

Statistical Physics of Granular Matter

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Lecture 1: Compaction

- Introduction to Granular Matter
- Density Relaxation
- Scaling Analysis
- The Parking Model
- Density Fluctuations

Lecture 2: Clustering

- Inelastic Collisions
- Homogeneous Cooling
- Molecular Dynamics I
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- Ballistic Aggregation
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Lecture 3: Unforced Gases

- Boltzmann Equation
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Lecture 4: Forced Gases

- Maxwell-Boltzmann Distribution
- Overpopulated High-Energy Tails
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- Velocity Correlations
- Extreme Driving
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- Higher Dimensions

Lecture 5: Alignment

- Rod alignment
- Master Equation
- Linear Stability Analysis
- Fourier Analysis
- Integer Partitions
- Phase Transitions
- Arbitrary Alignment Rates

References

The lectures are based on sections 3.1, 3.4-3.7, and 7.4 in my textbook on Nonequilibrium Statistical Physics.

A Kinetic View of Statistical Physics

P. L. Krapivsky, S. Redner, and E. Ben-Naim
(Cambridge University Press, Cambridge, 2010)

Lecture 1: Compaction

- P. L. Krapivsky and E. Ben-Naim, J. Chem. Phys. **100**, 6778 (1994).
- X. Jin, G. Tarjus, and J. Talbot, J. Phys. A **27**, L195 (1994).
- H. M. Jaeger, S. R. Nagel and R. P. Behringer, Rev. Mod. Phys. **68**, 1259 (1996).
- E. Ben-Naim, J.B. Knight, E. R. Nowak, H. M. Jaeger, and S. R. Nagel. Physica D **123**, 380-385 (1998).
- E. R. Nowak, J. B. Knight, E. Ben-Naim, H. Jaeger, and S. Nagel, Phys. Rev. E **57**, 1971 (1998).

Lecture 2: Clustering

- P. K. Haff, J. Fluid. Mech. **134**, 401 (1983).
- S. F. Shandarin and Y. B. Zeldovich, Rev. Mod. Phys. **61**, 185 (1989).
- G. F. Carnevale, Y. Pomeau and W. R. Young, Phys. Rev. Lett. **64**, 2913 (1990).
- W. H. Press, S. A. Teukolsky, W. T. Vetterline, and B. P. Flannery, Numerical Recipes 2nd ed. (Cambridge University Press, Cambridge, UK, 1992).
- S. McNamara and W. R. Young, Phys Fluids A **4**, 496 (1992).
- I. Goldhirsch, and G. Zanetti, Phys. Rev. Lett. **70**, 1619 (1993).
- E. Ben-Naim, P. L. Krapivsky, and S. Redner, Phys. Rev. E **50**, 822 (1994).
- E. L. Grossman, T. Zhou, and E. Ben-Naim, Phys. Rev. E **55**, 4200 (1997).
- L. Frachebourg, Phys. Rev. Lett. **82**, 1502 (1999).

- W. Losert, D. G. W. Cooper, J. Delour, A. Kudrolli and J. P. Gollub, *Chaos* **9**, 682 (1999).
- E. Ben-Naim, S. Y. Chen, G. D. Doolen, and S. Redner, *Phys. Rev. Lett.* 4069 (1999).
- I. Goldhirsch, *Ann. Rev. Fluid. Mech.* **35**, 267 (2003).
- D. C. Rapaport, *The Art of Molecular Dynamics Simulation* 2nd ed. (Cambridge University Press, Cambridge, UK, 2004).

Lecture 3: Unforced Gases

- J. C. Maxwell, *Phil. Trans. Roy. Soc.* **157**, 49 (1867).
- R. S. Krupp, *A nonequilibrium solution of the Fourier transformed Boltzmann equation*, M.S. Thesis, MIT (1967); *Investigation of solutions to the Fourier transformed Boltzmann equation*, Ph.D. Thesis, MIT (1970).
- C. Truesdell and R. G. Muncaster, *Fundamentals of Maxwell's Kinetic Theory of a Simple Monoatomic Gas* (Academic Press, New York, 1980).
- M. H. Ernst, *Phys. Rept.* **78**, 1 (1981).
- S. E. Esipov and T. Pöschel, *J. Stat. Phys.* **86**, 1385 (1997).
- E. Ben-Naim and P. L. Krapivsky, *Phys. Rev. E* **61**, R5 (2000).
- A. Baldassarri, U. M. B. Marconi, and A. Puglisi, *Europhys. Lett.* **58**, 14 (2002).
- E. Ben-Naim and P. L. Krapivsky, *Phys. Rev. E* **66**, 011309 (2002).
- M. H. Ernst and R. Brito, *Phys. Rev. E* **65**, 040301 (2002).
- T. Antal, M. Droz, and A. Lipowski, *Phys. Rev. E* **66**, 062301 (2002).
- E. Ben-Naim and P. L. Krapivsky, The inelastic Maxwell model, in: *Granular Gases*, Lecture Notes in Physics **624**, 63 (Springer, Berlin, 2004); (arXiv:cond-mat/0301238).
- N. Brilliantov and T. Pöschel, *Kinetic theory of granular gases* (Oxford University Press, 2004).
- S. Tatsumi, Y. Murayama, H. Hayakawa, M. Sano, *J. Fluid Mech.* **641**, 521 (2009).

Lecture 4: Forced Gases

- T. P. C. van Noije and M. H. Ernst, *Gran. Matt.* **1**, 57 (1998).
- K. Feitosa and N. Menon, *Phys. Rev. Lett.* **88**, 198301 (2002).
- X. Nie, E. Ben-Naim, and S. Y. Chen. *Phys. Rev. Lett.* **89**, 204301 (2002).
- K. Kohlstedt, A. Snezhko, M. V. Sakochnikov, I. S. Aranson, J. S. Olafson, E. Ben-Naim, *Phys. Rev. Lett.* **95**, 068001 (2005).
- E. Ben-Naim, B. Machta, and J. Machta, *Phys. Rev. E* **72**, 021302 (2005).
- E. Ben-Naim and A. Zippelius, *J. Stat. Phys.* **129**, 677 (2007).
- J. Harting, H. J. Herrmann, and E. Ben-Naim. *EPL* **83**, 30001 (2008)
- W. Kang, J. Machta, and E. Ben-Naim, *EPL* **91**, 34002 (2010),

Lecture 5: Alignment

- Y. Kuramoto, in: *Lecture Notes in Physics* **30**, 420 (Springer, New York, 1975).
- S. H. Strogatz, *Physica D* **143**, 1 (2000).
- I. S. Aranson and L. S. Tsimring, *Phys. Rev. E* **71**, 050901(R) (2005).
- E. Ben-Naim and P. L. Krapivsky, *Phys. Rev. E* **73**, 031109 (2006).