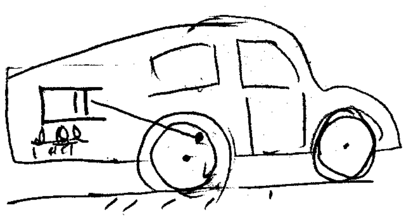
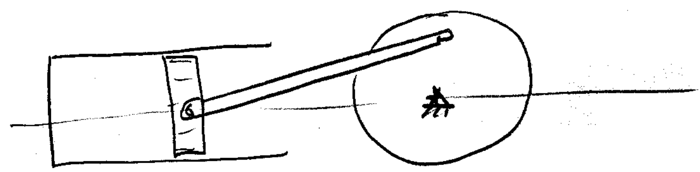
1st Law and the Heat Engine

Heat engine ⇒ a machine that converts HEAT INPUT into WORK OUTPUT

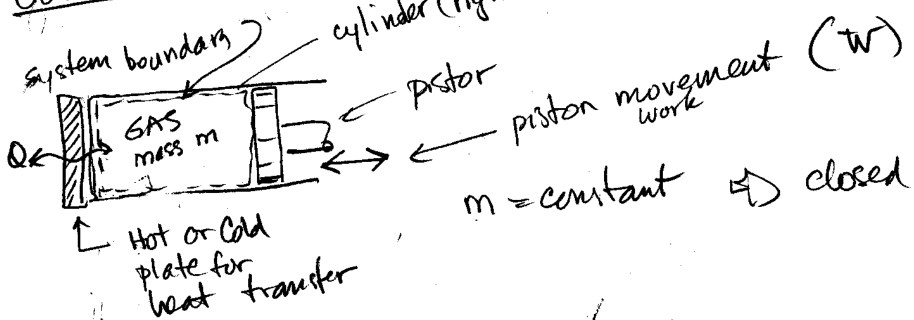
EXAMPLE: Piston–cylinder engine





Most common way to convert heat into work

Our model



$m = \text{constant}$ ⇒ closed system.

Note: Q transfer to gas only

$\Delta KE \approx 0$

$\Delta PE \approx 0$

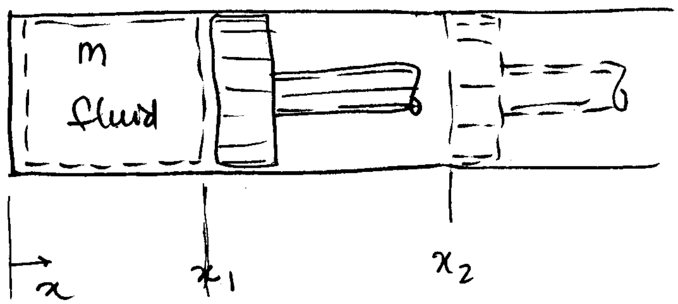
$\Delta U \neq 0$

Ideal Gas → $pv = RT = \frac{\bar{R}}{M} T$

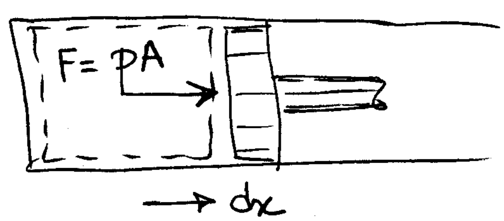
- R ← gas constant
- $\bar{R}$ ← universal gas constant: 8.314 kJ/kmol K; 1545 ft·lbf/lbmol °R; 1.986 Btu/lbmol °R
- M ← molecular mass; $M_{AIR} = 28.97 \frac{kg}{kmol}, \frac{lb}{lbmol}$
- v ← specific volume: $v = \frac{V}{m}$ (V ← volume, m ← system mass)

$pv = RT$ ⇐ Equation of state

Work of compression or expansion in a piston-cylinder



Consider a fluid of mass m going through an expansion process from x_1 to x_2. The system is identified as the fluid mass m enclosed by the dashed line inside the cylinder. The fluid exerts a force on the piston, and moves the piston in the positive x direction. The force exerted is $F = pA$



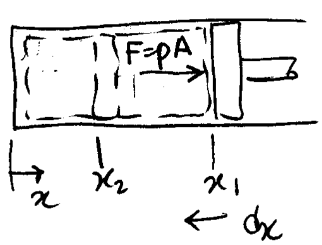
$$W_{12} = \int_{x_1}^{x_2} \vec{F} \cdot d\vec{x} = \int_{x_1}^{x_2} pA\,dx$$

Note that $A\,dx = dV$ = change in volume

Hence $W_{12} = \int_{V_1}^{V_2} p\,dV$

Note for expansion $W_{12} > 0$, work done **by** the fluid (work done **by** the **system**)

For compression:



$$W_{12} = \int_{V_1}^{V_2} p\,dV < 0 \qquad V_2 < V_1 \rightarrow dV < 0$$

work done **on** the **system**

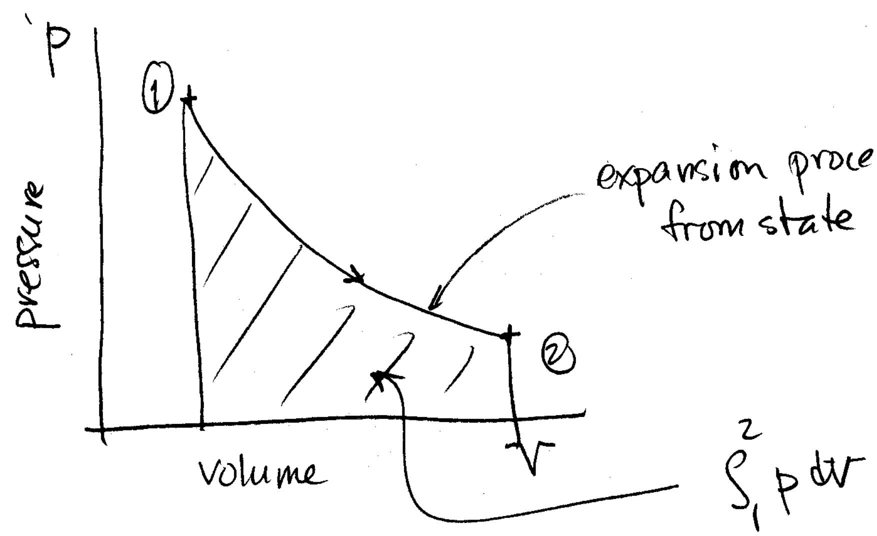
Note that in this example, the mass of the system remained unchanged throughout the process. Such a system is called a

CLOSED SYSTEM

Note: The expression for work (closed system)

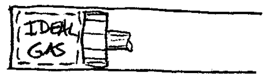
$$W_{12} = \int_1^2 p\,dV$$

is represents the area under the process curve $p = f(V)$



Application of first Law to a Piston Engine

Piston engine :



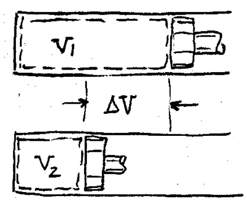
⇨ Ideal gas

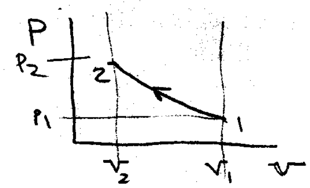
⇨ Closed system

PROCESS

compression
1→2

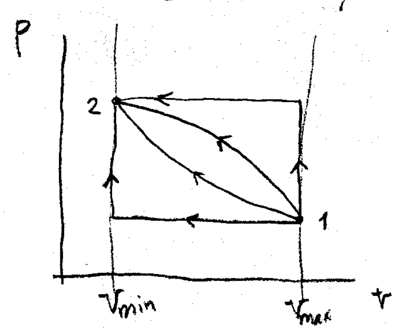
expansion
2→1



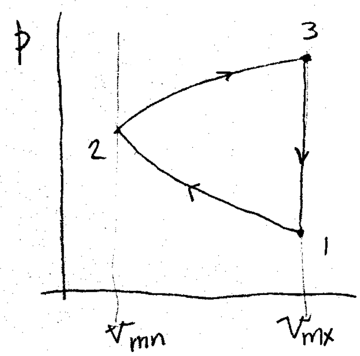


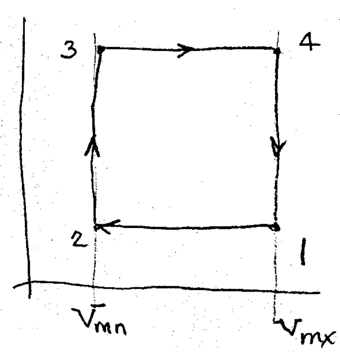
Compression - expansion between a maximum volume and a minimum volume

There are many possible routes between these extremes



The objective is to connect PROCESSES to create a CYCLE.
There are many ways to create a cycle between V_{min} and V_{max}





Our central issue is: what is the best path to take to produce the most efficient engine?

The piston engine is a heat engine that convert thermal energy into mechanical work. Our goal is to produce the most net work with the least amount of thermal energy input.

To determine the efficiency we need to calculate the heat and work for each process as well as the change in internal energy and apply the first law of thermo.

We shall illustrate several common heat engine cycles

We shall develop next a thermodynamic model of the Stirling engine, the engine you are building in class.