Stirling Engine

<u>Outline :</u>

1. Introduction
2. Engine and heat source
3. Why study Stirling engines?
    - 3-0. What is a Stirling engine?
    - 3-1. Heat and Temperature
    - 3-2. Work and *PV*-diagrams
    - 3-3. Heat engines
    - 3-4. Thermal efficiency
4. Demonstration of Stirling engine
5. Summary

<u>Reference :</u>

http://www.physics.ubc.ca/outreach/web/phys420/index.php
University Physics 10th edition, Addison Wisely, Young & Freedman

1. Introduction

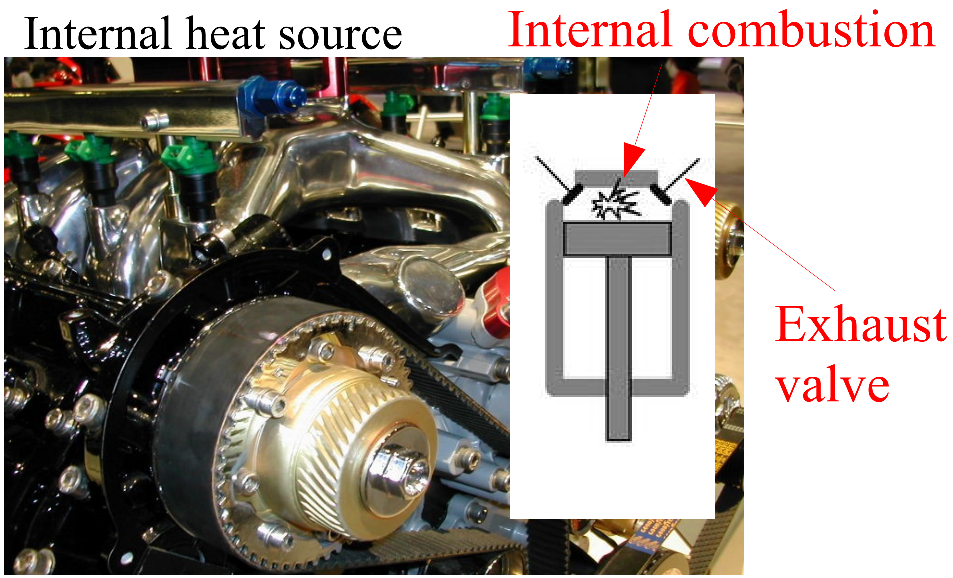
- Cars are very useful and a key transportation tool for people in Canada.
- Have you ever opened the hood of your car and wondered what was going on in there?
- Gasoline cars have heat engines (usually just called an engine).

2. Engines and Heat Sources

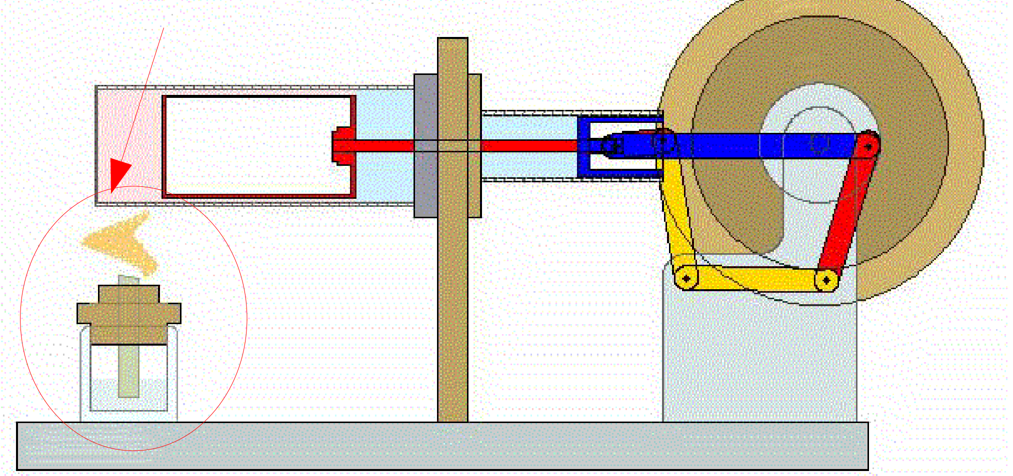
- Heat engine (engine) = a device that converts thermal energy (heat) to mechanical motion

- Two types of heat engines
  - Internal heat source
    Uses combustion of fuel inside a confined volume
    Ex. Gasoline engine
  - External heat source
    Uses an external heat sources (Gasoline, solar energy, decaying plant matter etc)
    Ex. Steam engine, Stirling engine

Internal heat source



External heat source

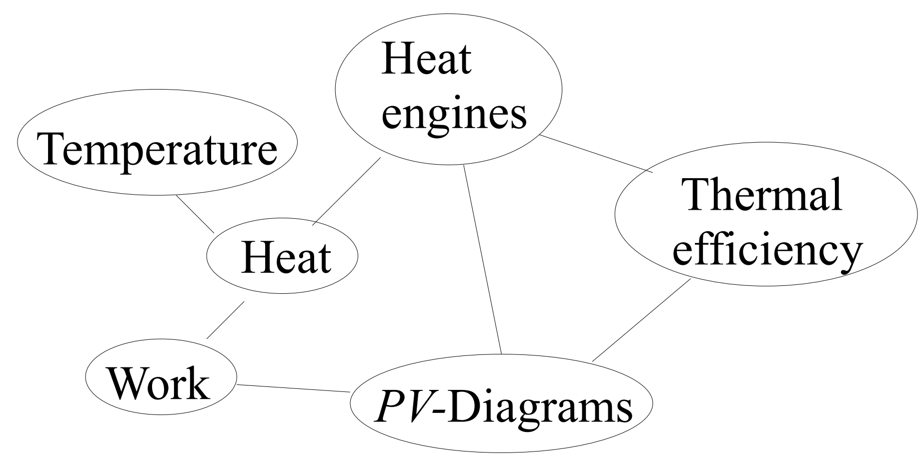


Schematic of Stirling engine

3. Why Study Stirling Engines?

- The Stirling engine uses an external heat source
  → Gas inside the Stirling engine does not leave the engine
  → Environmentally friendly alternative engine
- Using a Stirling engine as an example of a heat engine we can learn the following:

0. What is a Stirling engine?
1. Heat and Temperature
2. Work and *PV*-Diagrams
3. Heat engines
4. Thermal efficiency

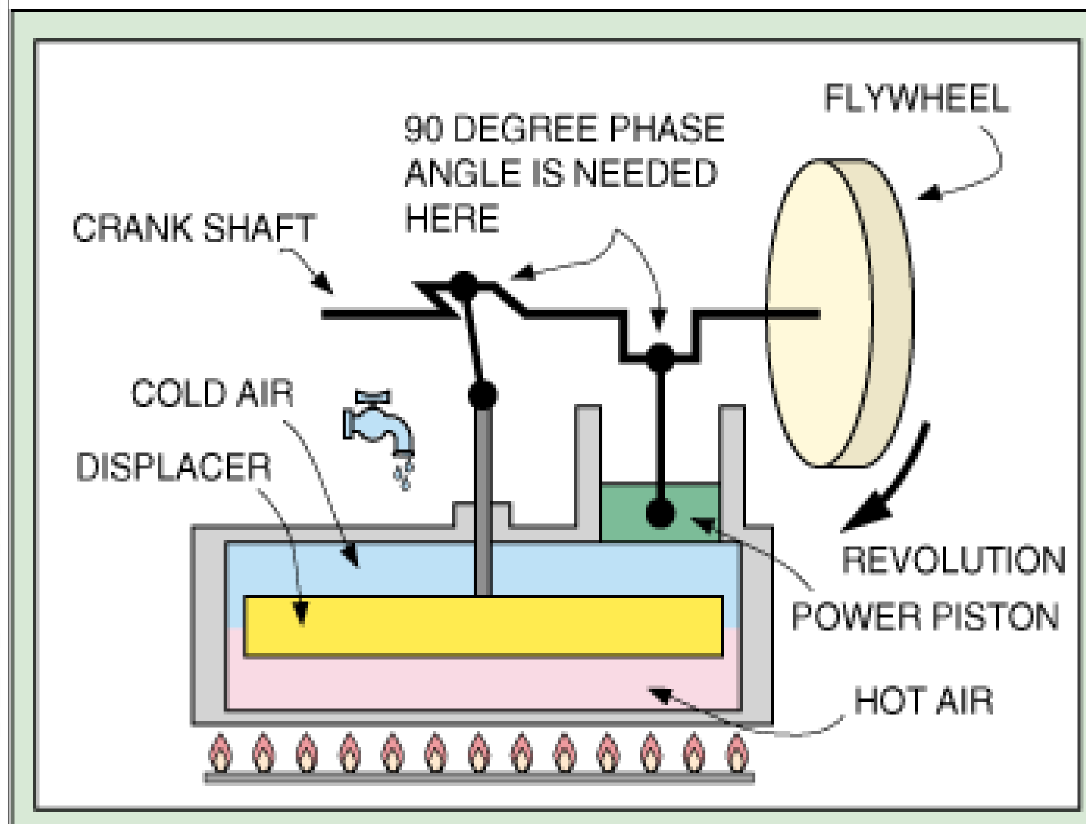


3-0. What is a Stirling Engine?

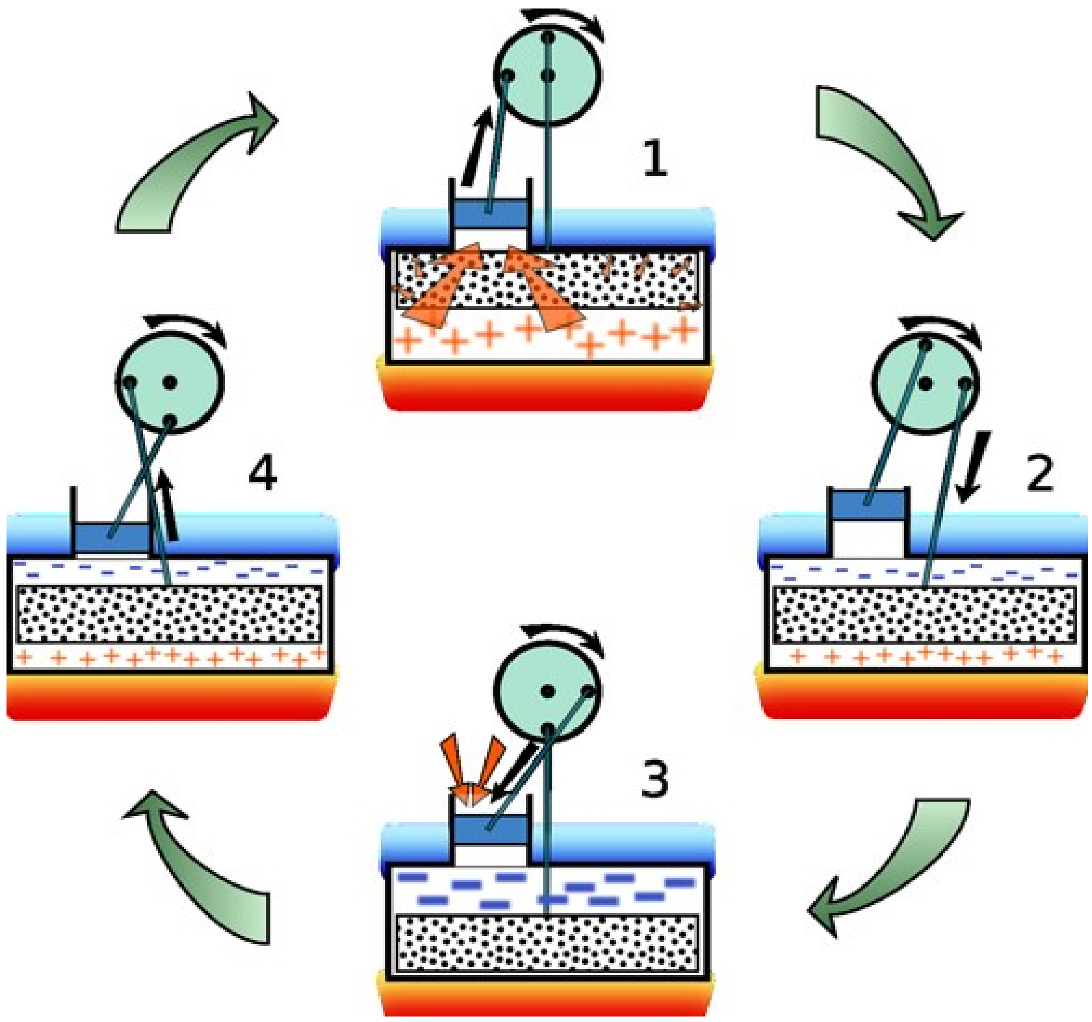

Model Stirling engine

6 components

1. Containers
2. Piston --- tightly sealed
3. Displacer --- large piston, loose
4. Crank shaft
5. Fly wheel
6. External heat source



3-0. What is a Stirling Engine?

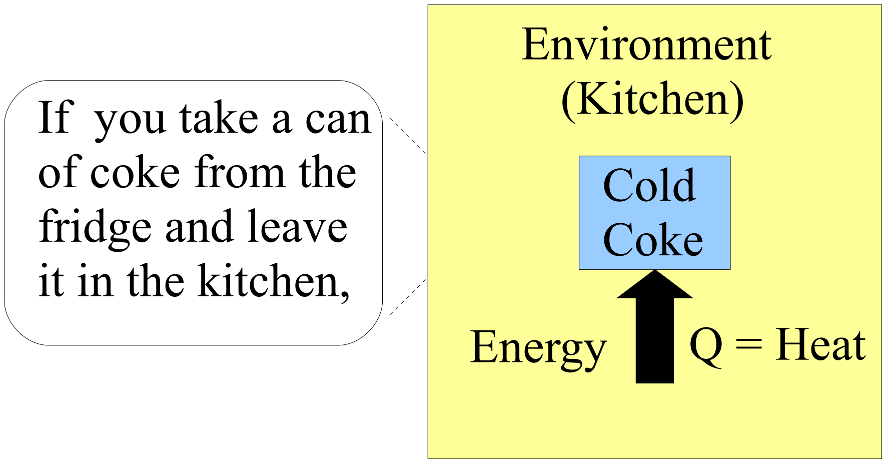


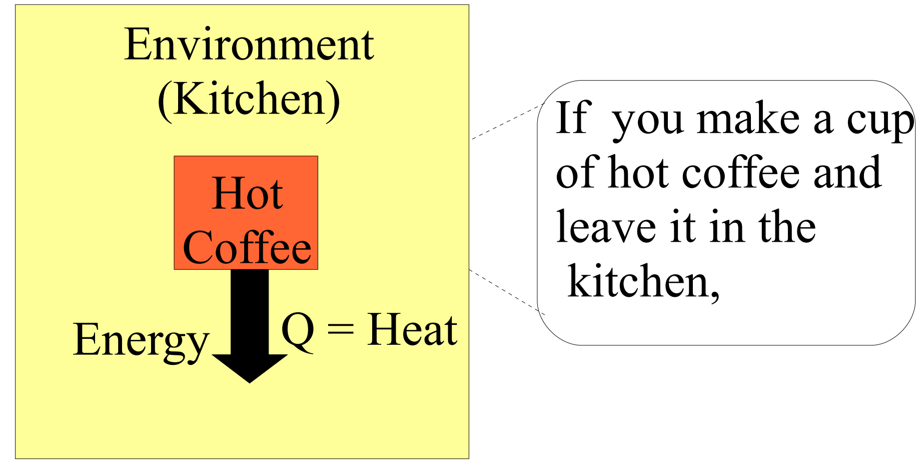
1. The air at the bottom heats up, creating pressure on the small power piston, which moves up and rotates the wheel.
2. The rotating wheel moves the big displacer down
3. The air cools down at the top, reducing the pressure and allowing the power piston to move down.
4. This motion of the power piston moves the displacer upwards and the air at the bottom is heated again.

The key principles of a Stirling engine:

a fixed amount of a gas is sealed inside the engine

3-1. Heat and Temperature





$T_{\text{Cold coke}}$ --- ↑

Because energy is transferred from environment to Cold Coke

$T_{\text{Hot coffee}}$ --- ↓

Because energy is transferred from Hot coffee to environment

Temperature = Indicator of how much energy matter has, [K]

- cold --- less energy
- hot --- more energy

Heat = Energy that is transferred between a system (coke or coffee) and its environment (kitchen) because of the temperature difference, [J]

3-2. Work

Work

Force = F

Distance traveled = Δl

Definition : Work

$$W = F \Delta l$$

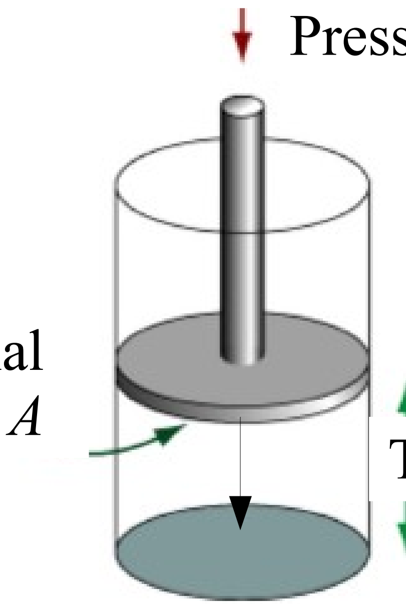
Unit :

$$1\ \mathrm{J} = 1\mathrm{N\,m}$$

Caution : Don't confuse W (work) with w (weight).

Work done by piston in cylinder

Pressure = P



Cross sectional Area = A

Traveled distance = Δl

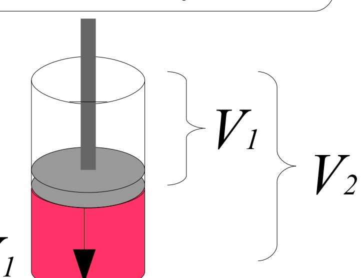
$$W = F \Delta l$$
$$= P A \Delta l$$
$$= P \Delta V$$

$P \equiv \frac{F}{A}$ ← Force acting on piston; ← Cross sectional area of piston

$A \Delta l = \Delta V$ Change in volume after piston moves by Δl

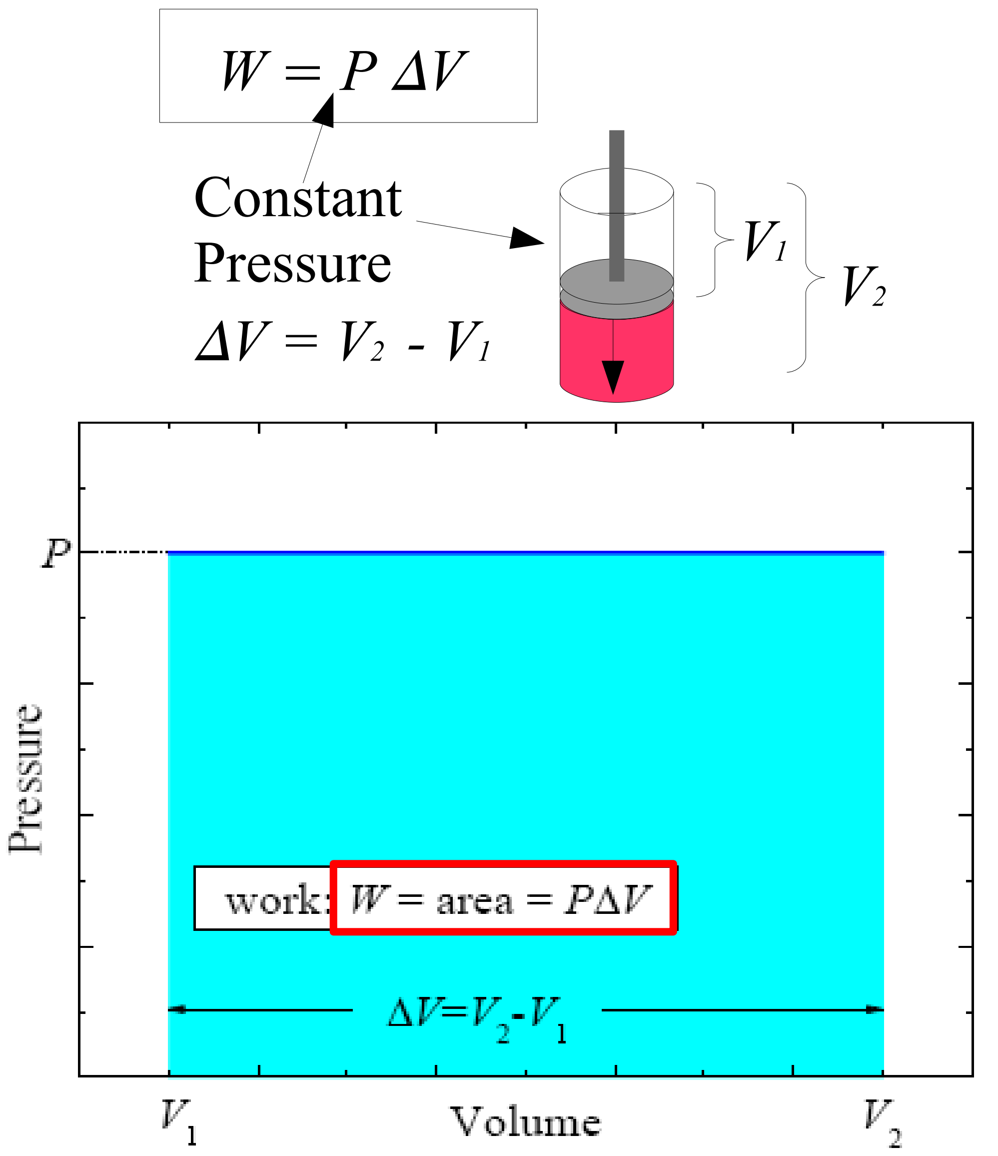
Work done in ΔV

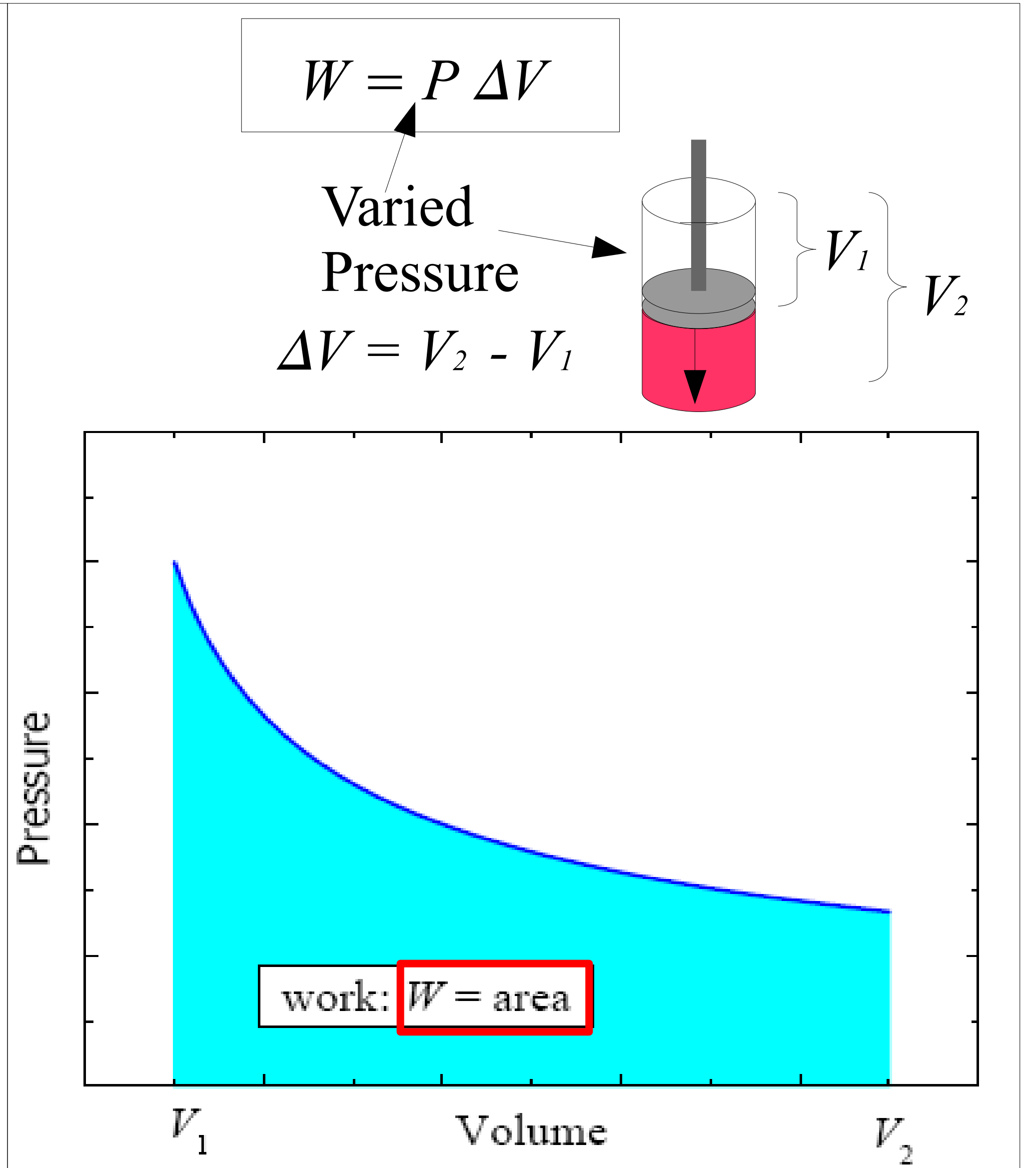
$$W = P \Delta V$$



$\Delta V = V_2 - V_1$

3-2. Work and *PV*-diagram

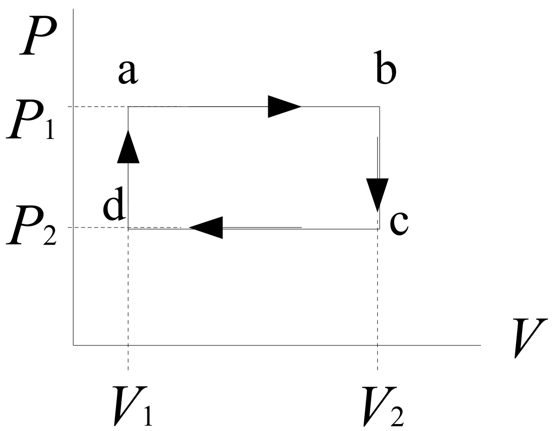




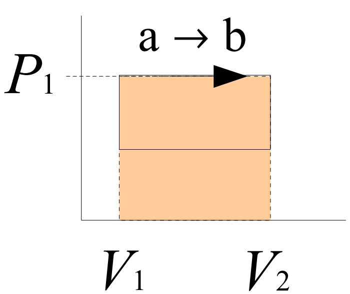
In a *PV*-diagram, work is area under the curve. ➡

- More work--- Larger area
- Less work --- Smaller area

3-2. Work in *PV*-diagrams



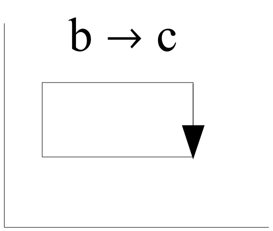
This *PV*-diagram represents the system going through a thermodynamic cycle (Ex. A piston moves from a to b, pressure decreases from b to c. Then the piston moves from c to d and pressure increases from d to a. This process repeats for a complete cycle) Which part of the diagram corresponds to work, W ?



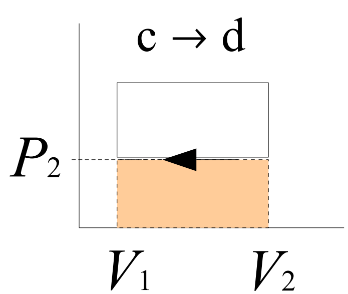
$W = P\,\Delta V$

$= P_1\,(V_2 - V_1)$ ⊕

$W > 0$



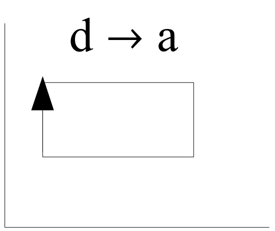
$W = 0$



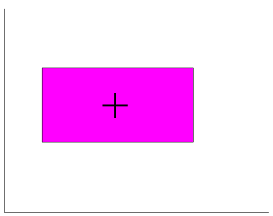
$W = P\,\Delta V$

$= P_2\,(V_1 - V_2)$ ⊖

$W < 0$



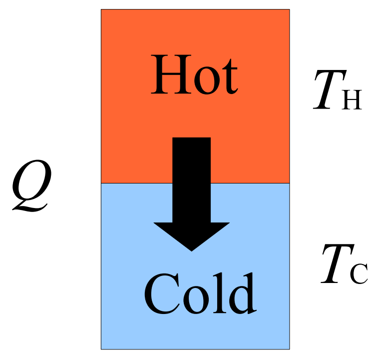
$W = 0$



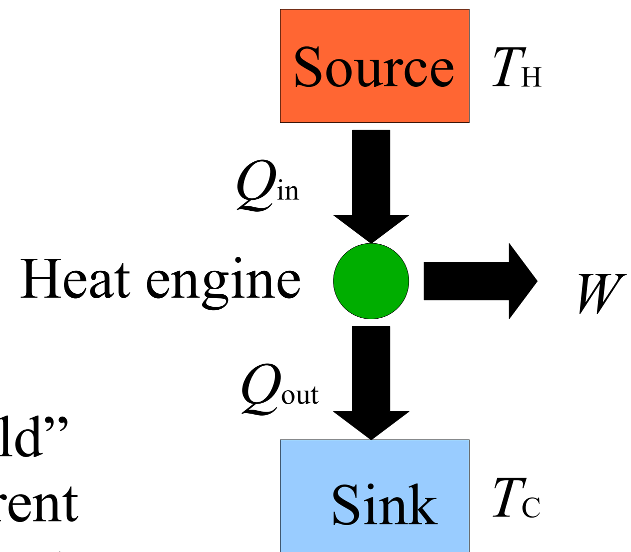
$W_{NET} > 0$

In *PV*-diagrams
Work is area inside closed path

3-3. Heat engine



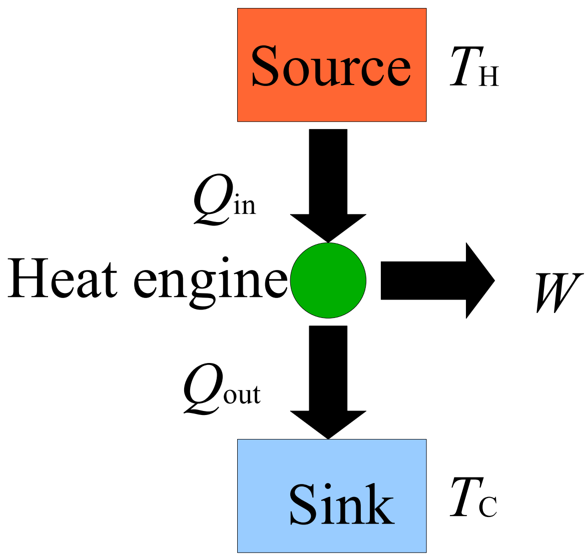
Heat flows from "Hot" to "Cold" when the two systems at different temperature are placed in contact.



Heat engine extracts work from the heat flow from "Hot" to "Cold".

Requires ⇒ { Source at T_H, Sink at T_C }

3-4. Thermal Efficiency



1. Source at T_H adds Q_{in} to heat engine
2. Heat engine does work W by using Q_{in}.
   Not all of Q_{in} is used to work.
   The left over heat is Q_{out}.
3. Q_{out} is dumped into sink at T_C

Heat engine repeats this cycle

$$Q_{in} - W = Q_{out}$$
$$W = Q_{in} - Q_{out}$$

Q_{in} = Heat flow from source to heat engine
Q_{out} = Heat flow from engine to sink
W= work done by heat engine

Efficiency for ideal engine

$$\epsilon = \frac{Output}{Input} = \frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}}$$

Ideal heat engine returns to its initial state (T_H) perfectly at the end of each cycle

$$\frac{Q_{out}}{Q_{in}} = \frac{T_C}{T_H}$$

Efficiency for ideal engine

$$\epsilon = 1 - \frac{T_C}{T_H}$$

4. Demonstration of Stirling Engine

When you place the Stirling engine on top of a cup of hot water, we are the following? (Assume that the engine is ideal.)

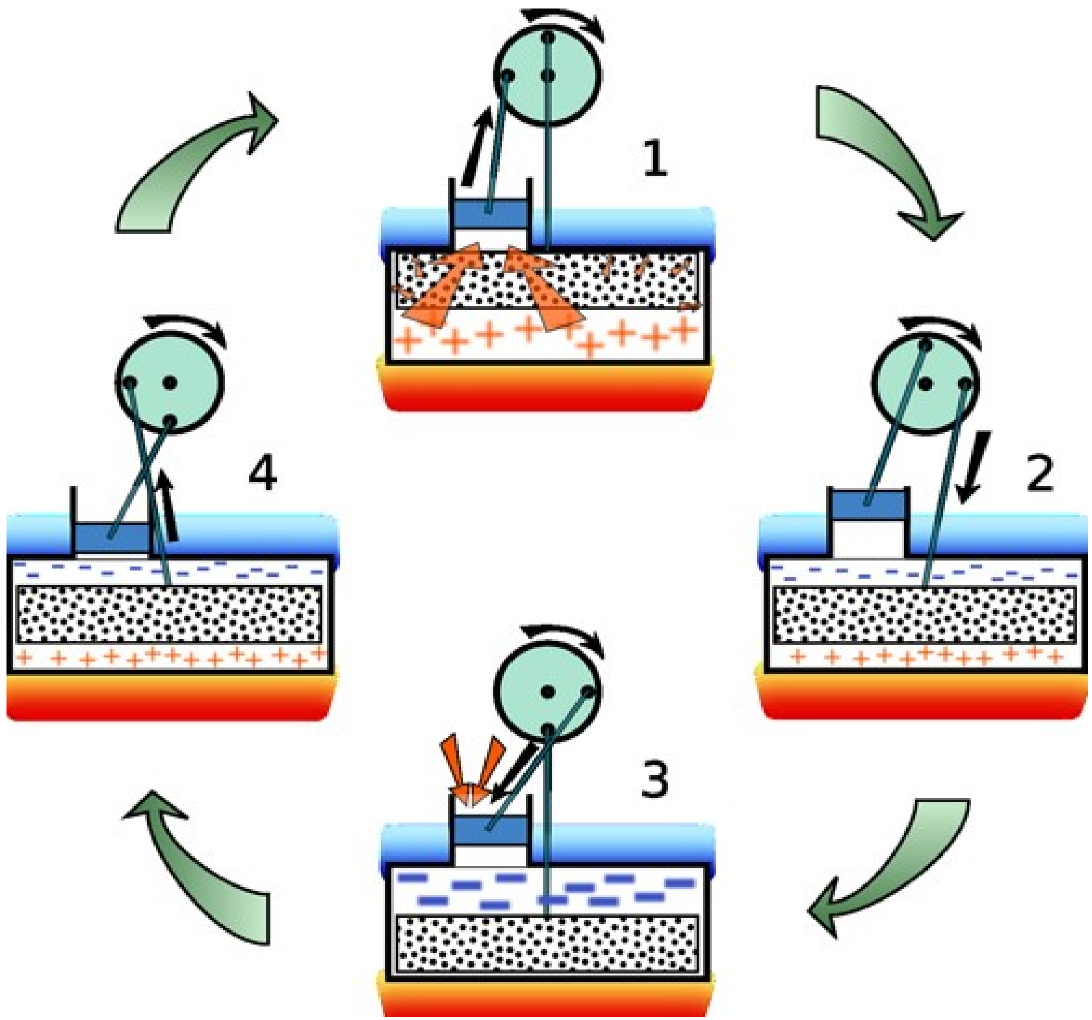
(a) the *PV*-diagram

(b) How much work does the engine do per cycle?

(c) What is the power P of the engine?

(d) What is the efficiency of the engine?

3-0. What is a Stirling Engine?



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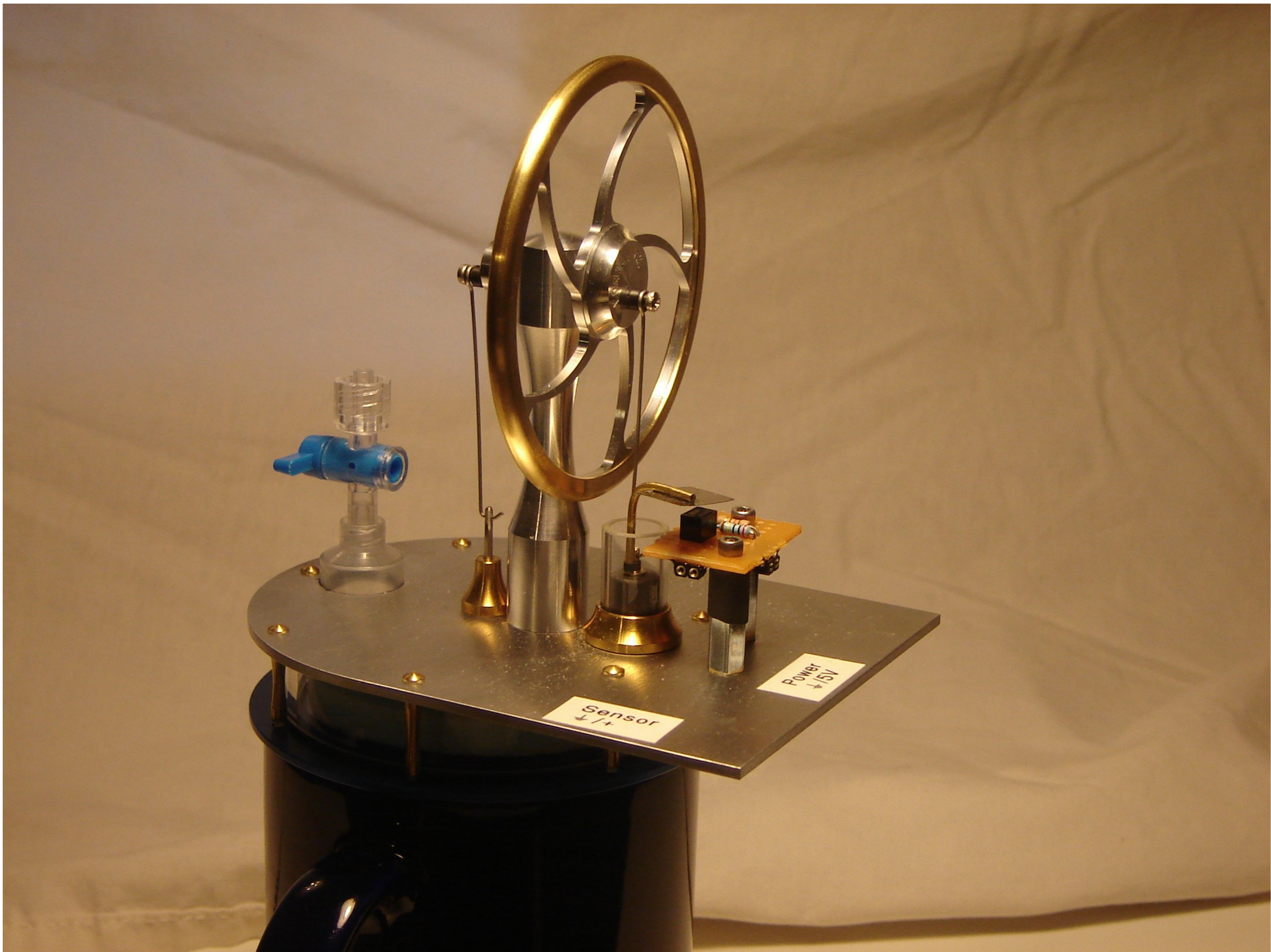
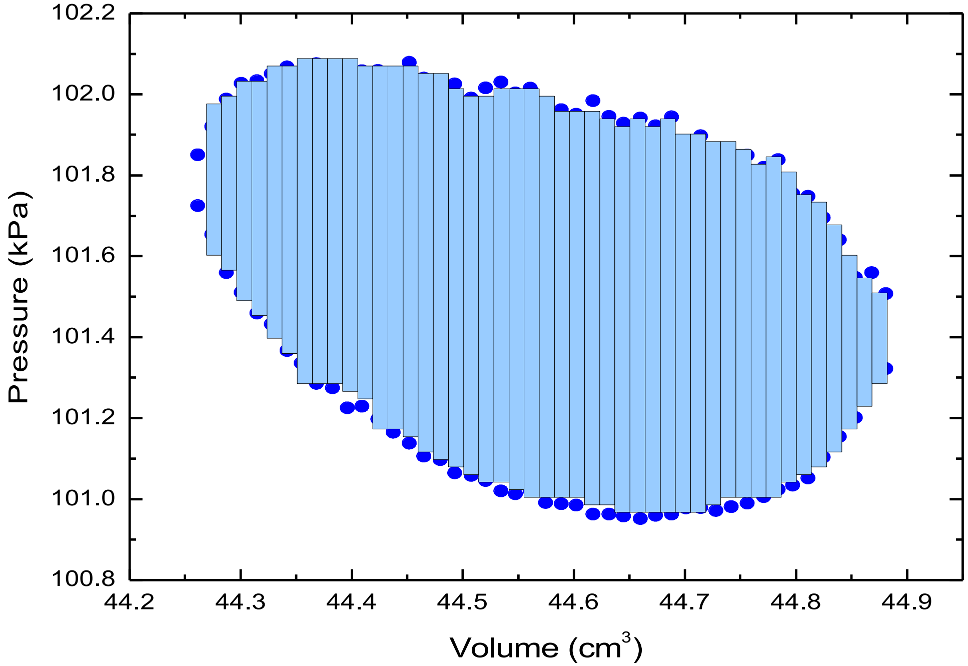

Sensor
⏚/+
Power
⏚/5V

4. Demonstration of Stirling Engine



(b) Closed area in *PV*-diagram. (Unit is J)

1. The area inside the loop was divided into small rectangles
2. Area of each rectangles were calculated
3. All area of each rectangles were added to obtain the area inside the loop.

Work = 0.46 mJ

(c) The power of the engine is *W* done per cycle divided by the time length of each cycle. (Unit is W)

1 HP (horse power) = 745.7 W

$$P = \frac{W\ [\mathrm{J}]}{t\ [\mathrm{s}]} = Wf = (0.46\ \mathrm{mJ})(7.5\ \mathrm{Hz}) = 3.4\ \mathrm{mW} = 4.6 \times 10^{-6}\ \mathrm{HP}$$

$P_{car} \sim 120$ HP

(d) Substitute the two temperature T_C and T_H

$$\epsilon = 1 - \frac{T_C}{T_H} = 1 - \frac{(24+273)\ [\mathrm{K}]}{(95+273)\ [\mathrm{K}]} = 0.193 \approx 19\%$$

19 %

6. Summary

From envronmentally friendly Stirling engine, we learned:

(1) Process of Stirling engine (How it works)

(2) Temperature is an indicator of how much energy matter has.
Heat is Energy transferred from one body to another body due to a temperature difference

(3) Work is product of force on a body and the distance traveled by that body.
Ex. Work of piston in cylinder --- $W = P \Delta V$

(4) Work in a *PV*-diagram is represented by area under curve/line and area in the closed path.

(5) Heat engine is a device that converts heat to mechanical work as it repeats as a cycle

(6) Efficiency for ideal engine is given by

$$\epsilon = 1 - \frac{T_C}{T_H}$$