prior to merger with HQS, etc.

To Conclude

Spin Quantum Entanglement Near Room Temperature



A schematic snapshot of the quantum entangled spin state (b) of a trimer spin-chain having periodic quantum mechanical magnetic exchange interactions J_1 - J_1 - J_2 along the spin chain (a) involving the wave function (c).

***S. M. Yusuf**
 Director, Physics Group
 Bhabha Atomic Research Centre, Mumbai-85, INDIA

Entangled spin states are found to be very stable against temperature and persist up to near room temperature (~250 K), which has a special importance for practical device applications in the upcoming quantum technology.

Quantum entanglement has drawn a tremendous attention of researchers for its importance in quantum technology. Quantum entanglement phenomenon occurs when a group of quasi-particles interact and share spatial proximity such that the quantum states of each particle of the group cannot be determined independently of the states of the other particles.

Recent study [A. K. Bera, S. M. Yusuf* et al., Nature Communications 13 has demonstrated for the first time the novel quasi-particle excitations in an entangled ground state [Fig. (b)] of a quantum spin-1/2 trimer-chain [Fig. (a)]. Such a model spin-1/2 trimer-chain antiferromagnetic compound $\text{Na}_2\text{Cu}_2\text{Ge}_2\text{O}_8$, where the group of three spin-1/2 ions are coupled to form a spin-trimer, and such trimers are magnetically coupled along the spin-chain [Fig. (a)]. The ground state of such a spin-trimer is found to be quantum entangled [Fig. (b)] wave function of two spins (out of three) as shown in [Fig. (c)]. Most importantly, such entangled spin states are found to be very stable against temperature and persist up to near room temperature (~250 K), which has a special importance for practical device applications in the upcoming quantum technology.



Dr. S. M. Yusuf, Director, Physics Group, BARC has been elected as a member of the distinguished prestigious Indian National Science Academy (INSA). Dr. Yusuf is recognized internationally for his contributions in the area of advanced magnetic materials and neutron scattering. He has published numerous research papers in internationally reputed peer reviewed journals. He has one US patent and one European patent to his credit. He is a member of the Indian Academy of Sciences, and the National Academy of Sciences. He was a past-deputy director of the National Laboratory, USA, and a visiting scientist of the Institute of Materials Science, Spain. Dr. Yusuf is a recipient of the Alexander von Humboldt Fellowship as well as the Spanish Ministry of Science & Education Fellowship.

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Dresden High Magnetic Field Lab.
M(H) up to 59 T, & ESR**

Sudip K. Saha

Manoranjan Kumar

D. T. Adroja, ISIS-RAL

David Voneshen, ISIS-RAL

**Thank you for your
kind attention**

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