Thermodynamic Cycles

- Objectives
  1. Define a **thermodynamic cycle**
  2. Explore ways to **classify thermodynamic cycles**
  3. Apply **conservation of energy** to generic cycles
  4. Examine **cycle performance**

- Define thermodynamic cycle (Write a sentence!)

  A thermodynamic cycle is a series of processes for a closed system that periodally returns to its initial state.

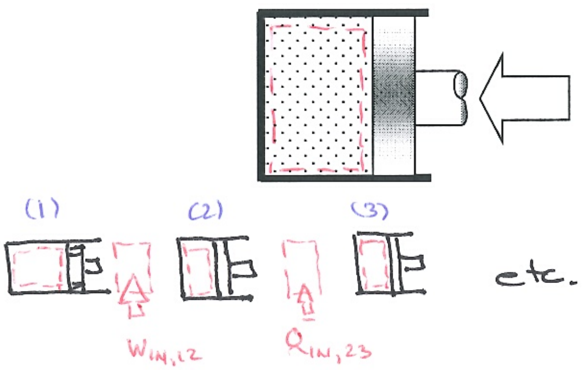
  Key Features:
  1) closed system
  2) Periodically returns to its initial state
  3) Series of processes

- Examples
  - Otto cycle } in internal combustion engines
  - Diesel cycle }
  - Refrigertors

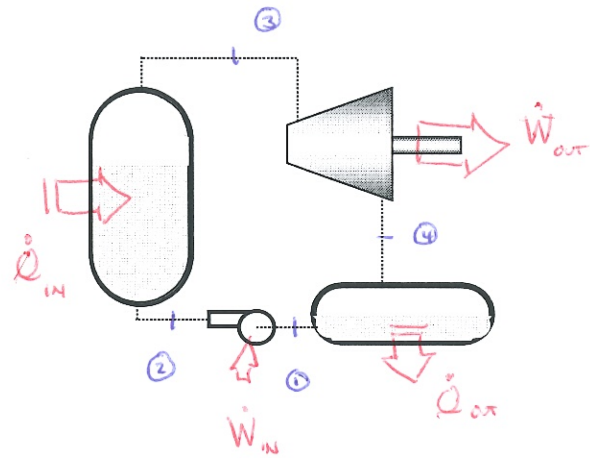
- Ways to classify
  - working fluid — single phase / two-phase
  - physical structure — closed system/ periodic / closed loop/ steady-State
  - purpose — power / refrigeration.

Classification by Structure

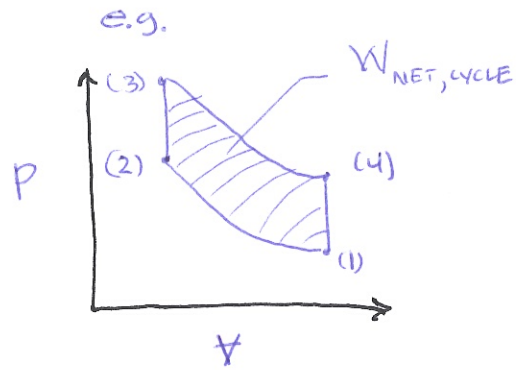
Closed, Periodic Cycles



Closed loop, Steady-state Cycles



How are these two systems the same?
How are these two systems different?
What's the important variable for describing property changes in each case?



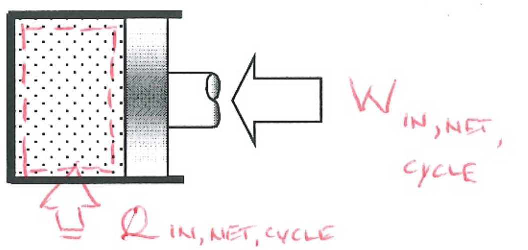
<u>Characteristics</u>

- Spatially uniform intensive properties
- Intensive properties vary *periodically with time.*

<u>Characteristics</u>

- Spatially varying intensive properties
- Intensive properties vary with location
- Interconnected components create continuous flow loop

Closed, Periodic Cycles



System is… Fluid inside over one complete cycle.

Conservation of energy:

$$\frac{d}{dt}(E_{SYS}) = \dot{Q}_{IN} + \dot{W}_{IN}$$

closed

Integrate energy *over one complete time cycle*, $t \rightarrow \Delta t$

$$\int_{E_t}^{E_{t+\Delta t}} dE_{SYS} = \int_t^{t+\Delta t} \dot{Q}\,dt + \int_t^{t+\Delta t} \dot{W}\,dt$$

$$E_{t+\Delta t} - E_t = Q_{IN,t+\Delta t} + W_{IN,t+\Delta t}$$

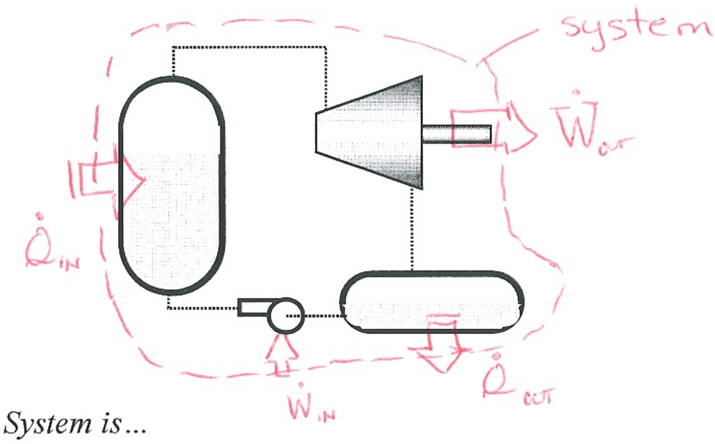
$\equiv 0!$

$$Q_{IN,NET,CYCLE} = -W_{IN,NET,CYCLE}$$

$$Q_{IN,NET,CYCLE} = W_{NET,OUT,CYCLE}$$

For a cycle

Closed loop, Steady-state Cycles



System is… all components taken together.

Conservation of energy:

$$\frac{d}{dt}(E_{SYS}) = \dot{Q}_{IN} - \dot{Q}_{OUT} + \dot{W}_{IN} - \dot{W}_{OUT}$$

$\rightarrow 0$ steady; closed

$$0 = \dot{Q}_{IN,NET} + \dot{W}_{IN,NET}$$

$$\dot{Q}_{IN,NET,CYCLE} = \dot{W}_{IN,NET,CYCLE}$$

For a cycle

... **Structure (cont'd)**

1) What conclusion can you draw form applying conservation of energy to the two cycles?

$\Delta E_{cycle} = 0$ -or- $dE/dt_{cyc} = 0$ $\Rightarrow$ $\dot{Q}_{NET, IN, CYCLE} = \dot{W}_{NET, OUT, CYCLE}$

2) Imagine you are a lump of working fluid flowing in the closed-loop cycle. How would your property variation compare to the periodic cycle case?

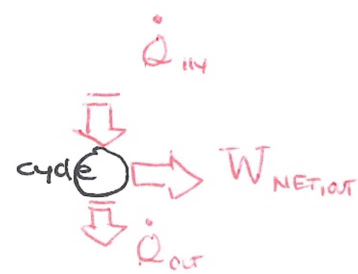
To you the cycle looks the same!

3) What are some examples of each type of cycle?

Classification by Purpose

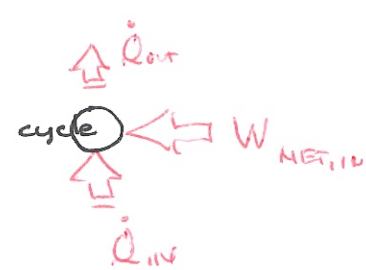
- Power cycles (Heat engines)

$\dot{W}_{NET, \underline{OUT}, CYCLE} > 0$



- Refrigerators/heat pumps (Reversed cycles)

$\dot{W}_{NET, \underline{IN}, CYCLE} > 0$



Comparing Cycle Performance

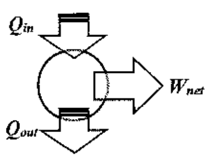
- To "buy" the best cycle, what do you need to compare?

desired effect vs. "cost"

- Generic measure of performance (*MOP*)

$$MOP = \frac{\text{desired effect}}{\text{"cost"}}$$

- **Power Cycles**



Desired effect $\dot{W}_{NET,OUT}$

Cost $\dot{Q}_{IN}$

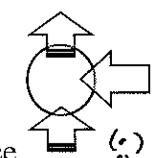
$$MOP = \eta = \frac{\dot{W}_{NET,OUT}}{\dot{Q}_{IN}}$$

Thermal Efficiency

NOT NET!

$0 < \eta < 1$

- **Refrigeration/Heat Pump Cycles**



MOP = COP Coefficient of Performance

Heat Pump	**Refrigerator**
Desired effect $\dot{Q}_{OUT}$	*Desired effect*
Cost $\dot{W}_{NET,IN}$	*Cost*
$COP_{HP} = \dot{Q}_{OUT} / \dot{W}_{NET,IN}$	$COP_R = \dot{Q}_{IN} / \dot{W}_{NET,IN}$