ENERGY TUTORIAL: Thermodynamics

1) State the First Law of Thermodynamics – first in words, then as an equation.

2) Which of the following statements about thermodynamic properties is FALSE:

A. Extensive properties can be converted to intensive properties by dividing by a measure of system size such as its mass or volume.
B. Volume is an extensive property
C. Heat is not a property of a system
D. Enthalpy is not a property of a system

3) TRUE or FALSE: the internal energy is ALWAYS equal to the thermal energy? If you choose FALSE, give a special case for when the internal energy IS equal to the thermal energy.

4) Explain the difference between closed and isolated thermodynamic systems.

5) How much heat is required to raise the temperature of a 2kg mass of a metal with a specific heat of 0.98 kJ/(kg.K) from 22 deg. C to 28 deg. C?

6) How much heat is required to raise the temperature of a 1.6 kg sample of aluminium from 286 K to 299 K. The specific heat of aluminium is 0.9 J/(g.K).

7) A 400 g sample of Nickel is heated from 30 deg. C to 80 deg. C. The amount of energy required is 8.8 kJ.

A. What is the *total* heat capacity of the given sample of Nickel?
B. What is the *specific* heat capacity of Nickel?

8) Use the data in your course book to determine the energy required to melt a 50 g sample of lead.

9) The energy required to evaporate 2 kg of propane is 856 kJ. What is the (specific) latent heat of vaporisation of propane?

10) How much work is done by a gas expanding reversibly against a piston from 42 L to 70 L at a constant external pressure of 101,325 Pa (1 atmosphere)?

11) Consider a gas in a cylinder at room temperature (T = 293 K) with a volume of 0.05 m^3. We usually assume that the internal gas pressure equals the external pressure; there are a number of reasons why this is not strictly true, however – e.g. during fast processes they are not equal in general. Another reason is the weight of the piston itself. Let's calculate the difference this makes: suppose the gas is confined by a piston of mass 10 kg and an area of 0.7 m^2. The pressure above the piston is atmospheric pressure. What is the pressure in the gas? Would you say this makes an 'important' difference? Why/why not?

12) What does the First Law of Thermodynamics simplify to for an adiabatic process?

13) State your favourite version of the Second Law of Thermodynamics.

14) Under what conditions is the change in enthalpy during a process equal to the heat transferred?

15) How much work is done by 1.9 mole of a gas expanding isothermally at 300 K, against a piston, from 42 L to 67 L?

16) Calculate the initial and final pressures for the above process.

17) The following processes are performed by an ideal gas at initial pressure of 200kPa and volume of $1m^3$:

Process I: Isovolumetric (isochoric) increase in pressure to 1400 kPa.
Process II: Isobaric compression to $0.5m^3$.
Process III: Isovolumetric (isochoric) decrease in pressure to 200 kPa.
Process IV: Isobaric expansion to $1.0m^3$.

A. Draw a pressure-volume diagram of these processes. Indicate each process, label the axes and make sure you show arrows to indicate the direction of each path.
B. Calculate the net work done by the gas in this system.
C. What is the net change in internal energy for this system?

18) An ideal gas, n=0.450, initially at T_1 = 350K, $P_1 = 1.013 \times 10^5$ Pa and $V_1 = 1.29 \times 10^{-2}$ m^3, undergoes the following sequential processes in a closed system:

Process I: Isovolumetric cooling to T_2 = 298 K, $P_2 = 8.63 \times 10^4$ Pa
Process II: Isobaric expansion to V_3 = 13.5 L and T_3 = 311 K.
Process III: Adiabatic compression to P_4 = 101.3 kPa and $V_4 = 1.29 \times 10^{-2}$ m^3

A. Sketch the process on a PV diagram, label the axes, label each process and use arrows to show the direction of each process.
B. Calculate the net work done by the gas. Show your calculations. Indicate if the net work is positive or negative.

19) The change in enthalpy is only equal to the heat transfer for processes at *constant pressure*; for *adiabatic* processes (no *heat transfer*) it can be shown that the *enthalpy* still changes and in fact can be calculated in the same manner as usual, according to

$$\Delta H = nC_p\Delta T$$

- If $C_p = \left(\frac{7}{2}\right) R$ where R is the ideal gas constant, calculate the enthalpy change for the adiabatic process above.

20) Use the ideal gas law (PV = nRT) and the equations for gas expansion/compression work to calculate the work done by a gas when one mole of carbon monoxide gas contained in a piston undergoes the following sequential changes:

A. Isothermal expansion at 700 K from 2.758×10^6 Pa and 2.110×10^{-3} m^3 to 5.520×10^5 Pa and 1.054×10^{-2} m^3.

B. Cooled at constant volume from 700 K and 5.52×10^5 Pa to 437.5 K and 3.45×10^5 Pa.
C. Cooled at constant pressure, 3.451×10^5 Pa from 437.5 K to 350 K.
D. Compressed adiabatically from 3.451×10^5 Pa at 350 K to 2.758×10^6 Pa at 634 K.
E. Heated at constant pressure, 2.758×10^6 Pa from 634 K to 700 K.

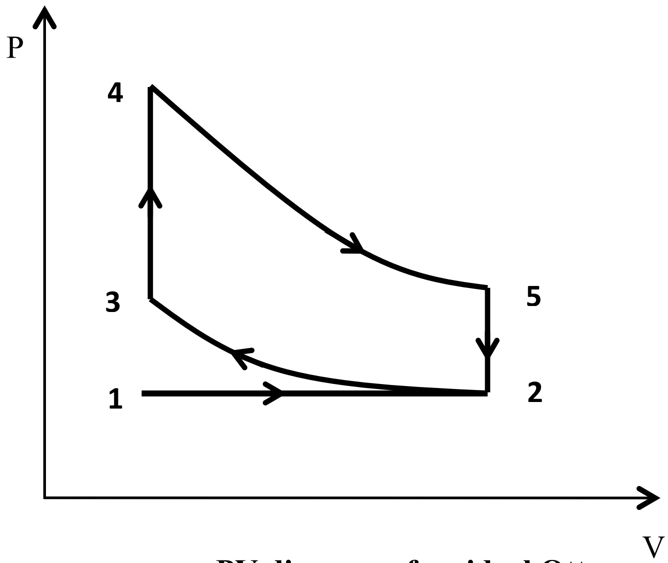
21) A reversible heat engine operates between a hot reservoir at 950 K and a cold reservoir at 450 K:

A. Calculate the maximum thermal efficiency of the engine.
B. The temperature of one of the reservoirs can be changed up or down by 75 K. Determine which reservoir you should change and what the new maximum thermal efficiency should be.

22) An engine using a piston-cylinder operates on an ideal Otto cycle. In the compression stage - 357 J of work are done on the gas; 383.5 J of heat are transferred to the gas at the beginning of the power stroke and the gas does 580.8 J of work in expansion. The temperature at the beginning of the compression step is 325K and at the end of the power stroke is 529K.

A. What is the thermal efficiency of the engine?
B. Give ONE reason why you might expect the actual engine efficiency to be lower than the value calculated above.

23) Analyse the performance of an experimental engine which operates based on ideal Otto Cycle. The PV diagram of this process is shown below.



PV diagram of an ideal Otto cycle

A. Identify the regions of combustion and the intake stroke on the PV diagram.
B. On this diagram label the area that corresponds to the *adiabatic expansion work done (power stroke)* done by the gas. Is this equal to the *net* work done? Why/why not?
C. Calculate number of moles (n) and any missing Volume (V) and Temperature (T) in the table below. For calculating n you need to show the working using Ideal Gas Law equation.

Should be 1486 K
(2016 Exam has mistake).

	2	3	4	5
Temperature, K	323	~~742~~		511
Pressure, Pa	1.10×10^5	4.04×10^6	6.4×10^6	1.74×10^5
Volume, m^3				

Compression ratio = 8 Cylinder Volume = 0.8 L C_v = 20.78 J/molK

D. Calculate work of compression ($W_{compression}$), work of expansion ($W_{expansion}$) and net work (W_{net}).
E. Calculate heat to (Q_{in}) and lost (Q_{out}) by the gas.
F. Calculate thermal efficiency (η).

24) *Challenge question*: during a *Carnot cycle* an amount of heat Q^{in} is added to the system at a temperature T^{in}, while later in the cycle an amount of heat Q^{out} is removed at a temperature T^{out}.

A. What is the net *entropy transported into* the system during the cycle, in terms of the above quantities?
B. What is the *overall change in the entropy of the system* after the cycle?
C. Use the above, along with the Second Law, to show that the actual thermal efficiency for one cycle is less than or equal to the Carnot efficiency, i.e. that

$$\eta = \frac{W^{net}}{Q^{in}} = 1 - \frac{Q^{out}}{Q^{in}} \leq \eta_{Carnot} = 1 - \frac{T^{in}}{T^{out}}$$

25) Consider the reaction:

$$4\ NH_3\ (g) + 5\ O_2\ (g) \rightarrow 4\ NO\ (g) + 6\ H_2O\ (g)$$

A. Write down a general expression for determining the overall Gibbs free energy of formation for a chemical reaction.
B. Use the following Gibbs free energy of formation values to calculate the overall Gibbs free energy of the reaction:

NH_3 (g): -16.5 kJ/mol; O_2 (g): 0 kJ/mol; NO (g): 86.6 kJ/mol; H_2O (g): -228.6 kJ/mol

C. Is the reaction exergonic or endergonic? Spontaneous or non-spontaneous?

26) A newly discovered substance, called 'Reverbranium', is being investigated for its potential as a new type of fuel. A 3.0 g sample of it is burned in a bomb calorimeter containing 1200 g of water at an initial temperature of 19 deg. C. After the reaction, the final temperature of the water is 35 deg. C. The heat capacity of the calorimeter (the "calorimeter constant") is 900 J/deg. C. The specific heat of water is 4.184 J/(g. deg. C) and the molar mass of the substance is 25 g/mol.

- Calculate the heat absorbed by the water, the heat absorbed by the calorimeter, the total heat released by the reaction and the enthalpy of combustion (in kJ/mol).

27) Use the data in your course book to compare the energy density of acetylene to that of petrol. The molar mass of acetylene is 26.04 g/mol.