

# Outline for Fundamentals of Statistical Physics

Leo P. Kadanoff

text:

Statistical Physics,

Statics, Dynamics, Renormalization

Leo Kadanoff

I also referred often to *Wikipedia* and found it accurate and helpful.

# Course Outline

part number	text chapter number	title	length (slides)	number of lectures
		Fundamentals of Statistical Physics		
1	1	Once over Lightly	16	1
2	2 & 3	Basics	24	2
3	4 & 13 & 15	Quantum Mechanics and Lattices	28	3
4	5	Diffusion and Hops	24	3
5	6 & 8	Momentum hops	27	3
6	9	Bose and Fermi	16	1
7	10	Phase Transitions & mean fields	40	2
8	11 & 12 & 13 & 14 & 15	Phase Transitions: Beyond mean fields	42	2
				17

# Part 1: Once over lightly

Concepts which specifically belong to statistical physics  
Interesting Physical Science Advances have a Major Statistical Component  
Probabilities: One die  
Quantum Stat Mech  
Classical Stat Mech  
Thermodynamics  
Random Walk  
Brownian Dynamics  
From Quantum to Classical: The Ising model  
Averages from Derivatives  
Degenerate Distributions  
Thermodynamic Phases  
Phase Transitions  
Big Words

# Part 2: Statistics

## Probabilities

- Simple probabilities
- averages
- Composite probabilities
- Independent events
- simple and complex
- Many dice
- Probability distributions

## Statistical Mechanics

- Hamiltonian description
- Statistical Independence
- one and many
- Structural Invariance
- Intensive and Extensive

## Gaussian

- Statistical Variables
- Integrals and Probabilities
- Statistical Distributions
- Averages
- Approximate Gaussian integrals

## Calculation of Averages and Fluctuations

- The Result
- Going Slowly
- sums and averages in classical mechanics
- more sums and averages
- homework

# Part 3: On a Lattice: From Quantum to Ising to RG

## From Classical Stat Mech to Quantum

- All of quantum mechanics
- one dimensional lattice
- from classical to quantum
- Summary
- from quantum to classical
- the path integral for particles

## The Linear Chain

- Ising model
- Transfer Matrix
- Dual Couplings
- Solution of One-Dimensional Ising Model

## On Quantum Chains

- Ground state averages
- Statistical Correlations
- Average magnetizations
- Correlations
- Correlation Length
- Bloch Wall

## Renormalization for 1D Ising

- Block Transform
- New Coupling

## 2D Ising

- High Temperature Expansion
- Low Temperature Expansion
- Duality
- Specific Heat
- Block Transform
- Physical quantities
- Flows

## Homework

# Part 4: Hopping

From Discrete to Continuous

Hopping on a Lattice

Notation: Even and Odd

From one step to many

An example

Continuous

Langevin equation

An integration

Gaussian Properties

Generating Function

A probability

Discrete

A probability

calculation

we get an answer!

fourier transform formulation

binomial theorem

Higher Dimension

pictures

continued

probability density

One dimension

Current

Diffusion equation

Higher Dimension

You cannot go back

# Part 5: Time Dependence

## Brownian Motion

Define Situation

Calculate momentum

Calculate Variance

Calculate Probability Distribution

## Probability Distribution in Classical Mechanics

Statistical and Hamiltonian Dynamics

Probability Distributions in Dynamical Systems

time dependence of dynamical systems

calculation set up

calculation continued

calculation concluded

Poisson bracket

generalizing stat mech

time dependence in Hamiltonian systems

one-particle distribution

Classical Mechanics

## Brownian motion again: toward a unique solution

friction

collisions

calculation set up

calculation continued

calculation concluded

a unique probability distribution

Summary

Homework

# Part 5: Time Dependence, continued

Boltzmann Equation

Scattering

forward

backward

all together

Symmetries

detailed balance-local equilibrium

conservation of particle number

H-theorem

sign of dissipation term

$dS/dt$

Homework

# Part 6: Bosons and Fermions

## Second Quantization

Second Quantization vs Classical

Quantum Description

One Mode

## Independent Excitations

Extreme limit for fermions

Extreme limit for bosons

## Waves

Waves= Special Bosons

photons in cavity

## Conserved particles

conserved fermions in a box

conserved bosons in a box

bose transition

## Dynamics

fermions

Boltzmann equation for fermions

bosons

## References

# Part 7: More is the Same

## Issues

Abstract

phases of matter

phase diagram water

basic physics in phase transitions

Gibbs definition; Ehrenfest classification

Magnetic Phase Diagram

a qualitative change in Behavior

from Gibbs to singularities

## Mean Field Theory

more is the same

for Ising model

Mean Field Theory is Only Partially Right

Calculate results

simplified phase diagram

Graph of Order Parameter

behavior in neighborhood of critical point

go after magnetization

go after energy

go after correlations

critical opalescence

basic equation

correlation function

susceptability

# Part 7: More is the Same, continued

Mean field theory of fluids

from van der Waals to Weiss

van der Waals' first effect

van der Waals' second effect Many Different Phase Transitions

After van der Waals

Landau Mean Field Theory

order parameter generalized

generalized mean field scheme

recent example

why minimize

vary M to vary F

$h=0$ , no space variation

jump like square root of  $T_c - T$

Summary

order parameter and free energy were basic

Look ahead:

a worry

# Part 8: Beyond Mean Field Theory: Less is the Same too

## Periodization

### Worries about Mean Field Theory

fluid experiment 1

fluid experiment 2

earlier hints

theoretical work

universality

turbulence

more rumbles

### Next Steps

toward the revolution

additional phenomenology

### Block Spin

less is the same

renormalization for Ising model

other renormalizations

fields relevant, irrelevant, ...

a worthwhile phenomenology

### The Wilson Revolution

particle RG before Wilson

the renormalization revolution

crucial ideas for the revolution

outcome of revolution

conceptual advances

# Part 8: Beyond Mean ... continued

## After the Revolution

2d XY model

RG point of view is absorbed into particle physics

Coulomb gas

Feigenbaum and routes to chaos

operator product expansion

field theory

summary

## Conformal Field Theory

Polyakov, Virasoro algebra

Friedan, Qiu, Shenker

correlation functions

many exact calculations

quantum gravity

## SLE

Schramm

critical shapes

ensemble of critical shapes

ensemble of critical shapes

## Summary

## References