**PHYSICS 157 Learning Goals:** these learning goals are a guide to what we expect you to be able to do after completing physics 157. They will be updated as the term progresses to include more specific goals. Goals written in blue are conceptual while those in black relate to quantitative problem solving skills.

## Part 1 Thermodynamics

### 1a Temperature and thermometry

- Describe what is meant by the conservation of energy.
- Explain at the microscopic level what is happening when an object is heated or cooled.
- List various macroscopically observable properties that change as heat flows into or out of an object
- Explain how we can tell whether two objects have the same temperature or if not, which one has a higher temperature
- Explain what is meant by two objects being in thermal equilibrium.
- State the zeroth law of thermodynamics and explain why this is necessary for the concept of temperature.
- Explain how a temperature-dependent macroscopic property of a material can be used to define a temperature scale or build a thermometer
- Describe the relationship between pressure and force
- Describe the typical magnitude of forces on everyday objects produced by gases at atmospheric pressure
- Explain how the Kelvin scale is defined
- Describe the difference between a linear relationship and a proportional relationship
- Explain why different thermometers might be more appropriate in different situations (e.g. to measure the temperature of a small volume of liquid)
- Calculate the force from a gas on a certain surface given the pressure and area or the pressure given the force and the area
- Convert between Kelvin and Celsius temperatures
- Calculate the pressure in a constant volume gas thermometer at some temperature given the pressure at another temperature. Calculate the temperature given the pressure of an ideal gas thermometer and the pressure at some other temperature
- Given the equation/graph for how a physical property depends on temperature, deduce the value of that property from the temperature or the temperature from a value of this physical property.
- Given the form of the relationship between temperature and some property (e.g. a linear relationship), come up with the equation or graph that describes this given enough data (e.g. two data points in the case of a linear relationship).

**1b Thermal expansion, stress, and strain**

- For an object made of some material, to calculate the changes in length or volume that material undergoes in response to changes in temperature and external forces (stress).
- To explain why the change of length of an object due to thermal expansion is proportional to its initial length.
- For systems consisting of two different materials, to quantitatively analyze effects resulting from the different expansion rates of different parts.
- To explain why the fractional change in volume of an object for a small change in temperature is three times the fractional change in length
- Give an example of a material where the thermal expansion coefficient has a significant temperature dependence and describe some consequences of this
- Define the concepts of stress and strain and explain how the Young's modulus of a material is defined
- To argue that the Young's modulus depends only on the material and not on the shape or size
- To calculate the fractional change in length of an object given its dimensions, the Young's modulus, and the forces applied
- For static systems with multiple parts, to use Newton's second and third law to related the various internal forces
- For structures involving multiple parts, to calculate the mechanical forces (thermal stress) of various parts of the system on adjacent parts arising from changes in temperature.

**1c Heat and temperature/phase change**

- To calculate the amount of heat required to change the temperature of an object by a fixed amount, or to change the phase of a given amount of material.
- For systems with multiple parts initially at different temperatures and/or in different phases, to calculate the final equilibrium temperature and/or portion of the system in each phase.
- Given data for the temperature as a function of heat added, or the temperature as a function of time for a heat source with a specified power, to deduce the specific heat and/or latent heat of a material

**1d Heat flow: Conduction, Convection, and Radiation**

- To calculate the rate of heating/cooling/phase change in situations where heat transfer is taking place via conduction.
- To be able to interpret spectrum graphs, calculating the relative power for different ranges of wavelengths and deducing the temperature of an object via Wien's law in the case of a thermal spectrum.

- To predict the power in electromagnetic radiation emitted by an object given its temperature, area, and emissivity.
- To calculate the equilibrium temperature of a radiating object when the ingoing energy is supplied directly via a power source or absorbed from some external source of radiation. To correctly take into account emissivity and albedo in these calculations.
- To be able to calculate the intensity (power per unit area) of radiation from a spherically symmetric source given the power of the source and the distance to the source, or to

**Thermodynamic processes, work, heat, and internal energy**

- To use the ideal gas law to predict how certain thermodynamics variables (pressure, volume, temperature) will change given the changes in the other variables.
- To calculate work for various processes based on forces and displacement or pressure and changes in volume. To calculate work in a process represented as a path on a PV-diagram.
- To calculate the change in internal energy of a gas given changes in temperature.
- To calculate heat added to a gas by making use of the First Law of Thermodynamics (via a calculation of work and internal energy).
- To calculate changes in P,V,T, U, W, and Q for processes involving constant pressure, constant volume, constant temperature or zero heat exchange (i.e. adiabatic processes).

**Cyclic thermodynamic processes, heat engines, and refrigerators**

- To calculate the net work done in a cyclic thermodynamics process
- To identify which in which parts of a cyclic thermodynamic process heat is flowing in to the system, and in which parts heat is flowing out.
- To calculate the efficiency of a heat engine, given a description of the thermodynamics processes associated with it, or a depiction of the cycle on a PV-diagram

**Part 2: Oscillations and waves**

**Simple harmonic oscillators**

- Given a graph of displacement vs time for a simple harmonic oscillator, determine the amplitude, period, angular frequency, and phase for the corresponding function (represented as a cosine).
- Given a graph of displacement, velocity, or acceleration vs time for a simple harmonic oscillator, sketch graphs for the other two quantities. Also, to say where each of these quantities is zero, maximum or minimum and give the maximum and minimum values.
- Given the displacement, velocity, or acceleration represented as a sinusoidal function of time, to calculate the functions corresponding to the other two quantities and sketch graphs of all three quantities.

- Given the graph or functional form of displacement, velocity, or acceleration for a simple harmonic oscillator, to determine the constant k in the force law given the mass of the object, or vice-versa.
- Given a physical system with a variety of relevant forces, to write an expression for the net force on some object in the system as a function of that object's position, and to use this to deduce the equilibrium position and the frequency for oscillations around equilibrium
- Given the description of the initial configuration for a physical system that will undergo simple harmonic motion, to predict the subsequent motion of the object, representing this as a sinusoidal function.
- Given the description of the initial configuration for a physical system that will undergo simple harmonic motion, to predict the amplitude or maximum velocity using conservation of energy.

**Damped and driven oscillators**

- Given a graph representing the displacement vs time or the acceleration vs time for damped oscillation, to deduce the time constant for the system or (given the mass) the damping constant b, and to write an equation for the displacement vs time.
- Given a graph representing the displacement vs time or the acceleration vs time for damped oscillation, to determine the energy lost per cycle.
- To determine the damping required to produce critical damping given a graphical or mathematical representation of the oscillations in an undamped or underdamped system.
- More to come…