Introduction to the course (i.e., technicalities)

- What is this course about?
- How the course is structured
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(A gentle) Introduction to Thermal Physics

- The first demo…
Introduction to the course (i.e. technicalities)

What is this course about?

Thermal physics is about energy, heat and work. As a subject it originated in the late 1700s when the first engines (mostly external combustion steam engines) were being developed. Because of this, it deals quite strongly with the properties of gases and how their macroscopic properties such as pressure and temperature create useful work, and useful or waste heat.

This history can also be its downfall. People often assume that because most of the work discussed in the course was done by scientists such as Watt, Carnot, Clausius, Boltzmann, Helmholtz and Gibbs (all of whom were dead and buried by World War I) and evolved from steam engines, that this is an old, dead and boring subject. This is nonsense. If anything, thermodynamics could easily be considered one of the most useful products of the history of physics and is quite important to modern engineering and design.

To give just one simple example, consider the Formula 1 engine on the title slide, the on-going development of these engines is heavily based on thermodynamics.

- How do I turn a given quantity of fuel into the maximum possible amount of useful work (i.e., energy transferred into forward motion) with the minimum amount of waste heat?
- How do I most efficiently get rid of that waste heat?
- How does the engine output vary with the compression pressure in the engine?, etc.
The same sort of questions can be asked about a variety of important systems: power stations, heaters, refrigerators, compressors, pumps, radiators, cooling systems, chemical reactors and even, as we’ll see later, how best to cook a steak.

At this point you might be thinking, ‘well that’s great, but I want to do physics research not engineering, why should I care?’ Thermal physics is central to a number of very important research topics at the moment, including:

- Biophysics: topics such as molecular motors, protein folding and the relationship between life and the 2nd law of thermodynamics.
- Complex systems: topics such as turbulence, atmospheric and ocean dynamics, and chaotic systems.
- Non-equilibrium systems: early thermal physics was about systems at or very close to equilibrium. Researchers are now dealing with systems that spend most of there time far away from equilibrium, for example, ecosystems, economics, and life.

How is the course structured?

This course will be VERY different to previous years of the course, in particular the way I will cover the syllabus will be rather different:

- Following the traditional text (Sears and Salinger), you take a very mathematical approach of cooking up some parameters, derive a bunch of mathematical relations and try to pull some understanding out of them. This approach is kind of nice because you can get almost all of thermodynamics by taking a few simple premises and ‘doing the maths’. It makes sense if you really understand the concepts of thermodynamics, but if you’re new to the subject it often leads to confusion because the physics is hidden in the algebra.

- My personal philosophy is that physics is about explaining the world we live in, ideally in words, and that mathematics is a tool that allows us to both increase this understanding and make quantitative predictions.

- Hence I’m going to follow (roughly) the approach Feynman takes to the subject in the “Feynman Lectures on Physics”, but this means the course will be kind of backwards compared to the Sears and Salinger approach used over the last 10 years here.

**Most importantly, I want you to focus on understanding the concepts and how to apply them, not on memorising formulas, equations or derivations. As a practising physicist you will need to know the concepts, you can always look up the exact formula or derivation in a text book.** (e.g., you are more likely to need to know what entropy is and how it is appearing in your system than to regurgitate the first principles derivation for entropy from the Carnot cycle.)
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DVS = D.V. Schroeder, SS = Sears and Sallinger, F = Feynman Lectures, ZD = Zemansky and Dittmann (n.b., this list is not exhaustive)

**PHYS2060 Lecture #1: Introduction to Thermal Physics**
What I expect in this course

Lectures

- A comprehensive set of lecture notes will be posted online after each lecture. The intention is that by not having to frantically scribble down every word on the overheads/blackboard, you will be able to focus on listening and thinking about what is being said. This doesn’t mean you shouldn’t take notes at all, not everything that I say or explain will be in the online notes (but all of the algebra and key points will be) at http://www.phys.unsw.edu.au/PHYS2060/

- The human attention span lasts about 20 minutes, therefore I will try to break my lectures into small ‘blocks’ with a gap in between. Sometimes these gaps will be filled with something to do, sometimes they will just be a momentary break to regather your thoughts.

- I am not here to simply download information into your brains, and if you expect to learn by osmosis without putting in any effort, you will be wasting your time. You should be thinking in the lectures, asking questions and responding when I ask you questions.

Tutorials

- There will be a number of tutorial/Q&A sessions in the course. I intend to leave these relatively unstructured for now and see how we go. I could choose one of the suggested questions to cover, I could take a question on notice (i.e., ask people to let me know which question they’d like done the lecture before) or I could just make it a broad Q&A session.

- You should work your way through the list of suggested problems that I will give you, but not blindly. Questions you find easy will not help you much, but the questions that are hard will. You should seek out and work through the problems that push your boundaries.
Assessment

There will be four assessment tasks in this course:

- **Assignments:** There will be two assignments, each worth 10%, they will be due in at the end of weeks 6 and 13.

- **Midsession Exam:** There will be a 1 hour midsession exam during the Thursday lecture in Week 8, it will be worth 20%.

- **Final Exam:** There will be a 2 hour final exam held during the university exam period, it will be worth 60%.

Unfortunately, the past PHYS2060 exams will not be a good example of the exams in this course, please use the assignments, tutorial questions and midsession exam as a guide. There will be a mix of questions requiring concept explanation, application to specific problems and some derivations. If you focus on understanding the concepts and how to apply them and, where applicable, how they can be derived from existing principles, you should fare well.
Reading/Resources

You should aim to be reading fairly widely in this course. The key texts for the course are:

D.V. Schroeder, *“An Introduction to Thermal Physics”* (Addison Wesley) and Sears and Salinger, *“Thermodynamics, Kinetic Theory and Statistical Thermodynamics”* (Addison Wesley)

Sears and Salinger (SS) has been the standard text for this course for many years, but it can be rather technical and difficult to follow, so I am supplementing it this year with Schroeder’s book (DVS), which is a lot more user-friendly.

Some other very useful books to read with this course are:

- Feynman, Leighton and Sands, *“The Feynman Lectures on Physics”* Vol. 1 (Addison Wesley) – This is an excellent text that contains many insightful explanations of a wide range of undergraduate physics topics, not just thermodynamics.

- Sonntag, Borgnakke and Van Wylen, *“Fundamentals of Thermodynamics”* 6th Ed (Wiley) – A very good general textbook with a bit more mathematics than the Feynman lectures, and a lot of very good problems and worked examples. Similar to DVS but more eng.

- Zemansky and Dittman, *“Heat and Thermodynamics”* (McGraw-Hill) – A far more technical thermodynamics text but very comprehensive. Very similar to SS in content but more readable.

Additionally, I will give some useful journal articles and passages from some older and more difficult to find books as reading when this is appropriate – these will appear in the reading section of the course website. The website is: [http://www.phys.unsw.edu.au/PHYS2060/](http://www.phys.unsw.edu.au/PHYS2060/)
Consultation Hours and Online Discussion Forum

The consultation hours for this course will be **Wednesday 12-2pm** in my office Rm 138B in the Old Main Building. Feel free to come at other times, but I won’t always be available – it might be better to arrange a time with me first outside Wed 12-2pm.

Something I’d like to trial in this course is an online discussion forum. I hate the new WebCT more than the old one, and probably as much as you do, so I’m going to use the School of Physics Forum Website for this (Link is: [http://www.phys.unsw.edu.au/forums/](http://www.phys.unsw.edu.au/forums/)). It is intended that this be a place for discussion of general topics in the course and for questions. I will also use it as a place to post answers to frequently asked questions that come up post-lecture or during the consultation hours.

I will check the forum regularly to answer questions, etc. Please feel free to answer questions on the forum yourselves, you might be surprised how much you learn by doing this. A common phrase in teaching medicine is ‘see one, do one, teach one’. You will see the material in the lectures, you will do the material in the tutorial, assignment and exam questions, and you can take the final step by discussing the material both in person and online and by answering each other’s questions.

We are also #10 if you search for ‘physics forums’ – so you can’t miss it!
Some tips for success in this course

1. I cannot overstate how important it is to THINK about the concepts in this course. You should be spending at least 20-30 minutes after each lecture thinking about what was in the lecture, but more importantly how it fits into your existing knowledge of physics. It can also help to look for systems in your daily experience where you can apply your knowledge.

2. Don’t hesitate to ask questions during the lecture, there is no such thing as a wrong or silly question. Having questions answered can make a huge difference to your level of understanding of the subject. One of the big challenges as a lecturer is finding out whether you are getting your point across correctly, so the other advantage of questions is that it gives me some feedback on whether I’m getting my message across effectively or not.

3. Try to do as many problems as possible. Problems will help you expose the holes in your knowledge and understanding of the subject. You can then work to fill these holes. The tutorial questions I will give are a rough guide, I encourage you to decide for yourself whether a question will help you or not, and find more or alternate questions if you need them.

4. A good exercise is often to think about how you’d explain the various concepts to someone else, for example, a student in the year below. You often learn more by trying to teach something to someone else than you will by just trying to learn it yourself.

5. Following on this point, do not hesitate to work together in small study groups on this course. Some of the best learning experiences come from sitting around and trying to improve your knowledge.

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1 N.B., these might not all work for you, each student is different – your journey as a student is to work out what works best for you, and use it.
collective understanding of a subject – two or three heads are always better than one. That said, be careful regarding the assignments, your submission should be your own work. Make sure you know the rules on plagiarism, see:


- One final tip – some of the best physicists often use what are known as thought experiments (or gedanken experiments), they are an excellent way to find holes in your understanding of a subject. In your head you can cook up all sorts of experiments, use what you know to figure out what should happen and then see if the outcome makes sense.

The Laws of Thermodynamics (or The Whole Course in 1 Slide)

0th Law: If system A is in thermal equilibrium with system B, and system B is in thermal equilibrium with system C, then system A is in thermal equilibrium with system C.

This law allows us to define a concept called temperature and says that thermal equilibrium is a universal concept – without this law there is no thermodynamics.

1st Law: The change in internal energy of a system is due to some combination of work done by or on the system and heat passing into or out of the system (commonly seen as \( dU = Q + W \)).

This law is just conservation of energy wearing different clothes.

2nd Law: A process whose only net result is to take heat from a reservoir and convert it to work is impossible or the total entropy of a system is always greater than (irreversible processes) or at best equal to (reversible processes) zero.

There are a large number of forms of the 2nd law (Clausius, Caratheodory, Carnot, Kelvin-Planck, etc.) and but basically the 2nd law says that disorder and loss of useful energy always occurs, you can’t useful energy or order for free.

3rd Law: At absolute zero, the entropy of any system will be zero or it is impossible to reduce the temperature of a system to absolute zero by any finite number of operations.

Basically, this one says that you cannot reach absolute zero or zero entropy.
(A gentle) Introduction to Thermal Physics

The Camper’s Handwarmer

We are going to begin by doing a quick demonstration/exercise. The aim of this exercise is to start you thinking about everyday objects where thermodynamics applies (very useful for thinking your way through this course), gain some experience in figuring out what meaningful questions to ask, how to compile those answers into an understanding of how something works, and get used to working on such problems in small groups.

The exercise will run as follows:

- I will show you the object and what it does.
- You should then break into groups of 2 or 3 (the people near you), you have five minutes to come up with questions that get information you need about the object.
- We will then have 5 minutes to ask questions. Your questions should be short answer. I will decline to answer questions like ‘how does it work?’ as it defeats the purpose.
- You will then have another 5 minutes to discuss what you think the operating principle is. We will then reconvene and see if you are right.

N.B. I will assume you remember solids, liquids and gases, solutions and some basic thermodynamics from first year physics.
Questions I’d have asked

- Is the process a one off or can it be done multiple times?
- If it can be used multiple times, how do you make that happen?
- What’s in the bag? (if you can’t tell me, how much can I deduce about what’s in the bag?)
- Can you make it work without the clicker? (How stable is it?)

Questions I’d be asking myself in working it out

- I have a liquid that becomes a solid, what are the possibilities for why this would happen?
- Is the reaction physical or chemical? Can I tell the difference?
- How is the heat being stored?
- How does the heat get in there in the first place?
- What might the clicker do to make the process work?
- Can I make it work without the clicker? Does it provide a necessary condition for the reaction?
- Can I induce the reaction with a crystal, thereby eliminating the clicker?
How it works.

- The bag, in its liquid form, consists of a supersaturated solution of sodium acetate salt in water. This state is what is known as a metastable equilibrium, its perfectly happy like that until you do something that causes some part of the solution to crystallise. When that happens, you get a runaway or spontaneous process – the crystal acts as a seed crystal for the salt around it to crystallise on.

- The bag, in its solid form consists of hydrated sodium acetate crystals, and a small amount of sodium acetate solution (concentration well below saturation). This state is what is known as stable equilibrium, no small change in the system will cause it to move away spontaneously from this state.

- The heat that gets released is stored as the energy that keeps the sodium and acetate ions separated and mobile in solution.

- The warmer can be regenerated by putting it in boiling water to dissolve ALL of the crystals, this is how the energy that appears as heat later gets put in. If you don’t dissolve all of the crystals, as soon as you cool it down, the sodium acetate will crystallise out and dump its energy.

- How the clicker works is not precisely known. Some suspect that the sonic energy of the ‘click’ causes the first seed-crystal to form, others think that it causes cavitation (formation of a bubble that collapses on itself), which brings two ions close enough together to trigger the formation of the solid salt. It has also been suggested that the dimples in the clicker trap small crystals, which are released when the clicker is activated.
What concepts of thermodynamics apply to this system?

- Equilibrium: We have a metastable equilibrium in the liquid phase and a stable equilibrium in the solid phase.

![Equilibrium diagram](image)

- First law: The internal energy of the system gets converted (almost) entirely into heat.
- Second law: The entropy of the system increases in going from the liquid to solid state, which means that the reverse process cannot occur spontaneously.
- Latent heat: The process is a physical one, where we see a phase transition from a liquid salt (individual ions free to move but strongly interacting) to a solid salt, this transition requires a specific amount of energy.
- The relationship between internal energy and temperature: unlike an ideal gas, where as we’ll see internal energy and temperature are almost the same thing, here the system sacrifices internal energy but increases in temperature.

And all this in a simple camping product worth only $5!! – We will probably revisit the handwarmer again later in this course.
Summary

- Thermal physics is about energy, heat and work, and their interactions with matter.

- An understanding of thermal physics is important to a large number of everyday applications and technologies from engines to refrigerators.

- Thermal physics also plays a major role in some very interesting topics at the forefront of physics research including biophysics, complex systems and non-equilibrium behaviours.

- I really want you to focus on being able to understand and explain the key concepts of thermal physics and apply them to a wide variety of systems. The handwarmer should be a good first demonstration of how to approach such systems.

In the next lecture we will start some serious thermal physics, looking closely at the concept of pressure in gases, and how you can understand it from a molecular point of view.