T12 SOLUTIONS (WAITZ)

a) $s_2 - s_1 = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{p_2}{p_1}\right)$

Q-S, ADIABATIC COMPRESSION

$s_2 - s_1 = 0$

$T_2 = 475$ $p_2 = 500\,kPa$
$T_1 = 300$ $p_1 = 100\,kPa$

INSTANTANEOUS COMPRESSION:

$s_2 - s_1 = 303\ J/kg\text{-}K$

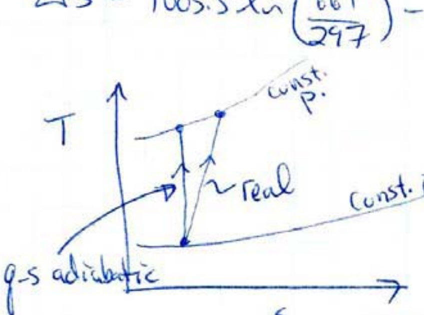
$T_2 = 643.2\,K$ $p_2 = 500\,kPa$
$T_1 = 300\,K$ $p_1 = 100\,kPa$

THE INSTANTANEOUS, IRREVERSIBLE PROCESS REQUIRED MORE WORK TO COMPRESS THE GAS AND RESULTED IN A GREATER CHANGE IN ENTROPY. THE Q-S ADIABATIC PROCESS IS REVERSIBLE ($\Delta s = 0$)

b) Q-S, ADIABATIC PROCESS: $p_2 = 1473\,kPa$, $p_1 = 101.3\,kPa$
$T_2 = 638\,K$, $T_1 = 297\,K$
$\Delta s = 0$

REAL PROCESS: $p_2 = 1473\,kPa$, $p_1 = 101.3\,kPa$
$T_2 = 661\,K$, $T_1 = 297\,K$

$\Delta s = 1003.5 \ln\left(\frac{661}{297}\right) - 287 \ln(14.54) = \boxed{34.6\ J/kg\text{-}K}$



Energy can take many different forms (kinetic energy, internal energy, potential energy, chemical energy). Energy can be exchanged from one form to another (e.g. using fuel to get power out of an engine, or using an electric stove to heat water, or dropping a rock from your hand to the ground) but the only way to change the total energy (the sum of all the various forms of energy) of a system is to add or remove heat or for the system to do work or have work done on it. If heat is added to, or if work is done on a system its energy increases. This is a statement of the First Law of Thermodynamics. It is a very good law but it allows many processes that are impossible in our world.

If I touch a hot and a cold brick together I get two medium temperature bricks. The First Law of Thermodynamics also allows that the opposite can happen. It allows that two medium temperature bricks in contact with each other can spontaneously produce a hot brick and a cold brick, as long as the total energy of the two bricks together hasn't changed. This is impossible in our world, as are many other "reverse" processes: the spontaneous un-mixing of two gases in a container (the reverse of perfume spreading across a room), low pressure air spontaneously collecting itself into a small high pressure volume (the reverse of a balloon breaking), a rock collecting heat from the ground and spontaneously converting it to kinetic and then potential energy to jump into your hand (the reverse of dropping a rock from your hand). Of course, it is possible to reverse all of these processes but only by using work (they won't spontaneously happen). So when we say something is irreversible, we mean that it can not be reversed *without the application of work from the surroundings.*

All real processes are to some degree irreversible. Things that cause processes to be irreversible are unrestrained expansion, friction, molecular diffusion, heat transfer across a finite temperature difference, etc. The Second Law of Thermodynamics provides the tool for sorting out which processes allowed by the First Law are possible and which are not. If the process is possible, a thermodynamic property called entropy will increase (if calculated and summed for both the system and the surroundings). The Second Law also allows us to characterize the "degree of irreversibility" by measuring how much the entropy of the system and surroundings increases as a result of a process. Some processes have more irreversibility (e.g. more friction) than others. The more irreversibilities in a device, the less efficient it is. Reversible processes are not possible, but they are useful idealizations that let us understand the best that can be achieved (we know that a pendulum without friction will run forever, but how efficient could an engine be without friction?). For example, if the power plant at MIT were ideal (no friction, no heat transfer across finite temperature differences, no free expansions, etc.), then all the processes that make it work could run equally well forward and reverse without application of additional work from the surroundings. In this ideal case, application of the First Law of Thermodynamics can be used to show that for each unit of energy that goes into the power plant as fuel, about half that unit of energy comes out as useful work. However, for the real MIT power plant , with all its irreversibilities, each unit of fuel energy only results in about 1/4 of a unit of useful work. Quite a significant impact indeed.