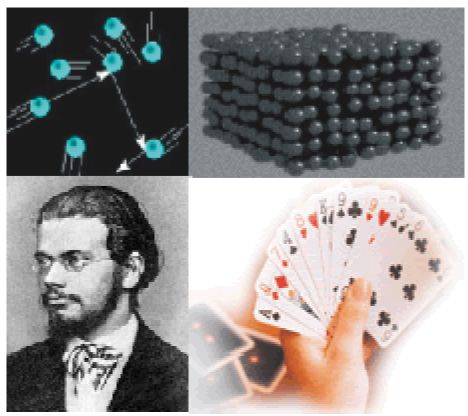
Introduction to Thermodynamics and Kinetics

F31ST1



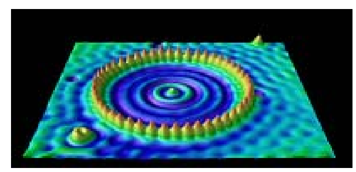
School of Physics & Astronomy

Module Information

I. What will we cover in this module and why is it important?

Thermodynamics is concerned with the *macroscopic* thermal properties of large-scale systems. Some of the properties studied under the banner of thermodynamics include pressure (P), volume (V), temperature (T), specific heats, coefficients of expansion, and heat conduction. However, it is not just the measurement of these quantities that is of interest. Rather, arguably the primary importance of thermodynamics lies in the discovery of *relationships* between these macroscopic variables (for example, P, V, and T) and the subsequent analysis of how these relationships impact on or control the thermodynamic *state* of the system.

The physics and chemistry of thermodynamics was largely developed in the 17th, 18th and 19th centuries by scientists whose names we will encounter time and time again in this module: Boltzmann (shown to the left), Maxwell, Joule, Carnot and Boyle (amongst others). This was long before the development of quantum theory and indeed, even in the 19th century, some time before the scientific community had completely accepted the then hypothetical concept of atoms.



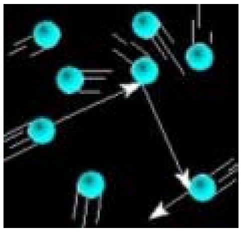
However, in the 21st century we know that matter consists of atoms. We can routinely image individual atoms using scanning probe microscopes (and, for some well-chosen materials, push, pull and position single atoms and molecules). In this microscopic (or nanoscopic) world, quantum mechanics controls the forces that individual atoms and molecules 'feel'. The question that needs to be addressed is: how do the macroscopic properties measured in thermodynamics (P, V, T etc..) arise from the microscopic structure of matter? In other words, how do the countless numbers of molecules and the even greater countless (!) number of possible arrangements of molecules in a gas give rise to well defined pressures, temperatures and volumes?

A bridge between the microscopic and macroscopic……

Statistical mechanics provides a link between the macroscopic and microscopic worlds because it deals with the arrangements or possible *distributions* of atoms amongst the many energy states that are available to them. Remembering just how many molecules there are in, for example, a mole of gas (***?*** *how many are there?)* the number of permutations of molecules is not just a very large value, *it is an inconceivably huge number*. Probability theory plays a central role in statistical mechanics because the equilibrium state[†] of the system is assumed to be that with the highest probability. Although we will not cover statistical mechanics in any detail in the *Thermodynamics & Kinetics* module (in 2nd year you will take a *Statistical & Thermal Physics*

[†] Defining precisely what is meant by *thermal equilibrium* is something which will occupy us for a substantial part of this module. For now, we can use the definition that when a gas is in thermal equilibrium all of its molecules will have the same *average* kinetic energy.

module), we will rely heavily on concepts related to distribution functions and probability when describing kinetic processes.



At this point you may be asking just what is meant by '*kinetics*' in the context of thermodynamics. Kinetic theory differs from statistical mechanics in that although in both cases we're interested in the microscopic structure of the system - i.e. we're concerned with how the atoms and molecules are behaving – in kinetic theory we merge the laws of mechanics (Newton's laws etc…) with probability theory to describe the *motion* (see illustration to left) of the atomic constituents of the gas, liquid or solid. Kinetic theory can treat *non-equilibrium* situations such as diffusion, effusion (molecules escaping from a hole in a container), heat conduction, viscosity, and the rates of chemical reactions. You will be introduced to each of these topics in this module.

NOTES

II. Module organization and *what is expected of you*.

Contact details:	Philip Moriarty, philip.moriarty@nottingham.ac.uk, *Office*: B403, *Telephone extension*: 15156

! *Please first contact me via e-mail to organize an appointment if you need to discuss any element of the module with me.*

Lectures

You will be given handouts of printed lecture notes throughout this module. I will endeavour to provide you with notes well in advance of the lecture and you will gain significantly more from this module *if you read the lecture notes before the lecture*. The material covered in the lectures will be presented as computer-based slides and I will use the blackboard sparingly (except when *explaining* certain concepts).

! *You are not expected to slavishly copy down everything from the slides displayed during the lectures.*

The information in the lectures will largely be given in the printed lecture notes. However, the lectures will not simply mirror the printed lecture notes you'll be given and you will need to attend the lectures to ensure that you get the 'complete picture'. There are two specific and key areas where the lectures will strengthen and complement the printed notes:

(i) The lectures will feature computer-based and 'real world' demonstrations of thermal and kinetic physics;

(ii) The notes feature a number of questions in each section, the answers to which will be explored in the lectures.

Furthermore, you'll also see that blank sections are left here and there in the notes so that you can write down anything that you feel is particularly important during a lecture. You could also use these blank sections to write down the answers to the questions posed in the lectures.

Finally with regard to the lectures, the module has been designed to promote learning *during* the lecture period. I am relying to a large extent on *your* contribution to make this happen. This year I will make extensive use of the University's "Keepad" technology to determine, via multiple choice questions, the extent to which the concepts in the lectures are understood.

Web

The website for the course may be found at: **www.nottingham.ac.uk/~ppzpjm/F31ST1.** The lecture notes handouts and the slides from the lecture presentations may both be downloaded from the website. Note however that the slides for a particular lecture will only be made available for download *following* the lecture.

Coursework

As for the other core 1st year modules, you will have four sets of problems to answer during the spring semester. The cover sheet should be filled in and attached to your answers. Answers may be handed in late *provided you have a good reason* either to your tutor or to the School of Physics & Astronomy main office (C14). Model answers will be displayed following the submission and marking of a particular coursework set.

Any student found guilty of plagiarism or cheating by copying another student's work will be dealt with very severely.

! *The coursework contributes 15% of the module assessment.*

Examination

The examination is a conventional 2 hour exam. whose format is identical to those of other core modules. *The examination contributes 85% to the module assessment*.

NOTES

Recommended Textbooks and websites

Although printed notes will be handed out in the lectures do not rely on these alone. **Use the library** and consult the textbooks and websites listed below

1) The <u>primary recommended textbook</u> is *Physics for Scientists and Engineers*, Paul A Tipler, 5th ed, Freeman, 2004. You all should have a copy of this. Part III (Chapters 17-20) deals with thermal and kinetic physics.

Secondary references

1) It is very well worth reading Chapters 10 -12 of Volume 1 of *Matter & Interactions: Modern Mechanics*, Ruth Chabay amd Bruce Sherwood. This textbook approaches thermal physics in a rather novel fashion (but at a 1st year level). It is particularly good at highlighting the links between thermal physics, kinetic theory, probability and classical mechanics.
2) *The Feynman Lectures on Physics*, RP Feynman, edited by RB Leighton, and M. Sands. Chapters 39 - 46.
3) Chapter 1 of *Introductory Statistical Mechanics,* Bowley and Sanchez. Although, as you'll have guessed from the title, this is a statistical mechanics textbook, the first chapter provides very clear descriptions and explanations of the thermal physics we'll cover in this course. In addition, note that Prof. Bowley is currently the lecturer for the *Thermal and Statistical Physics* 2nd year module.
4) *Thermal Physics*, CBP Finn, Chapters 1 – 5
5) Greg Goebel's online thermal physics course: http://www.vectorsite.net/tpecp5.html
6) *Hyperphysics* website: http://hyperphysics.phy-astr.gsu.edu/hbase/heacon.html#heacon (note that not all of the information at this site may be at a 1st year level).
7) There is also a chapter from a book on thermodynamics and statistical physics at: http://www.geo.cornell.edu/geology/classes/Chapters/Chapter02.pdf. Note however that this is written for a geology class. Nevertheless, it includes some helpful discussions of thermodynamic principles and processes.

I will also be using a number of Java applets (i.e. web-based simulations) during the course and will provide the URLs for these as we go along.

NOTES

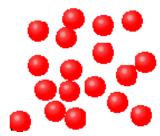
SYLLABUS

There are 5 primary topics to cover in this module. We will first focus on kinetic theory, considering the microscopic structure of matter, before moving on to cover thermodynamics. (However, the aim throughout will not be to view these as two completely separate areas, rather to consider thermodynamics and kinetic theory as two sides of the same coin).

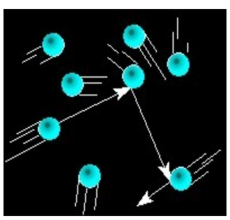
Note that the syllabus may not be covered in exactly the same order as suggested by the lists below.

I. Three states of matter: Solid, Liquid, Gas

- Interatomic forces and potentials: bonding;
- Introduction to temperature and changes of phase;
- Vapour, vapour pressure and evaporation;
- Latent heats;



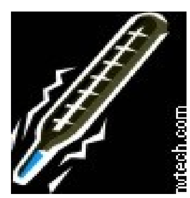
II. Kinetic theory: Distributions, Energy and Heat flow



- Distributions and the mathematics of averaging;
- The ideal gas law; ideal and real gases; van der Waals' equation;
- Boltzmann factors; Maxwell-Boltzmann distribution;
- Equipartition theorem, degrees of freedom, specific heats;
- Blackbody radiation;
- Diffusion, mean free paths, viscosity;
- Conduction, convection, radiation;

III. Thermodynamics from micro- and macroscopic perspectives

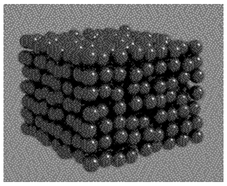
- The 0th law, thermal equilibrium, and thermometry;
- Heat, energy, and the 1st law; isothermal and adiabatic processes; PV diagrams;
- The ideal gas law and Boltzmann revisited; expansion of gases;
- Phase diagrams, isotherms and phase transitions;



IV. Entropy and probability

- Probability, disorder and the 2nd law;
- Reversibility and irreversibility;
- Microstates, macrostates and entropy;
- Engines, refrigerators and the Carnot cycle;
- Efficiencies of engines

V. Thermal and kinetic properties of solids and liquids



- Thermal expansion;
- Heat conduction; phonons and electrons;
- Lattice vibrations and Einstein's model;
- Radiant heat and limitations of kinetic theory;
- Fluid dynamics – viscosity, Reynolds number.