

## Indian Institute of Technology Kanpur

### Proposal for a new course

**Title:** Statistical mechanics and network analysis of granular materials

1. **Course No.:** ChE 6xx
2. **Structure:** Lectures: 3 (L), Tutorial: 0 (T), Laboratory: 0 (P), Additional hours [0-2]: 0 (A), credits (3-0-0-0): 09.
3. **Duration of course:** Full semester
4. **Prerequisite:** None.
5. **Open to:** PG students and third and fourth-year UG students.
6. **Proposing instructor:** K. P. Krishnaraj (email: [krishnaraj@iitk.ac.in](mailto:krishnaraj@iitk.ac.in))
7. **Proposing department:** Department of Chemical Engineering
8. **Other faculty members interested in teaching the course:**
10. **Course description:**
  - A. **Objectives:** This course aims to provide a theoretical understanding of statistical mechanics and network-based description of granular materials. It introduces theoretical frameworks for understanding the behavior of granular assemblies, emphasizing the limitations of classical equilibrium statistical mechanics and the development of athermal statistical frameworks, including the Edwards ensemble and related approaches. The course also explores the representation of granular media as complex contact and force networks, enabling the characterization of their structural organization, force transmission, and mechanical stability using graph-theoretic concepts. By integrating statistical mechanics with network science, the course enables students to understand how microscopic organization gives rise to macroscopic behavior in granular systems.
  - B. **Content:** Lecture-wise break-up (considering the duration of each lecture is 50 minutes)

| S. No. | Title                                       | Topics                                                                                                                                                                                          | No. of lectures |
|--------|---------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| 1      | Introduction to granular materials          | <ul style="list-style-type: none"><li>Granular solids, liquids and gases</li><li>Particle interactions</li><li>Packing properties of granular assemblies</li><li>Jamming and rigidity</li></ul> | 6               |
| 2      | Classical statistical mechanics             | <ul style="list-style-type: none"><li>Microstates and macrostates</li><li>Phase space</li><li>Probability distributions</li><li>Classical ensembles</li><li>Partition function</li></ul>        | 8               |
| 3      | Statistical mechanics of granular materials | <ul style="list-style-type: none"><li>Why classical statistical mechanics fails</li><li>Edwards ensemble</li><li>Stress ensemble</li><li>Limitations, validation, and open challenges</li></ul> | 8               |

|              |                                           |                                                                                                                                                                                                                                                                                                                                |           |
|--------------|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 4            | Introduction to complex networks          | <ul style="list-style-type: none"> <li>• Graphs</li> <li>• Directed and weighted graphs</li> <li>• Matrix representations</li> <li>• Structural measures of networks</li> </ul>                                                                                                                                                | 4         |
| 5            | Network analysis of granular materials    | <ul style="list-style-type: none"> <li>• Granular assemblies as networks</li> <li>• Force networks and force chains</li> <li>• Graph-theoretic measures for granular networks</li> <li>• Network topology and mechanical response</li> <li>• Percolation and connectivity</li> <li>• Network evolution and dynamics</li> </ul> | 9         |
| 6            | Statistical description of force networks | <ul style="list-style-type: none"> <li>• Contact force distributions</li> <li>• The q-model</li> <li>• Force network ensemble</li> <li>• Limitations and future directions</li> </ul>                                                                                                                                          | 5         |
| <b>Total</b> |                                           |                                                                                                                                                                                                                                                                                                                                | <b>40</b> |

#### References:

- Edwards, S. F., & Oakeshott, R. B. S., Theory of Powders. *Physica A: Statistical Mechanics and its Applications*, 157, 1080–1090 (1989).
- Jaeger, H. M., Nagel, S. R., & Behringer, R. P., Granular Solids, Liquids, and Gases. *Reviews of Modern Physics*, 68(4), 1259–1273 (1996).
- McQuarrie, D. A., *Statistical Mechanics*. University Science Books, Sausalito, CA (2000).
- Newman, M. E. J., *Networks: An Introduction*. Oxford University Press (2010).
- Andreotti, B., Forterre, Y., & Pouliquen, O., *Granular Media: Between Fluid and Solid*. Cambridge University Press (2013).
- Bi, D., Henkes, S., Daniels, K. E., & Chakraborty, B., The Statistical Physics of Athermal Materials. *Annual Review of Condensed Matter Physics*, 6, 63–83 (2015).
- Barabási, A. L., *Network Science*. Cambridge University Press (2016).
- Papadopoulos, L., Porter, M. A., Daniels, K. E., & Bassett, D. S., Network Analysis of Particles and Grains. *Journal of Complex Networks*, 6, 485–565 (2018).

Dated: July 26, 2026

Dated: 26 Jul 2026

Proposer: Dr. K. P. Krishnaraj 

DUGC/DPGC Convener: 

**The course is approved/not approved**

Chairman, SUGC/SPGC

Dated: