What should I have learnt from the Thermal & Kinetic module?

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Section 1

- Potential energy curves: simple harmonic oscillator, Morse potential curve – what are the differences? When can we approximate the potential energy curve for atoms in a solid to that of a simple harmonic oscillator?
- Changes of phase – what happens to the temperature of a solid at the solid-liquid or liquid-gas phase transition?
- What is meant by heat capacity and latent heat?
- What is meant by 'saturated vapour pressure'? Why does a liquid cool as it evaporates and how does the rate of evaporation depend on humidity? How is evaporation different from boiling?

Section 2

- What is a distribution function? How is an average quantity determined from the expression for a distribution function? (See also autumn semester Modelling notes + 1st year lab. manual).
- Know and be able to apply the ideal gas law ($PV = RT$, $PV = N_A kT$) ;
- Know <u>derivation</u> for $PV = 1/3 \, mN<v^2>$ given in Section 2.2. of the notes;
- Understand what is meant by the *mean square speed* of a molecule;
- Know that the internal energy of an ideal gas is only related to translational energy (no other degrees of freedom) and therefore depends only on the temperature of the gas: $U = \frac{1}{2} m<v^2>$
- Know what is meant by a *free expansion*.
- Under what conditions can a real gas be treated as an ideal gas?
- What is a Boltzmann factor? Know <u>derivation</u> of Equation 2.21 in Section 2.3.
- How is the probability of finding a system in a state of given energy related to the Boltzmann factor?

- Be able to sketch curves for the distribution of molecular **speeds** (Maxwell-Boltzmann distribution) and the distribution of molecular **velocities** in a gas. Understand the effects of temperature on both these distributions. (You will be given the Maxwell-Boltzmann distribution function if needed in the exam). Understand what *f(v)* in Eqn. 2.31 represents.
- Be able to derive expressions for $<v>$, v_{rms}, and $v_{most\ probable}$ from Eqn. 2.31 (see CW Set 2).
- Understand what is meant by *equipartition of energy* and *degrees of freedom*.

- Know that in a reversible expansion of an ideal gas the work done is given by $dW = -P\,dV$ (remember sign convention for work : - ve $\Rightarrow$ gas does work on surroundings).
- Know and understand the 1st law of thermodynamics (conservation of energy, $dU = dQ + dW$) – see also Section 4.
- Know the expression for specific heat at constant volume/ pressure (Eqns 2.39, 2.42)
- Understand and be able to <u>derive</u> the relationship between the specific heats for an ideal gas ($C_P = C_V + R$)
- Be able to explain why the ratio of specific heats for an ideal monatomic gas differs from that of a diatomic gas. Why is this ratio temperature dependent when classical equipartition theory predicts that it should be independent of temperature? How is this related to the vibrational and rotational energy levels of the molecules comprising the gas?
- Understand what is meant by the mean free path, λ, of a gas molecule.
- Understand what is meant by the terms 'random walk' and 'coefficient of diffusion'
- Understand why diffusion acts to remove concentration gradients so that molecules fill the available space uniformly and how this is related to the concept of entropy.
- Understand the steps in the derivation of the formula for the thermal conductivity of a gas.
- Understand the steps in the derivation of the diffusion equation and be able to sketch how the solution to the diffusion equation changes as a function of time (Fig. 2.35). (You will not be expected to derive the diffusion equation).
- Know what is meant by the term *heat current* and be able to determine the heat current for simple systems (see also Section 5).

- Know what is meant by *blackbody radiation*. Be able to sketch the classical Rayleigh-Jeans and quantum (Planck) intensity curves for blackbody radiation. Be able to explain what is meant by the *ultraviolet catastrophe*.
- Be able to show that the Planck expression (2.56) may be reduced to the classical expression for blackbody radiation when an appropriate limit is used. What is that limit?
- Understand the steps in the derivation of Eqn. 2.55.

Section 3

- Be able to explain, using the concepts of entropy and thermal equilibrium, why thermal energy (heat) flows from a hot to a cold object.
- Be able to show that the Planck expression (2.56) may be reduced to the classical expression for blackbody radiation when an appropriate limit is used. What is that limit?
- Know that the formula for the spacing of the quantum mechanical energy levels of a 1D simple harmonic oscillator is $E_n = (n + \frac{1}{2}) \hbar \omega_0$
- Be able to describe the essential features of the Einstein model of a solid.
- Know the difference between a permutation and a combination and be able to calculate numbers of possible permutations/ combinations for simple systems. (Note that if you are required to use the formula for the no. of arrangements of q quanta amongst N oscillators it will be provided on the exam paper).
- Be able to explain what is meant by a *microstate* and a *macrostate*. Know the *fundamental assumption of statistical mechanics* (Section 3.3).
- Understand what is meant by entropy in terms of the number of accessible microstates. Know and be able to apply the following formulae to simple systems: $S = k \ln (\Omega)$ and $dS = dQ/T$. (NB These formulae will not be provided in the exam).
- Be able to state the 2nd law of thermodynamics.
- Understand why a homogeneous sharing of energy quanta between the oscillators comprising a system is by far the most probable arrangement and know how this is related to the 2nd law and changes in entropy.
- Know what is meant by a *reversible*, *irreversible*, and *quasistatic* process.
- Be able to calculate the change in entropy for simple irreversible processes (Section 3.8) and understand why the expression dS = dQ/T may be used in the calculation (see also Section 4).
- Know that the change in the entropy of the Universe for a reversible process is 0.

Section 4

- Know what is meant by thermal and thermodynamic equilibrium.
- Understand what is meant by the term *isotherm* and be able to sketch isotherms for ideal gases.
- Understand what is meant by the terms 'function of state' and 'equation of state'. Which of the following are functions of state: Q, W, ΔU, S?
- Know the formula for work done in an adiabatic process for an ideal gas.
- Know what is meant by an *isobaric, isochoric*, and *isothermal* process. Be able to calculate work done, heat transferred, and change in internal energy for each of these. Be able to sketch pathway associated with each process on a PV diagram.
- Know the difference between *isothermal* and *adiabatic* processes..
- Know how the expression for the efficiency of a reversible heat engine is derived.
- Know and understand the steps in the Carnot cycle for an ideal gas.
- From a consideration of entropy and the 2nd law, be able to show that no heat engine can have a higher efficiency than the (reversible) Carnot engine.

Section 5

- Be able to explain why the average thermal energy of 1 mole of a solid is $3RT$ according to the equipartition of energy theorem.
- Be able to explain why the specific heat of a solid is not temperature independent i.e. why equipartition theory fails (cf Section 2 re. specific heats of gases).
- Be able to calculate heat current in simple systems (see worked examples, Lecture 20/21).
- Know how thermal expansion arises and be able to apply formula for linear expansion to simple problems.