

### **Solution to T1 by Waitz. (Unified Thermodynamics)**

*Below is a schematic diagram of a helium-pressurized, bipropellant rocket engine system (for the fourth stage of the Peacekeeper ballistic missile). Describe the conversions of energy (internal, potential, kinetic and chemical) and exchanges of heat and work for this system and that of the rocket itself. Note at which points in the process heat is transferred to/from the surroundings. (LO#1, LO#2, LO#3)*

It is understood at this point in Unified that you have only had one or two lectures on thermodynamics, and no propulsion and fluid mechanics lectures. So what is expected is that you recognize conversions between various forms of energy when they occur and know then difference between transfers of energy called “work” and transfers of energy called “heat”.

For the gases in the system, changes in potential energy will typically be small compared to the changes in internal energy, kinetic energy and chemical energy due to their low density. Internal energy is stored in the high pressure helium. The helium expands, pushing against (i.e., applying a force over a distance or doing work on) the propellants. As the helium expands, its internal energy is reduced. Energy may also be exchanged with the surroundings through heat transfer if the high pressure helium tank and the tubing and valves are not thermally-insulated. The work from the helium probably does not raise the internal energy (pressure and temperature) of the propellants very much since there is a pressure regulator in the system. However, it does cause the propellants to move (i.e., giving the propellants kinetic energy). The propellants flow into a combustion chamber where they react, converting chemical energy stored in the propellants into internal energy (high temperature and pressure) in the gases formed as products of the reaction. Here again, energy may be exchanged with the surroundings through heat transfer depending on how well thermally-insulated the combustion chamber and nozzle are. These high temperature and high pressure gases are then accelerated through an exhaust nozzle (exchanging internal energy for kinetic energy). As they pass through the exhaust nozzle they push on the walls of the nozzle doing work on the rocket. The kinetic and/or potential energy of the rocket increase as a result. Any energy left in the exhaust (internal and kinetic) is lost to the atmosphere which sees a very slight increase in internal energy (e.g. temperature) as a result of the whole process.