This homework is due **Wednesday, November 2nd, 2016.**

Each problem is worth the points indicated in the parentheses. While a collective work on the assignments is allowed and encouraged, a *brute* copying of the solution from your fellow-students is absolutely not acceptable; see Dean Cilento’s Memo.

1. **Multiple choice questions (30 points)**

   (1a). (3p) A process can proceed if it…
   
   (A) Satisfy both the 1st and 2nd Laws of Thermodynamics.
   
   (B) Violates both the 1st and 2nd Law of Thermodynamics.
   
   (C) Satisfy the 1st law but violates the 2nd Law of Thermodynamics.
   
   (D) Satisfy the 2nd law but violates the 1st Law of Thermodynamics.
   
   (E) It depends…

   (1b). (3p) The following phrase(s) is (are) valid regarding the Kelvin-Planck statement of the 2nd Law:
   
   (A) It is possible for a device to operate on a cycle to receive heat from a single reservoir and produce a net amount of work.

   (B) Thermal efficiency of a heat engine could reach 100% if no friction is involved.

   (C) A net positive work can be output by a device that adsorbs energy from a high temperature reservoir without ejecting energy to a low temperature reservoir.

   (D) Work can always be converted to heat directly and completely, and the reverse is true.

   (E) If the thermal efficiency of a device is less than 100%, it must be an irreversible device.

   (F) It is necessary to have a low temperature reservoir to reject waste heat energy for a heat engine operating on a cycle.

   (1c). (3p) The following phrase is valid regarding the Clausius statement of the 2nd Law of Thermodynamics.

   (A) The transfer of heat from a hot reservoir to a cool one without consuming energy violates the Clausius statement of the 2nd Law of Thermodynamics.

   (B) Energy input is required to transfer heat energy from a low temperature reservoir to a high temperature reservoir.

   (C) A refrigerator is a not cyclic device.

   (D) Energy can be transferred from a low temperature reservoir to a high temperature reservoir and produce a net positive work out.

   (E) Any device that violates the Kelvin–Planck statement does not always violate the Clausius statement.

   (1d). (3p) Which is not an application of the 2nd Law of Thermodynamics?

   (A) Predicting the direction of a process.

   (B) Quantify the power produced by a device.

   (C) Asserting that energy has quality.

   (D) Determining the best theoretical performance of cycles, engines, and other devices.

   (E) Predicting the degree of completion of chemical reactions.

   (1e). (3p) The statement that the efficiency of a reversible heat engine cycle is 100% violates:

   (A) The 1st Law of Thermodynamics.

   (B) Both the 1st and the 2nd Laws of Thermodynamics.

   (C) The Kelvin-Planck statement of the 2nd Law of Thermodynamics.

   (D) The Clausius statement of the 2nd Law of Thermodynamics.

   (E) The Carnot Principle.
(1f). (3p) The thermal efficiency of an actual power cycle A and a reversible power cycle B works under same hot (H) and cool reservoir (C) are $\eta_A$ and $\eta_B$, respectively. Please circle the one satisfy the Carnot Principle:

(A) $\eta_A > \eta_B$.
(B) $\eta_A = \eta_B$.
(C) $\eta_A < \eta_B$.
(D) Cannot be decided based on the information provided.

(1g). (3p) Please circle the valid statement(s):

(A) For an internally reversible process, no irreversibilities occur within the boundaries of the system during the process, and no irreversibilities occur outside the system boundaries.
(B) Reversible processes deliver the most and consume the least work.
(C) A process is called reversible if the system and all parts of its surroundings cannot be exactly restored to their respective initial states after the process has occurred.
(D) In irreversible processes, the surroundings usually do some work on the system and therefore does not return to their original state.
(E) During a cycle, a system can be restored to its initial state following a process, regardless of whether the process is reversible or irreversible.

(1h). (3p) A heat engine that creates energy is known as:

(A) A perpetual machine of the zeroth kind.
(B) A perpetual machine of the first kind.
(C) A perpetual machine of the second kind.
(D) A perpetual machine of the third kind.
(E) None of the above.

(1i). (3p) Please circle the source(s) of irreversibility(ies) among the following items.

(A) Mixing of two fluids.
(B) Friction.
(C) Frictionless pendulum.
(D) Heat transfer across a finite temperature difference.
(E) Unrestrained expansion of gas at high pressure.

(1j). (3p) Please circle the valid statement(s):

(A) The Carnot heat engine is the most efficient of all heat engines operating between the same high- and low-temperature reservoirs.
(B) The efficiency of reversible heat engines is independent of the working fluid and its property
(C) All reversible heat engines operating between the same two reservoirs have the same efficiency.
(D) All irreversible heat engines operating between the same two reservoirs must have the same efficiency.
(E) No heat engine can have a higher efficiency than a reversible heat engine operating between the same high- and low-temperature reservoirs.
(F) A Carnot engine is a reversible engine.

2. (12 points) A power cycle operates between two reservoirs at 700 K and 300K, respectively. $Q_H$ is the heat (thermal energy) received from the hot reservoir. $Q_L$ is the heat rejected to the cool reservoir. $W_{mech}$ is the mechanical work produced. Please determine if the following cycles are possible and explain why. Note: you need to clearly identify the thermodynamic law violated if the cycle is impossible.

(2a). (3p) $Q_H=700 \text{ kJ}, W_{mech} = 400 \text{ kJ}, Q_L = 300 \text{ kJ}.$
(2b). (3p) $Q_H=700 \text{ kJ}, W_{mech} = 500 \text{ kJ}, Q_L = 200 \text{ kJ}.$
(2c). (3p) $Q_H = 700 \text{ kJ}, W_{mech} = 300 \text{ kJ}, Q_L = 600 \text{ kJ}.$
(2d). (3p) $Q_H = 700 \text{ kJ}, W_{mech} = 600 \text{ kJ}, Q_L = 100 \text{ kJ}.$
3. (6 points) A refrigerator with a coefficient of performance of 2.5 consumes 18 kW of electricity when running. Determine the rate of heat ejected into the kitchen by this refrigerator.

4. (7 points) A heat engine receives heat from a source at 900 °C and rejects the waste heat to a sink at 15 °C. If heat is rejected from this engine at a rate of 30 kJ/s, please determine the maximum power produced by this heat engine.

5. (10 points) Assume that WVU’s Engineering Sciences Building (ESB) is always maintained at 27°C, while the outside temperature today is 12°C. The building is heated by means of a heat pump of the coefficient of performance (COP) \( \gamma = 3.5 \), which provides the energy at an average rate of 100 kW. The electricity costs $0.13/kWh. Please find:

   (5a). (3p) The actual operating cost needed to maintain the ESB during a week (7/24).
   (5b). (3p) The minimum theoretical operating cost needed to maintain the ESB during a week.
   (5c). (4p) The potential cost to maintain the ESB during a week if the heat is provided by a resistor heater.

6. (12 points) A piston-cylinder assembly, containing nitrogen, \( N_2 \), undergoes a Carnot power cycle between two thermal reservoirs of temperatures 27 °C and 477 °C. After the isothermal expansion process, accompanied by the 55 kJ heat transfer to the gas, the volume and pressure of the system are 1 \( m^3 \) and 0.6 MPa, respectively. You can assume \( N_2 \) to be an ideal gas at these conditions.

   (6a). (3p) Please determine the thermal efficiency of this power cycle.
   (6b). (5p) Please find the initial volume and pressure (those before the beginning of the isothermal expansion).
   (6c). (2p) Please determine the heat rejected to cool reservoir.
   (6d). (2p) Please find the work produced during this cycle.

7. (10 points) A heat pump with an average coefficient of performance of \( \text{COP}_{HP} = 3.0 \) heats the air in a rigid, insulated cuboid room of size 25 m x 10m x 4m. The heat pump consumes 15 kW of power. The initial temperature and pressure in this room are 12 °C and 1 bar, respectively. How long will it take to raise the temperature in the room to 27 °C?

8. (13 points) The figure on the right shows the main components of a steadily operating refrigerator using R134a as a refrigerant. As shown in this figure, R134a enters the condenser at 800 kPa and 35 °C at a rate of 0.2 kg/s, and it leaves the condenser at 800 kPa as a saturated liquid. The compressor consumes 5.6 kW of power.

   (8a). (7p) Please determine the rate of heat rejected from the condenser.
   (8b). (3p) Please determine the rate of heat absorption from the cooling compartment to the evaporator.
   (8c). (3p) Please determine the (COP) of this refrigerator.