Statistical Physics 2013 – Handout 1

Tim Horbury, 19 November2013

Introduction

Welcome to statistical physics. This is a fascinating subject, covering one of the most powerful, most elegant and yet poorly understood areas of physics. It's hard even to describe it, but in essence it deals with the statistical consequences of the dynamics of many-particle systems. That sounds arcane, but in fact all thermodynamic systems are like this and as you will see we can use a statistical description of the microscopic behaviour of such systems to make remarkable – and accurate – predictions about their properties.

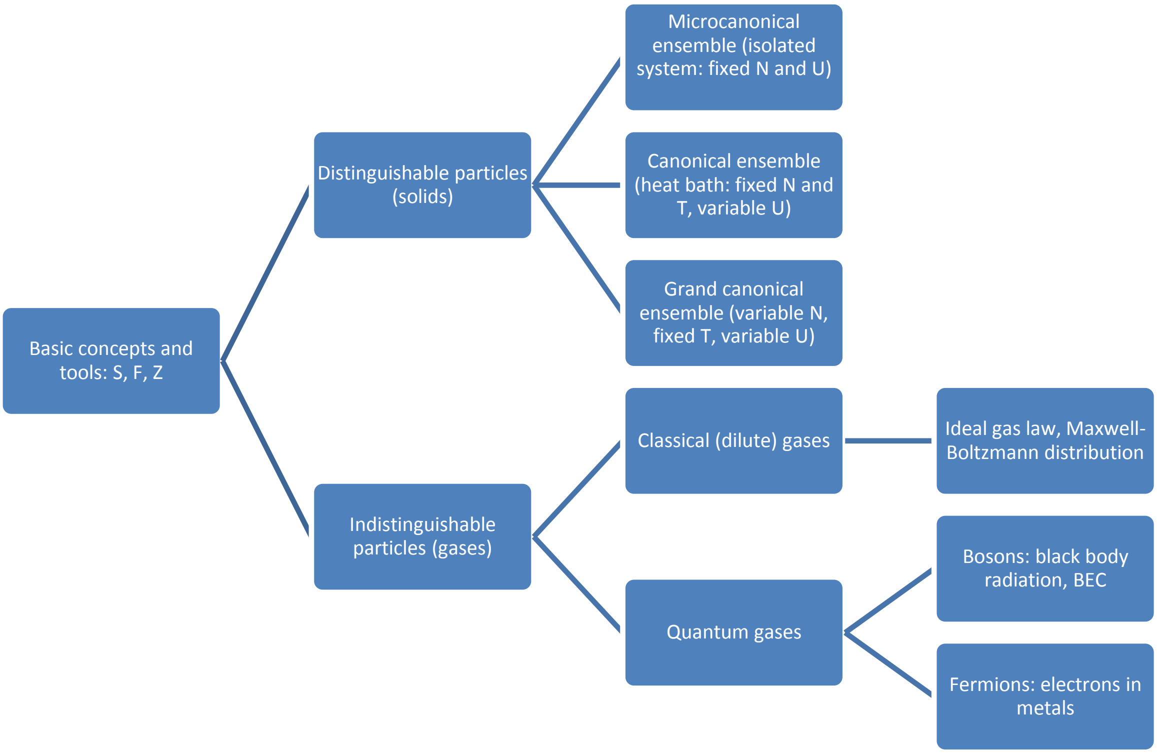
It takes up the story where thermodynamics left off, but goes far beyond it. We will see how energy is distributed between particles in a wide range of systems, derive the ideal gas law from first principles, calculate the spectrum for black body radiation, understand the macroscopic manifestation of quantum mechanics in Bose-Einstein condensation, and much more besides.

Statistical physics is interesting for another reason. It was developed in the second half of the 19th and the early 20th century, at a fascinating time in physics when some of the ideas that we now take for granted were highly contentious or even not yet imagined. It was the field of statistical physics that provided some of the compelling early evidence for quantum behaviour and it provided a strong argument for the existence of atoms which, astonishingly, were not universally accepted even by 1900. We will meet some of the key physicists of this time: Einstein (who was awarded a Nobel prize for his work in this field), Planck, Helmholtz, Gibbs, Bose, Fermi. Most importantly, though, we will see how one man, Ludwig Boltzmann, created a large part of this field. Tragically, he was a very unhappy man and his work was not accepted by many of his peers: he committed suicide in 1906.

All this in only 14 lectures. We'll have to go quickly and importantly, we'll be using the problem sheets to cover some of the material so *please make sure you attempt all the problem sheets!*

Structure of the course

We cover lots of different types of systems: solids and gases; classical and quantum; isolated ones; ones in heat baths; ones that can exchange particles with their surroundings. It's very easy to get lost in all of these systems and the fact that many of them have historical names like "grand canonical ensemble" doesn't help. In the diagram below I've tried to give you an idea of how the course fits together and I'll keep referring back to it so we can see where we've got to. After a brief introduction, we're going to treat distinguishable particles (basically, solids) first and in the second half of the course we'll treat gases, both classical and quantum.



The rest of this handout is about the administrative details of the course. Keep it for later reference.

Aims

The aim of this course is to give you an understanding of how the laws of thermodynamics and the macroscopic thermodynamic properties of physical systems follow from the microscopic laws of nature.

Objectives

On completion of the course, you should

- understand the difference between the macroscopic and microscopic descriptions of a system
- know how to use an ensemble of microstates to describe a macrostate
- know the basic postulates of statistical mechanics of isolated systems and the definition of the microcanonical ensemble
- know the microscopic definition of entropy and be able to use it to explain the second law of thermodynamics and the direction of natural processes ("arrow of time")
- understand the difference between distinguishable and indistinguishable particles and between bosons and fermions and how it affects the statistics of microstates
- know the definitions and the relevance of the canonical and grand canonical ensembles and be able to derive them from the microcanonical ensemble
- understand the meaning of temperature and chemical potential in statistical mechanics
- be able to write down the partition function for a given ensemble and use it to calculate state variables
- be able to derive the partition function for a perfect gas and the Fermi-Dirac (FD) and Bose-Einstein (BE) distributions
- be able to derive the equation of state of an ideal gas
- be able to apply the BE distribution to a photon gas and derive the Planck law for black body radiation
- understand the basic principles of Bose-Einstein condensation
- understand the meaning of degenerate fermion gas and its basic physical consequences

Contact details

I'm Tim Horbury and I'm a member of the Space and Atmospheric Physics Group. My research focuses on space plasma physics, particularly turbulence, shocks and the interaction of the solar wind with the Earth. I also lead the team that's building a magnetic field instrument for the Solar Orbiter mission, due to fly in 2017.

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My office is Huxley 6M72, on floor 6M of the Huxley building. The easiest way to find it is to take the lifts between Blackett and Huxley to floor 6M. My office is just on the right when you leave the lifts.

Office hours

While the course is running, office hours are Thursday 12-1pm and Friday 12-1pm. Please come along: office hours are a great chance to talk through bits of the course that aren't clear.

There will also be office hours in the weeks running up to the exam; look at Blackboard for more information nearer the time.

Schedule

The tables below show the schedule for lectures and problem sheets.

Remember: unless otherwise stated, *all* material is examinable, including handouts and problem sheets. Indeed, we have so few lectures, and so much material to cover, that there will be topics covered in the problem sheets that are *not* discussed in detail in the lectures, but are still examinable.

Lecture	Topic	Date	Time
1	Microstates and macrostates	Tuesday 19th November	9am
2	Isolated systems: microcanonical ensemble	Friday 22nd November	4pm
3	The Boltzmann distribution	Monday 25th November	2pm
4	Heat baths: canonical ensemble	Tuesday 26th November	9am
5	Link to thermodynamics	Thursday 28th November	11am
4	Link to thermodynamics: example	Friday 29th November	4pm
7	Variable particle number: grand canonical ensemble	Monday 2nd December	2pm
8	Entropy and the arrow of time	Tuesday 3rd December	9am
9	Indistinguishable particles: gases	Thursday 5th December	11am
10	Maxwell-Boltzmann distribution	Friday 6th December	4pm
11	Classical vs quantum gases	Monday 9th December	2pm
12	Bosons	Tuesday 10th December	9am
13	Bose-Einstein condensates	Thursday 12th December	11am
14	Fermions	Friday 13th (!) December	4pm

There will also be a revision lecture on Friday 23rd May at 4pm.

Problem sheet	Date handed out
1	Friday 22nd November
2	Friday 29th November
3	Friday 6th December
4	Friday 13th December

Answers to problem sheets will be available on BlackBoard two weeks after the sheets are handed out.

Textbooks

There might well be things that you don't understand about the course as it goes along. Looking at a book, which gives a different – and, perish the thought, perhaps even a clearer – explanation can often be helpful. Here are some textbooks that you might find useful:

Statistical Physics by T. Geunault (*Routledge*) – a slim text which doesn't cover everything, but is very clear for what it does. Try this first. Available from the library.

Statistical Physics by F. Mandl (*Wiley*) – pretty comprehensive. Several copies in the library.

An introduction to Statistical Physics by W. G. V. Rosser (*Ellis Horwood*) – covers almost all the course. Several copies in the library.

Other course materials

I'm not planning to distribute an official set of notes: you are much more likely to learn and understand the material if you write it down yourself in the lectures. There will be a handout with key equations at the end of the course, but please takes your own notes during the lectures.