AP Physics Name:

Stirling Engine Worksheet

Key Principles & Assumptions

- Working fluid acts as an ideal gas, so the state variables P (pressure), V (volume), N (number), and T (temperature) are related by the ideal gas law:

  $PV = NkT$

- The internal energy of a gas is contained entirely in the kinetic energy of its constituent molecules, and is directly proportional to temperature

  $U_{internal} = {}^{3}/_{2}NkT$

- Heat (Q_{in}) flows into the system from a high-temperature reservoir (in the case of our Stirling engine, the flame of a candle) and flows out of the system (Q_{out}) into a low-temperature reservoir – can be the ambient air or, in the case of the Stirling engine, some ice.
- Manipulating the gas allows it to do work on the environment around it (in the case of our Stirling engine, keeping the flywheel turning despite frictional energy losses). If a working fluid expands against its outside environment, it does work $W = P\Delta V$ (this energy needs to come from somewhere, either the heat into the system or the internal energy of the gas). The gas can compress when work is done to it – again using the formula $W = P\Delta V$. (More generally, work is the *area* under the curve on a pressure-volume diagram.)
- The various manipulations are called *thermodynamic processes* and include:
  - *Isothermal expansion and compression*. For these, the temperature and therefore total internal energy of the system stays constant, meaning all the heat in Q_{in} is converted to work W done on or by the environment (depending on if it was an expansion or compression.) So: $Q_{in} > 0$, $\Delta U = 0$, so $W > 0$ and $W = Q_{in}$.
  - *Adiabatic (isentropic) expansion and compression.* For these, no heat flows into the working fluid. Any work done by (or to) the gas is realized in a change in internal energy of the gas. So: $Q_{in} = 0$, $W > 0$ so $\Delta U < 0$.
  - *Isochoric process.* No work is done by the gas during an isochoric (constant volume) process. However, the gas gains or loses pressure and energy depending on the amount of heat flowing into or out of the working fluid.
  - *Isobaric expansion and compression*. For these, the pressure stays constant during the expansion. Here we can have $Q_{in} \neq 0$, $W \neq 0$ *and* $\Delta U \neq 0$, depending on the circumstances. During an isobaric expansion, the gas cools and does work on the environment around it.
- The efficiency of a heat engine is the ratio of work delivered to heat input: $\varepsilon = W_{net} / Q_{in}$. The ideal efficiency of a Carnot cycle predicted by Sadi Carnot is related only to the temperatures of the heat source & heat sink in the system: $\varepsilon_{ideal} = 1 - T_{low}/T_{high}$.
- Engine processes are *cyclical* when plotted on a PV diagram.