

Heat

- If two bodies are in contact but initially have different temperatures, heat will transfer or flow between them if they are brought into contact.
- heat is the energy transferred, given the symbol Q .

Temperature and Equilibrium

- Temperature is Energy per Degree of Freedom
- Heat flows from hotter to colder object
 - Until temperatures are equal
 - Faster if better thermal contact
 - Even flows at negligible Δt (for reversible process)
- The Unit of Temperature is the Kelvin
 - Absolute zero (no energy) is at 0.0 K
 - Ice melts at 273.15 Kelvin (0.0 C)
 - Fahrenheit scale is arbitrary

State Variables of System

- **State Variables - Definition**

Measurable Static Properties

Fully Characterize System (if constituents known)

e.g. Determine Internal Energy, compressibility

Related by Equation of State

- **State Variables: Measurable Static Properties**

- Temperature - measure with thermometer

- Volume (size of container or of liquid in it)

- Pressure (use pressure gauge)

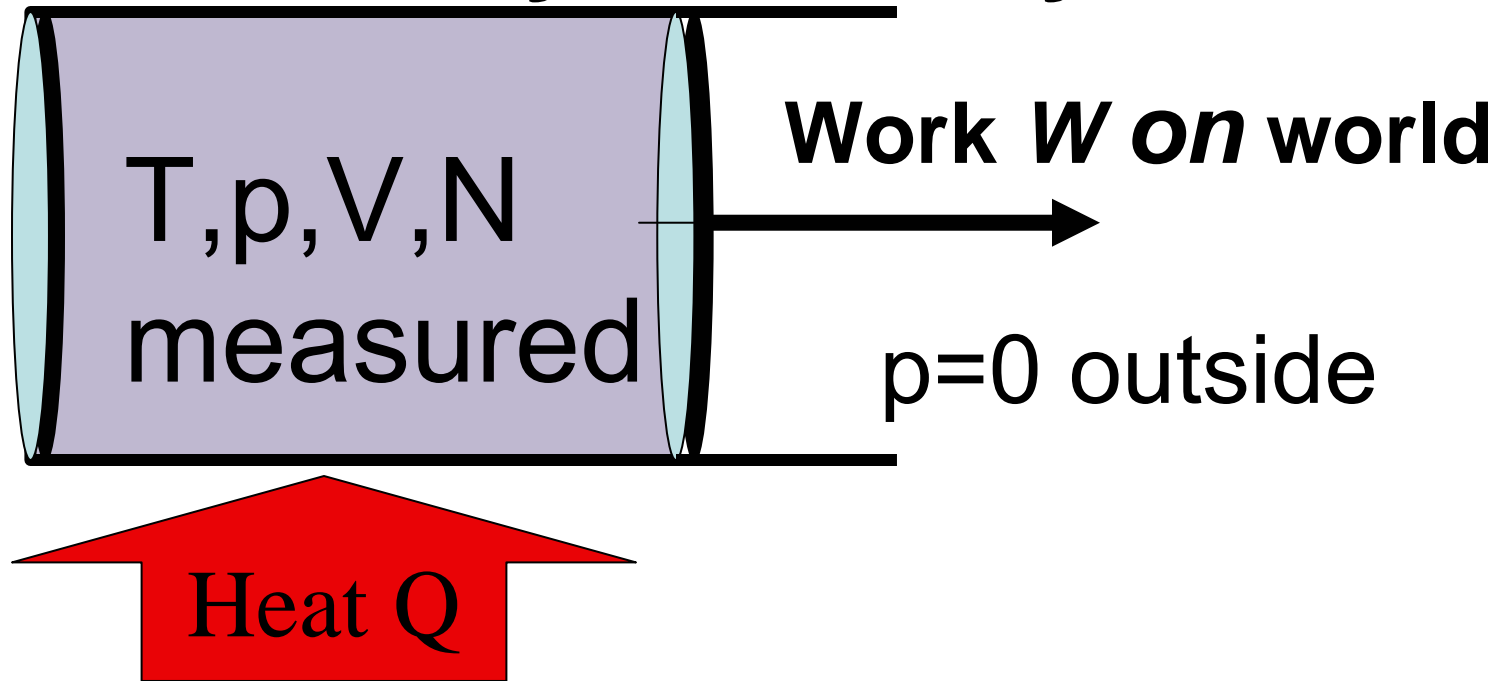
- Quantity: Mass or Moles or Number of Molecules

- Of each constituent or phase (e.g. water and ice)

Heat and Work are Processes

- Processes accompany/cause state changes
 - Work **along particular path** to state B from A
 - Heat added along path to B from A
- Processes are **not state variables**
 - Processes change the state!
 - But Eq. Of State generally obeyed

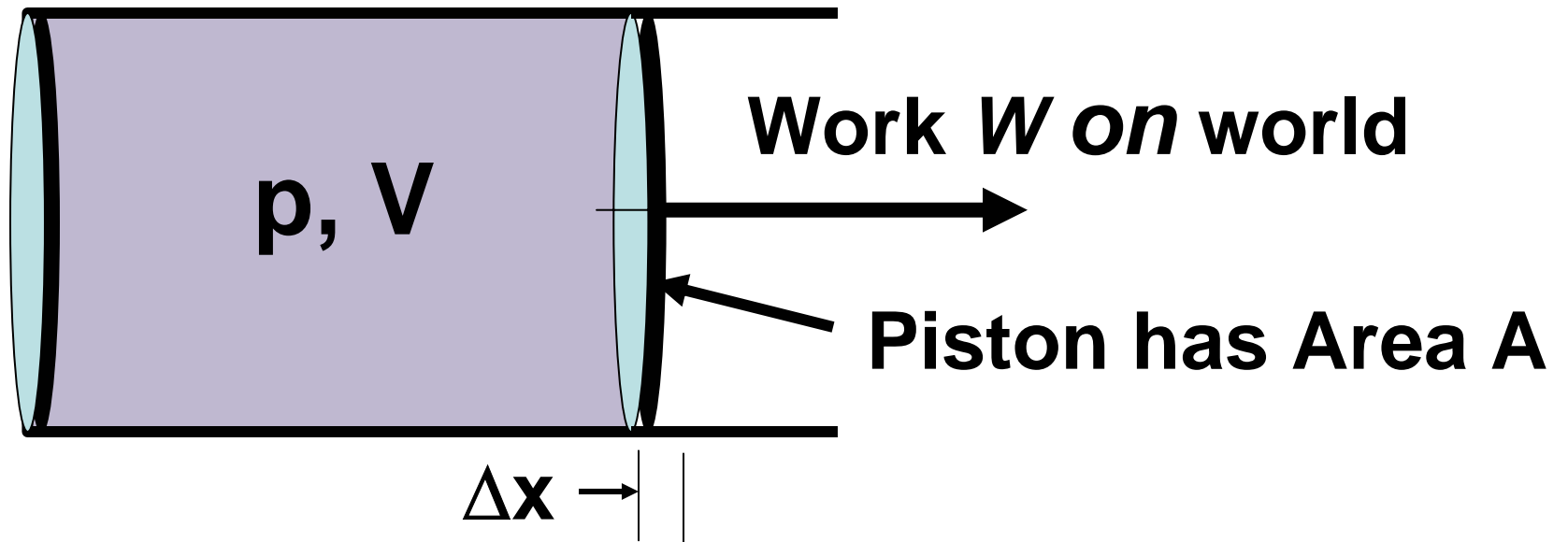
Thermodynamic Systems



The state variables are changed only in response to Q and W

No other work or heat enters

Work



Find Work if piston moves Δx :

$$W = F \Delta x = pA \Delta x = p\Delta V$$

In General :

$$W_{fi} = \int_i^f p(V, T) dV$$

Variables in First Law

- Q is the **Heat Added**
 - Could find from Temperature Gradient
 - But need Heat Conductivity and Area
 - Generally determine from First Law
- W is the **Work done by** system
 - Equal to pDV
- U is the **Internal Energy of** system
 - It is determined by state variables
 - From equipartition, proportional to T

Internal Energy

Based on Equipartition:

-each coordinate of each particle

$$\frac{1}{2} m \langle v_x^2 \rangle = \frac{1}{2} m \langle v_y^2 \rangle = \frac{1}{2} k_B T$$

$$\frac{1}{2} \mu \langle v_{\text{rel}}^2 \rangle = \frac{1}{2} k_B T \text{ ..molecule}$$

For an ideal monatomic gas:

$$U(T) = \frac{3}{2} N k T$$

For an ideal diatomic molecular gas:

$$U(T) = \frac{5}{2} N k T \text{ (no vibration)}$$

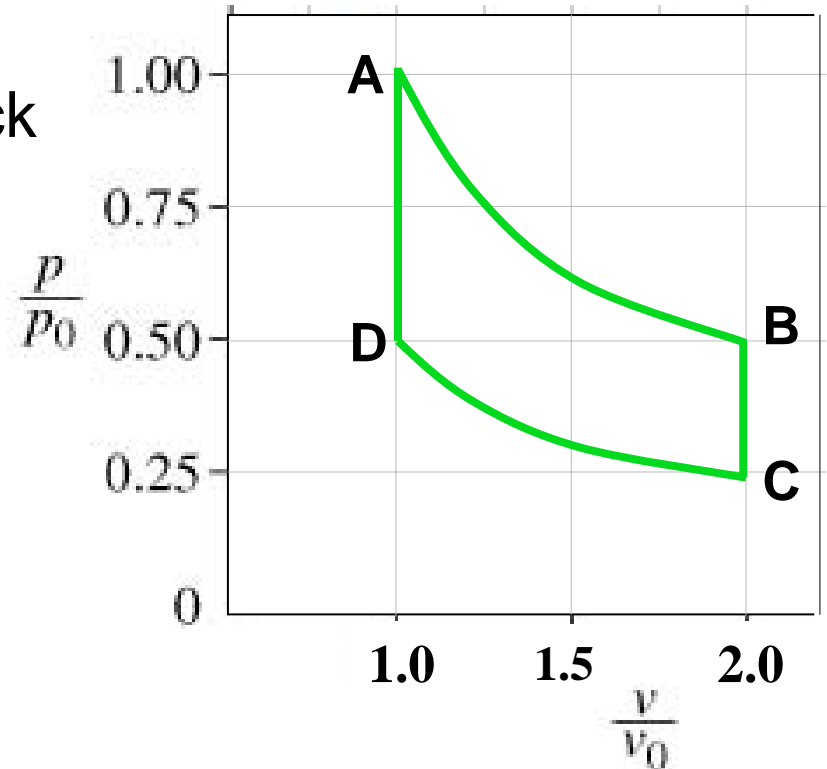
Thermodynamic cycles

A thermodynamic cycle is any process that brings a system back to its original state.

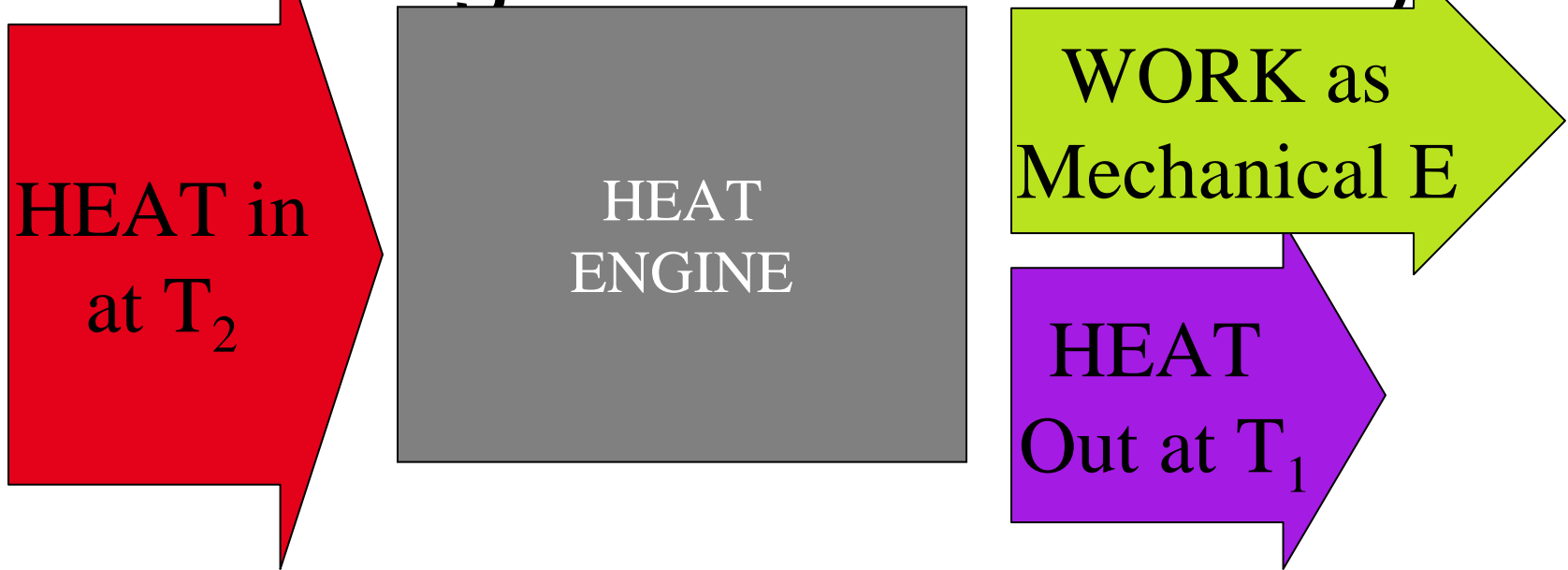
The cycle involves a path in state space over which various processes may act.

Addition/Removal of heat and work are typical processes.

Often the objective is to get work from heat or vice versa, as in a *heat engine* or *heat pump*.



Heat Engines and Efficiency



Energy Conserved $Q(\text{in at } T_2) = W_{\text{cycle}} + Q(\text{out at } T_1)$

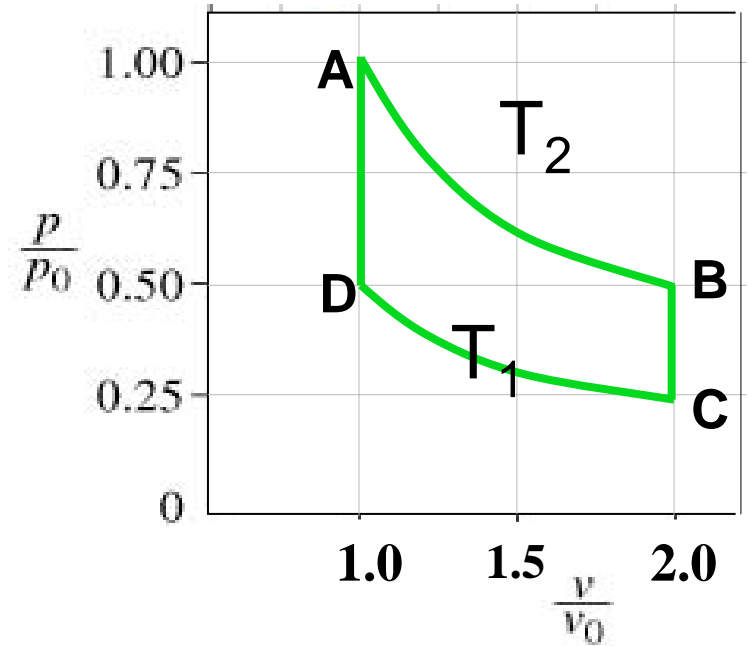
Heat Engine Efficiency: $\varepsilon = \frac{W_{\text{cycle}}}{Q(\text{in at } T_2)}$

Reversibility of Cycle

We showed that any leg of this cycle is reversible.

Therefore, the entire cycle (heat engine) could operate in reverse

In this case the total Work and the Heat flow will be reversed.

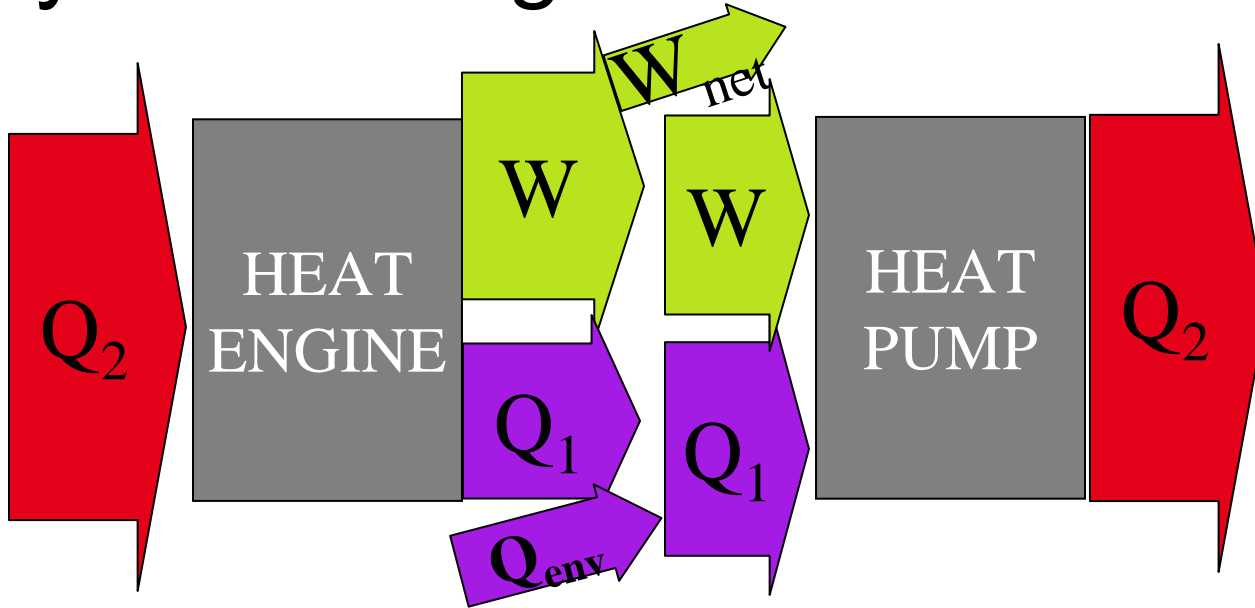


Operated in reverse it is a refrigerator that removes heat at the lower temperature

Or a heat pump delivering heat at the temperature T_2

Why Carnot is Maximum

Say a heat engine exceeded Carnot Limit



Hook it to a perfect gas heat pump with the same T_1

Net Effect: Heat Q_{env} becomes work W_{net}

Second law of Thermodynamics

No process shall have the only result that Heat is turned into Work

or

No process shall have the only result that Heat is transferred from cooler to hotter.

The second law is the formal statement of the irreversibility of Nature on a classical scale: friction can irreversibly convert mechanical energy into heat; nothing can reverse this process.