College Physics I: 1511 Mechanics & Thermodynamics

Professor Jasper Halekas
Van Allen Lecture Room 1
MWF 8:30-9:20 Lecture

Announcements

- Final Equation sheet and sample Final (from last year) posted on "Notes" page
- Final will be in this room 8:00-10:00 pm on Monday 12/12
- Schedule for rest of semester
  - This week: Thermodynamics
  - Next Monday: Intro to Waves
  - Next Wed: Detailed review of post-midterm material
  - Next Friday: Full semester top-level review

Ideal Gas Thermo Processes

$$\Delta U = Q - W$$

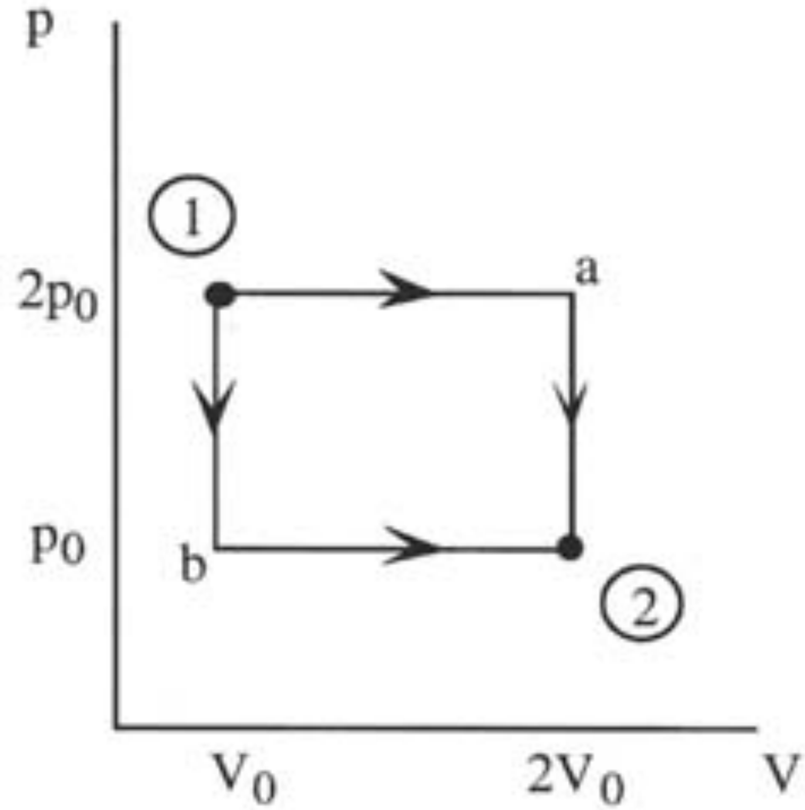
Process	ΔU	Q	W
Constant Volume (Isochoric)	3/2 nR ΔT (monatomic)	3/2 nR ΔT (monatomic)	0
Constant Pressure (Isobaric)	3/2 nR ΔT (monatomic)	5/2 nR ΔT (monatomic)	$P\Delta V = nR\,\Delta T$

W, Q, and U along different paths

- ΔU only depends on end points

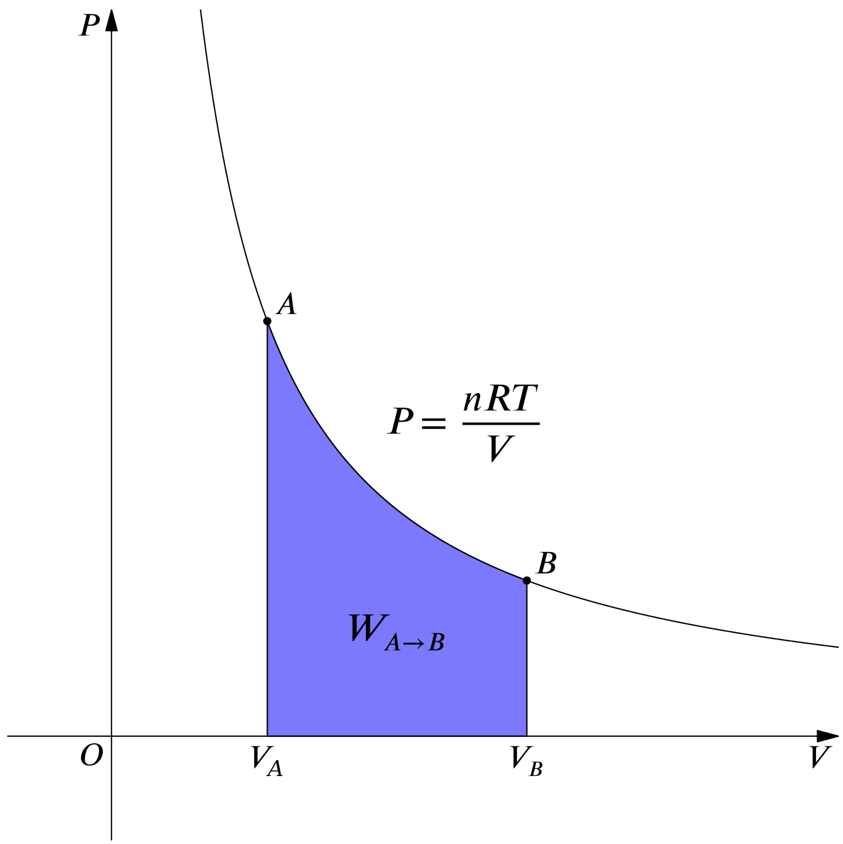
- W depends on path
- Q depends on path

- This can be exploited to convert work into heat and vice versa



Work Done by Isothermal Gas

- Ideal gas means PV = nRT
  - Constant n & T => PV = constant

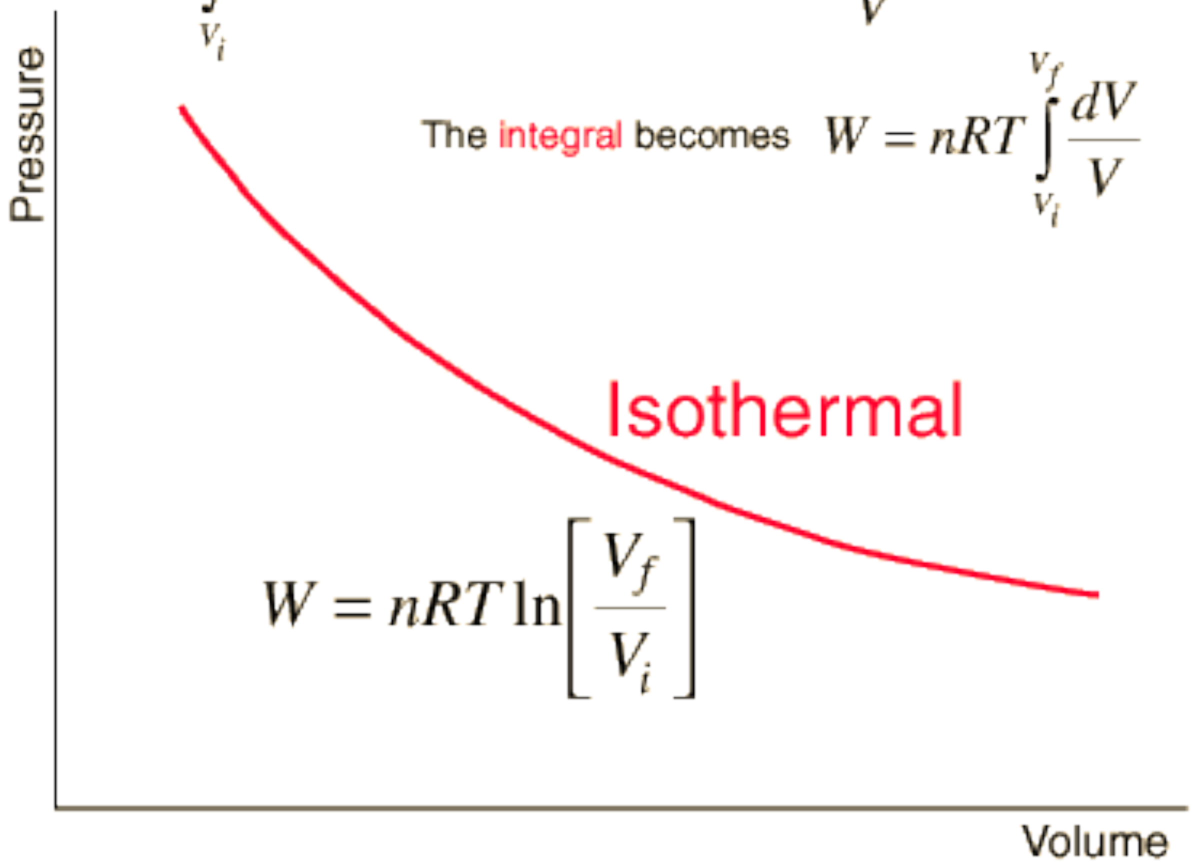


Work Done by Isothermal Gas

Since the temperature is constant, the pressure P in the work integral

$W = \int_{V_i}^{V_f} P\,dV$ can be replaced by $P = \frac{nRT}{V}$ using the ideal gas law.

The integral becomes $W = nRT \int_{V_i}^{V_f} \frac{dV}{V}$



$$W = nRT \ln\left[\frac{V_f}{V_i}\right]$$

Work Done by Isothermal Gas

- $V_f > V_i$
  - $\ln (V_f/V_i) > 0$
  - Work done by gas is positive

- $V_f < V_i$
  - $\ln (V_f/V_i) < 0$
  - Work done by gas is negative

$\boxed{\text{Isothermal}}$

$$\Delta U = Q - W = 0$$

$$(\Delta T = 0)$$

$$W = nRT \ln(V_f/V_i)$$

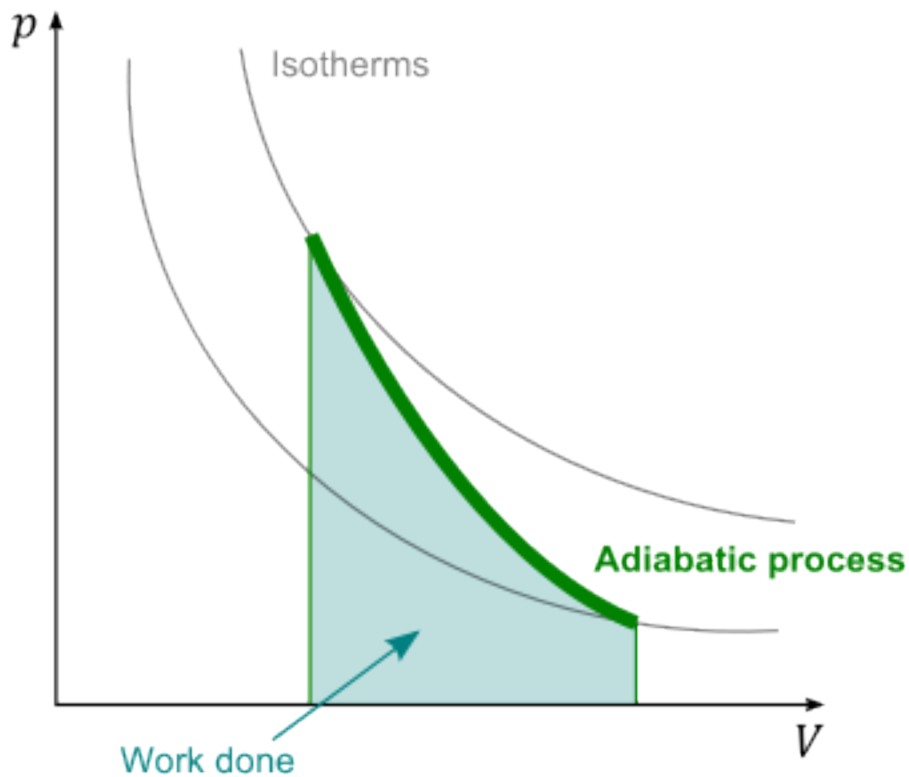
$$Q = W = nRT \ln(V_f/V_i)$$

Heat Transferred to/from Isothermal Gas

- $\Delta U = Q - W = 0$ (since $\Delta T = 0$)
- $Q = W = nRT \ln(V_f/V_i)$
- All heat added to gas is used to do work
  - Or, vice versa, if converting work to heat

Definition: Adiabatic

- "Adiabatic" = a process during which no heat is transferred to/from a system



Work Done by Adiabatic Gas

- $\Delta U = Q - W = -W$
- For monatomic gas $U = 3/2\ nRT$
- If n constant, $\Delta U = 3/2\ nR\ \Delta T$
- $W = -\Delta U = -3/2\ nR\ \Delta T$

$\boxed{\text{Adiabatic}}$

$$\Delta U = Q - W$$
$$= -W \qquad (Q = 0)$$

For monatomic $U = \frac{3}{2} nRT$

If n constant $\Delta U = \frac{3}{2} nR\Delta T$

$$W = -\Delta U = -\frac{3}{2} nR\Delta T$$

Adiabatic curve:

$$PV^\gamma = \text{const.}$$

$$\gamma = C_P / C_V > 1$$

For monatomic

$$\gamma = (5/2)/(3/2) = 5/3$$

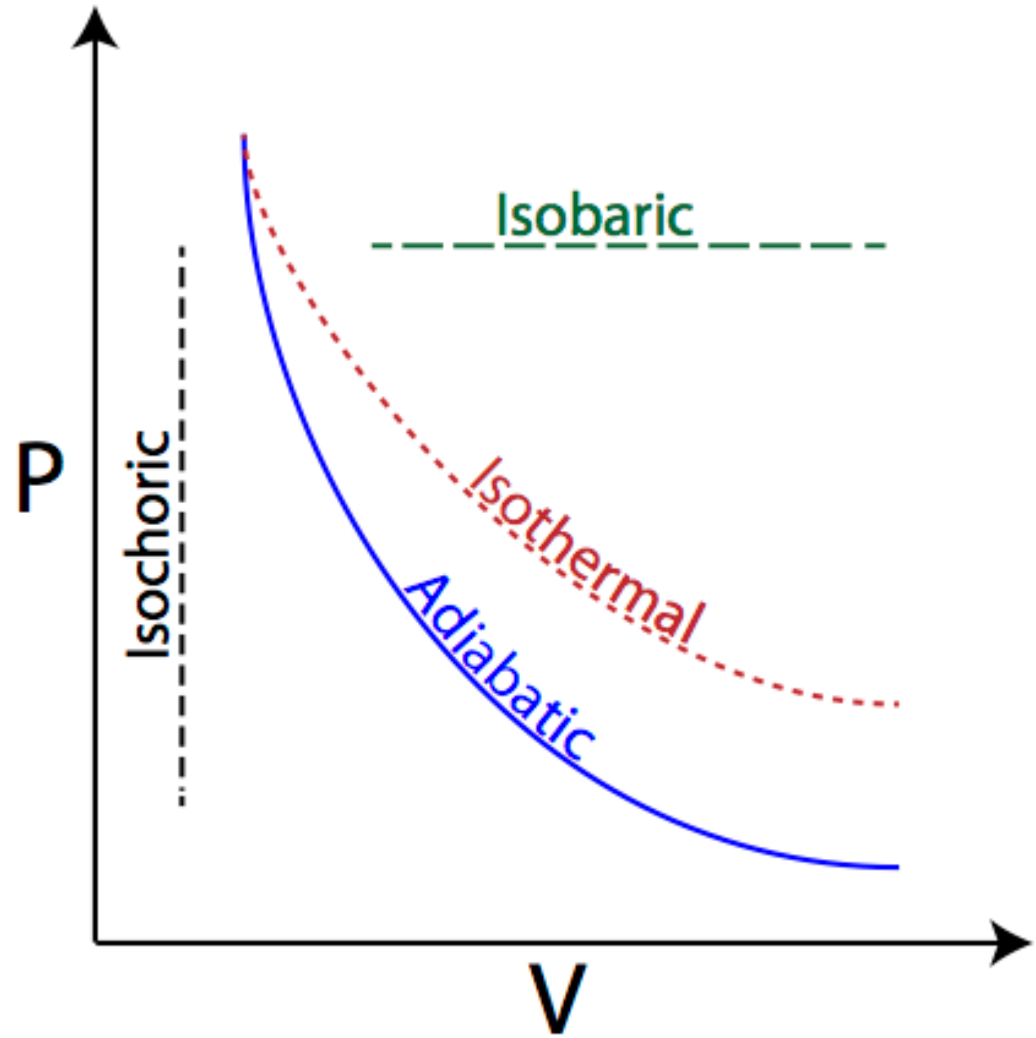
Adiabatic Condition

Adiabatic Processes

$$PV^{\gamma} = const.;\ \gamma = \frac{C_P}{C_V}$$

For monatomic gas:

$\gamma = (5/2)/(3/2) = 5/3$



Concept Check

- If a gas expands (increases volume) adiabatically, what happens to its internal energy?

A. Goes up
B. Goes down
C. Stays constant

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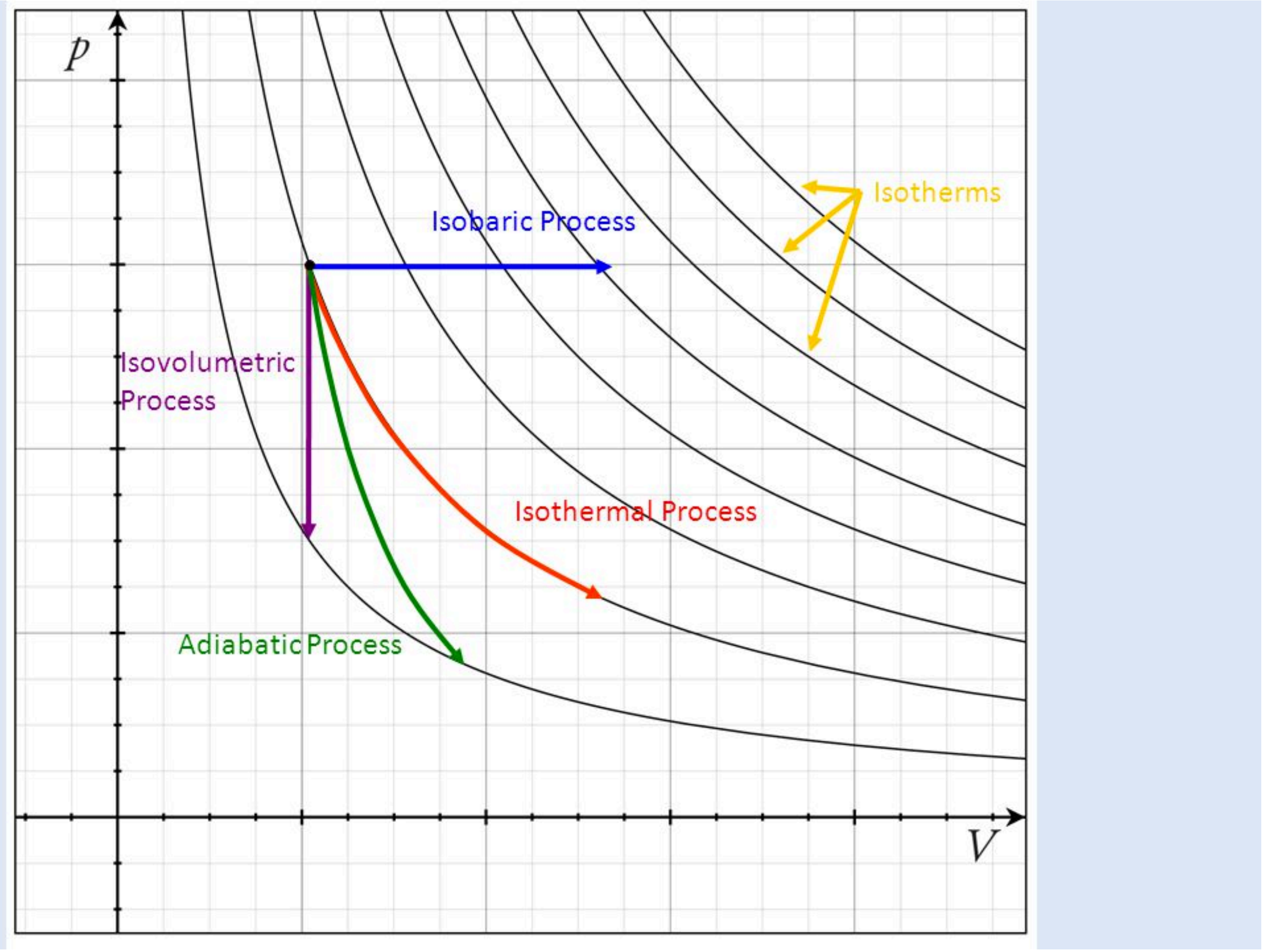
Isotherms



p
V
Isotherms
Isobaric Process
Isovolumetric
Process
Isothermal Process
Adiabatic Process

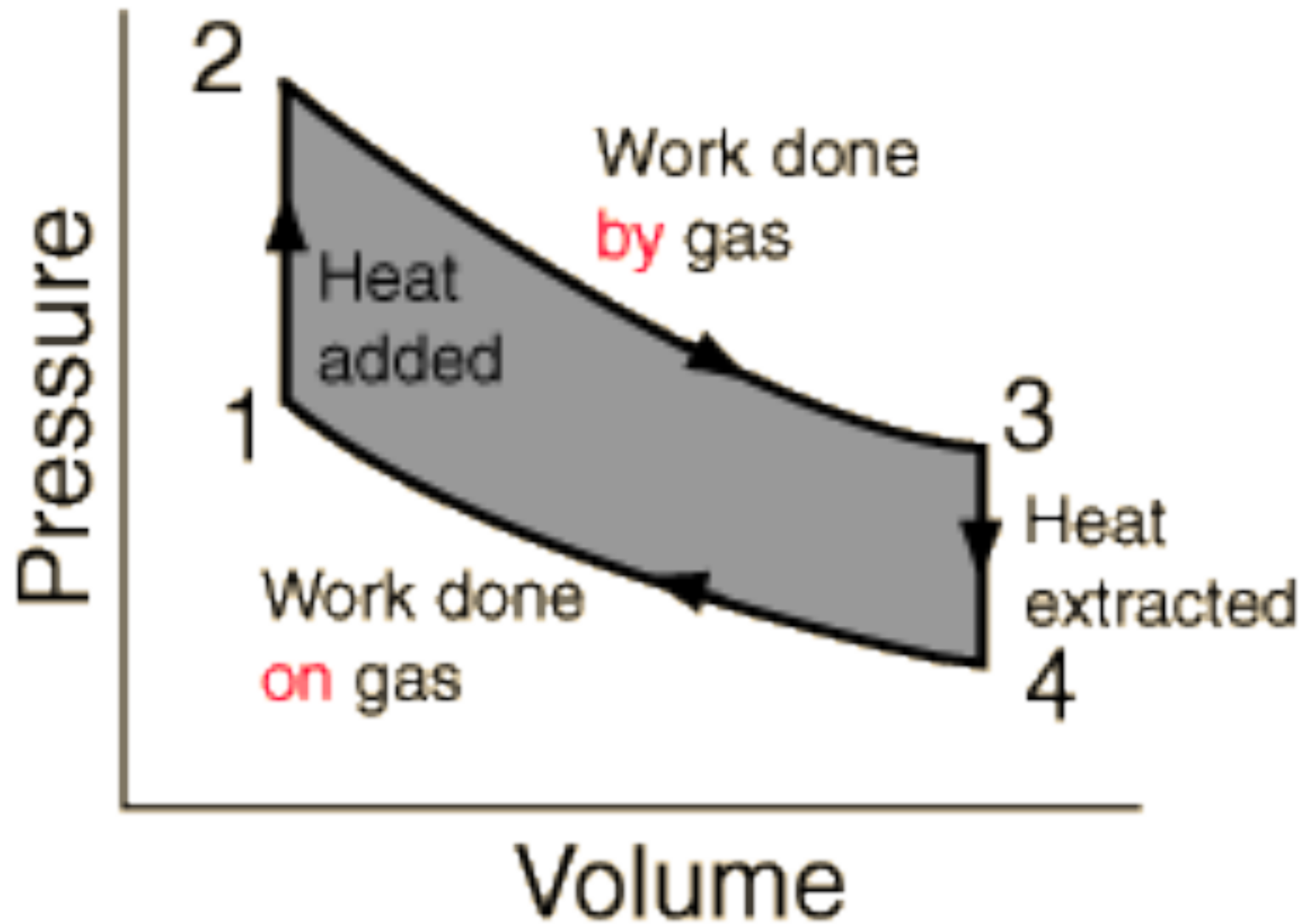
Pressure, Volume, Temperature for Adiabatic Process

- $\gamma > 1$ for any gas, so the adiabatic curve ("adiabat") on a PV diagram is steeper than an isotherm
- For a decrease in temperature, pressure goes down, volume goes up, and positive work is done by the gas
- For an increase in temperature, pressure goes up, volume goes down, and negative work is done by the gas (positive work is done on the gas)

Ideal Gas Thermo Processes

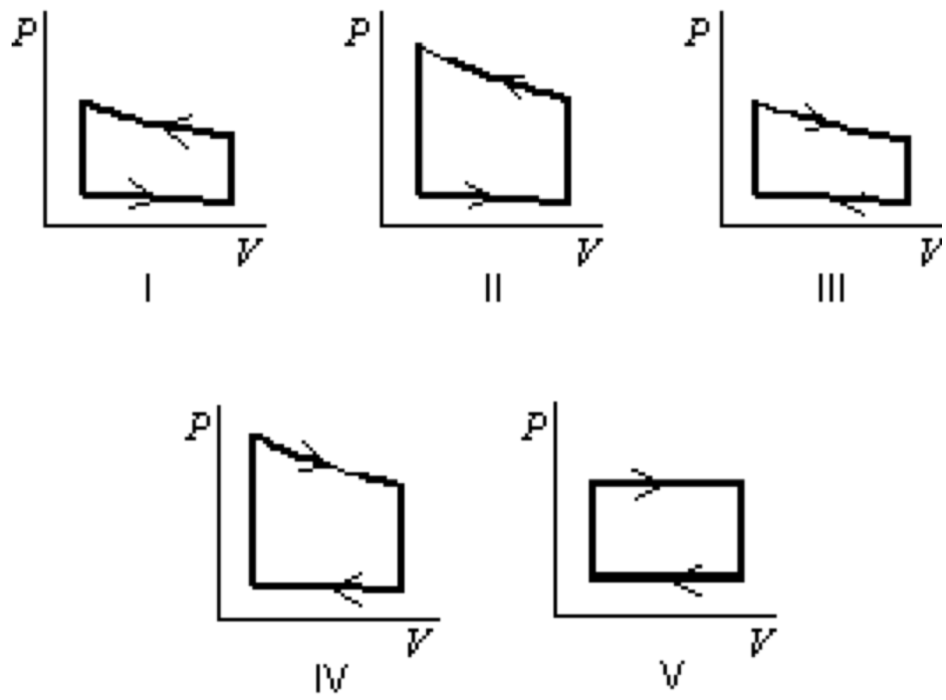
Process	ΔU	Q	W
Constant Volume	$3/2\ nR\ \Delta T$ (monatomic)	$3/2\ nR\ \Delta T$ (monatomic)	0
Constant Pressure	$3/2\ nR\ \Delta T$ (monatomic)	$5/2\ nR\ \Delta T$ (monatomic)	$P\Delta V = nR\ \Delta T$
Constant Temperature	0	$nRT \ln (V_f/V_i)$	$nRT \ln (V_f/V_i)$
Adiabatic (pV^{γ} = constant)	$3/2\ nR\ \Delta T$ (monatomic)	0	$-3/2\ nR\ \Delta T$ (monatomic)

Work and Heat for Ideal Gas



Concept Check

Q24) Pressure vs. volume graphs for a certain gas undergoing five different cyclic processes are shown to the right. During which cycle does the gas do the greatest positive work?



Concept Check

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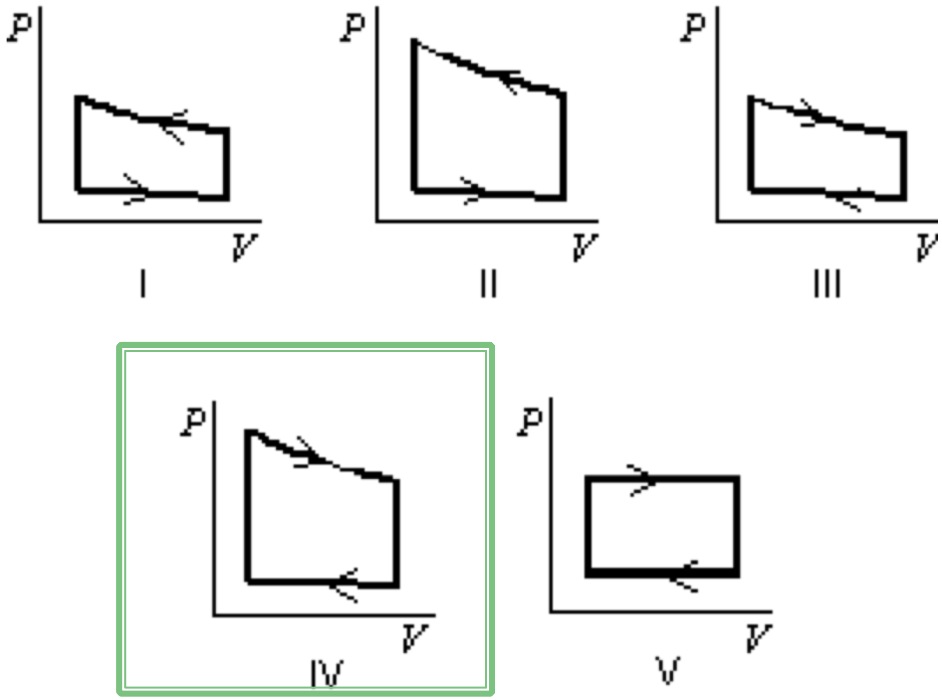
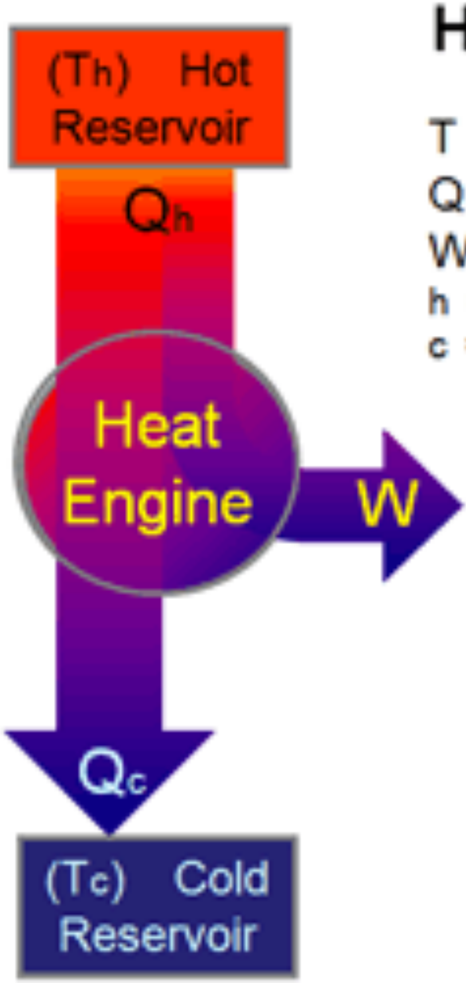
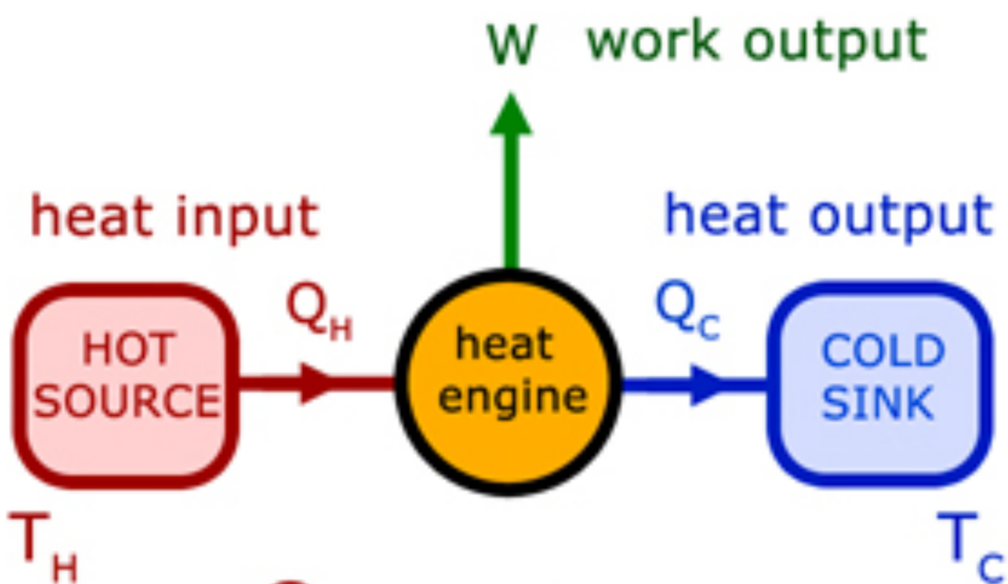


Heat Engines



Heat Engine

T = Temperature (°K)
Q = Heat (J)
W = Work (J)
h = hot
c = cold



$$Q_H - Q_C = W$$

Hero's Engine

- Works by heating water to produce steam which is expelled and converted to mechanical motion (which can do work)
- Steam is lost
- Not reversible!

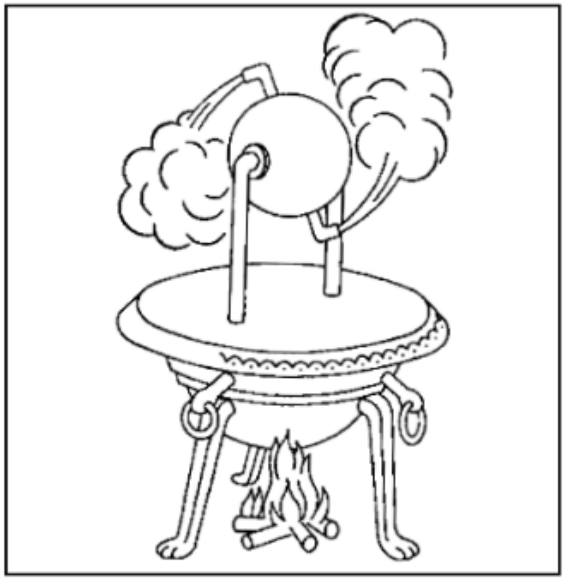
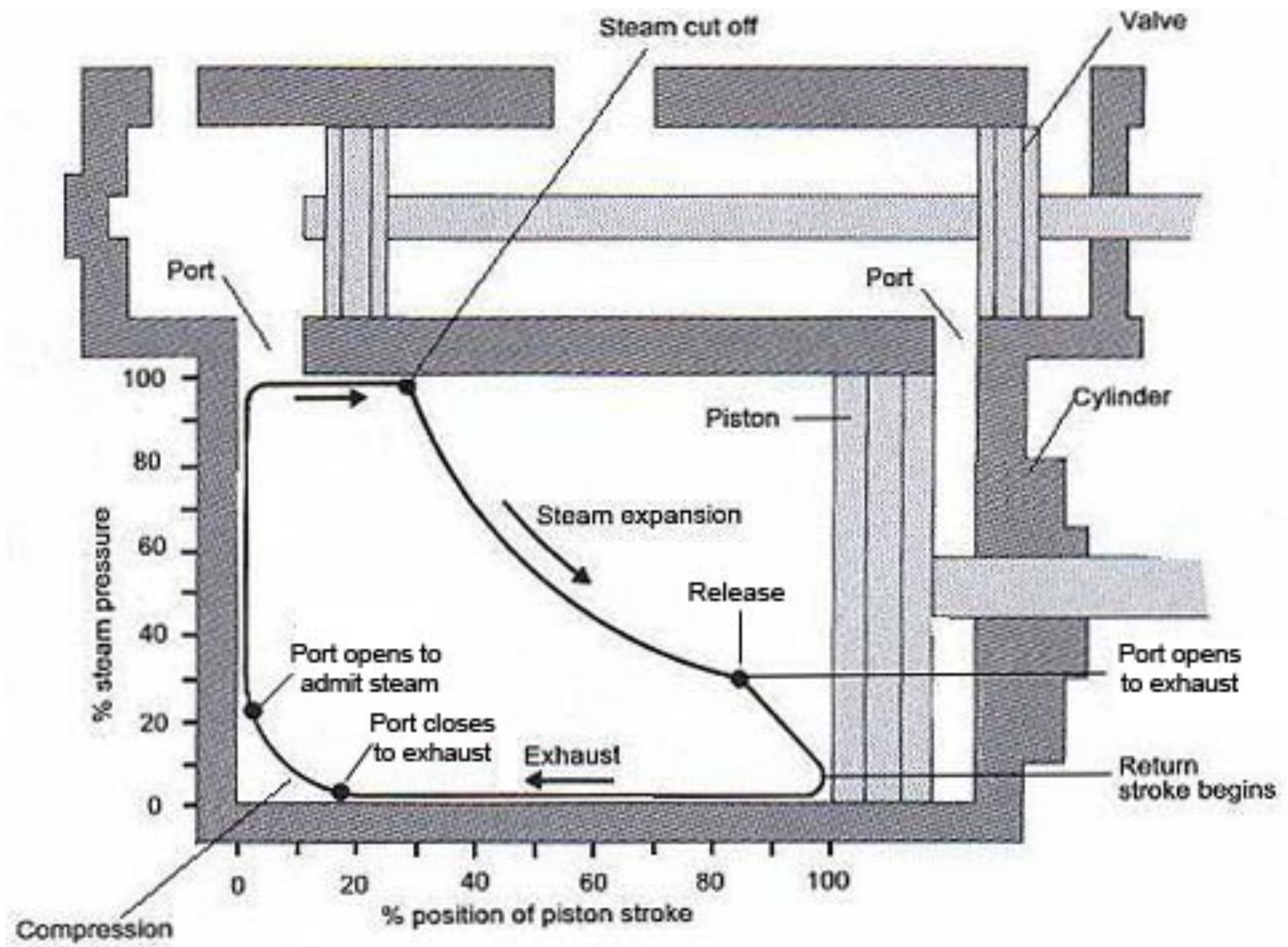


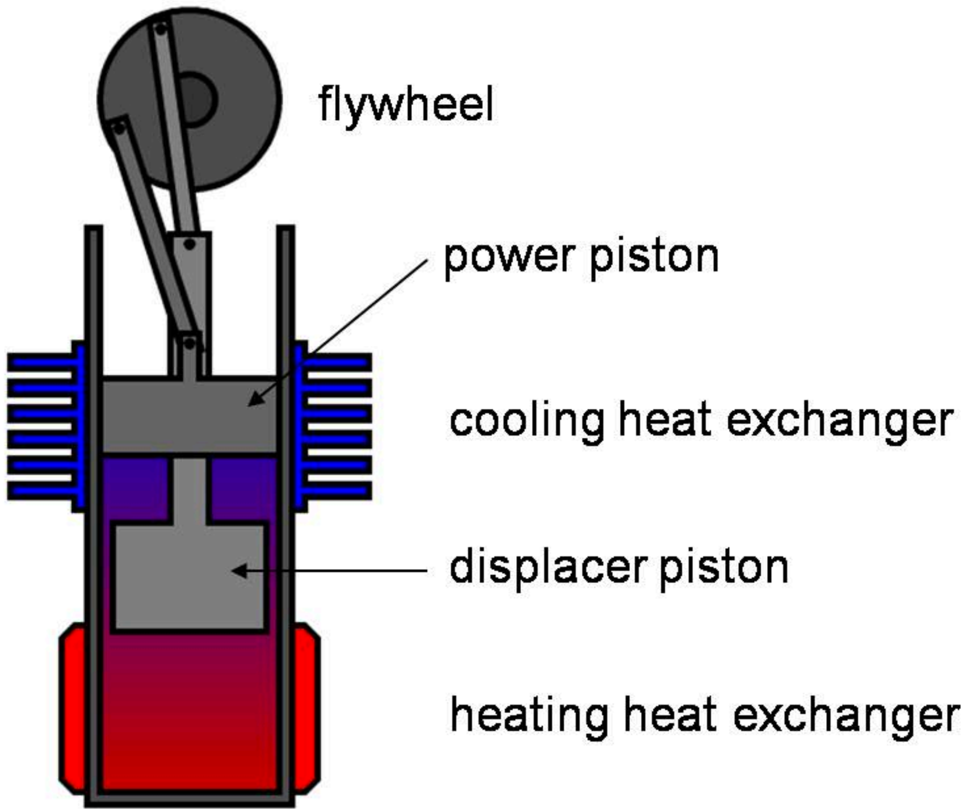
Figure 2-1. Hero's Aeolipile

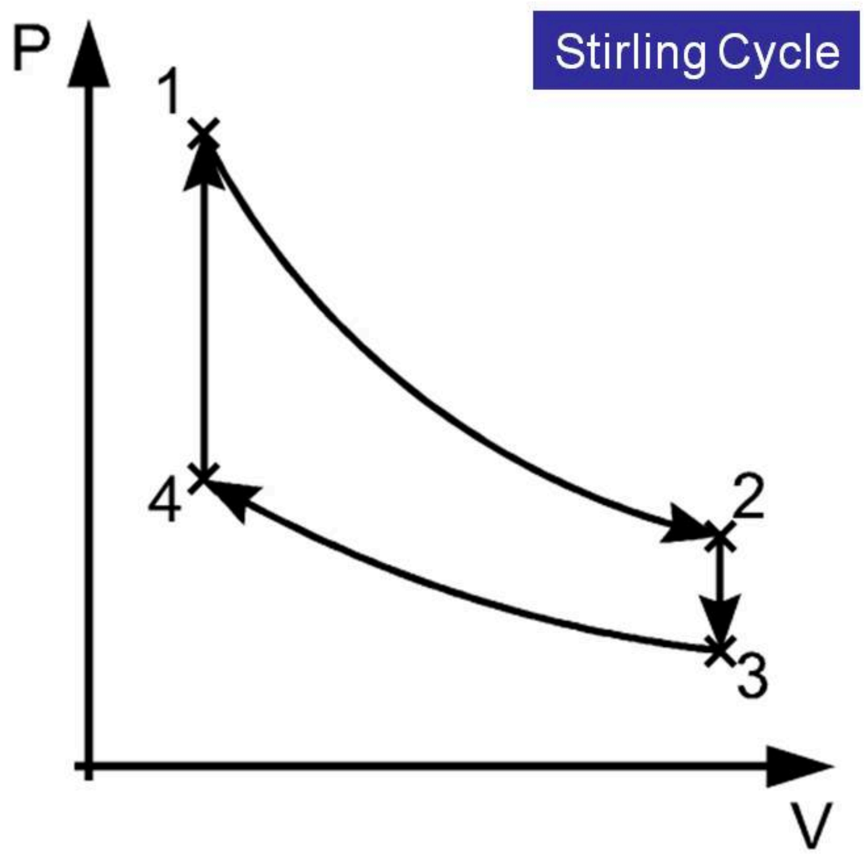
Steam Engine



Steam is lost, must be replaced, not reversible

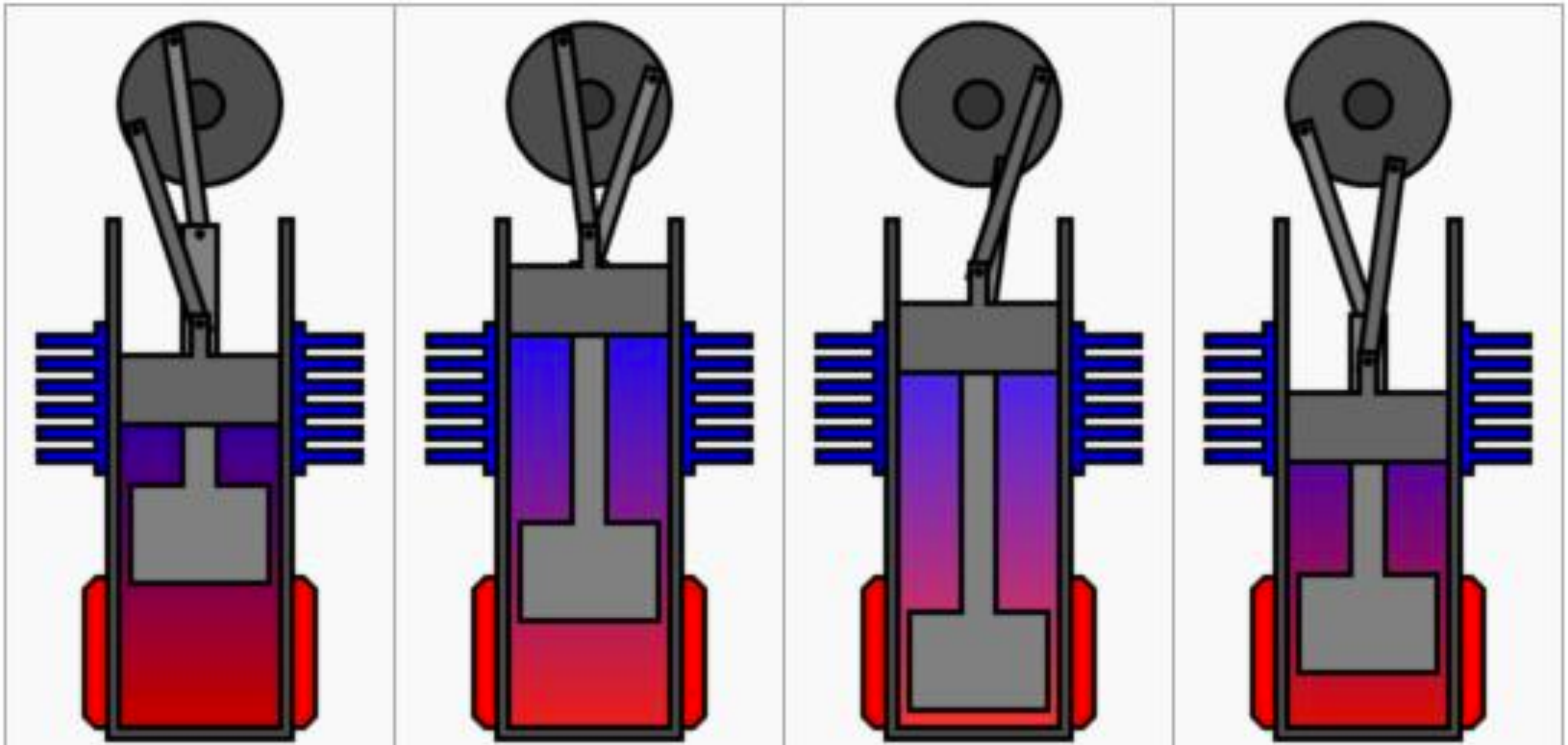
Stirling Engine





Stirling cycle is reversible in principle

Stirling Cycle



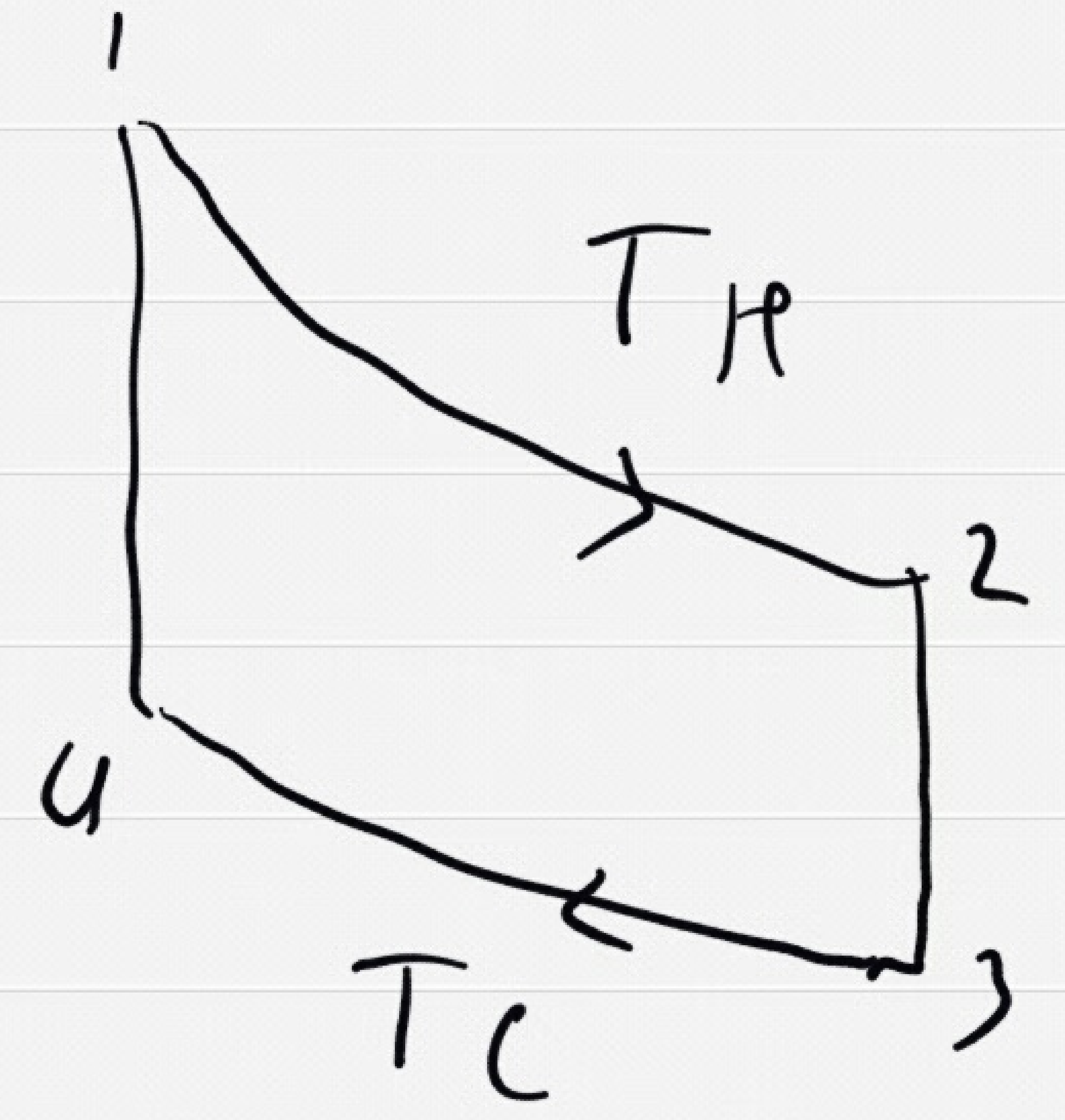
1. Power piston (dark grey) has compressed the gas, the displacer piston (light grey) has moved so that most of the gas is adjacent to the hot heat exchanger.

2. The heated gas increases in pressure and pushes the power piston to the farthest limit of the power stroke.

3. The displacer piston now moves, shunting the gas to the cold end of the cylinder.

4. The cooled gas is now compressed by the flywheel momentum. This takes less energy, since when it is cooled its pressure dropped.

Stirling Cycle



$W_{23} = W_{41} = 0$

$$W_{12} = nRT_H \ln\left(V_{23}/V_{14}\right) = Q_H > 0$$

$$W_{34} = nRT_C \ln\left(V_{14}/V_{23}\right) = Q_C < 0$$

$$W_{tot} = W_{12} + W_{34} = Q_H + Q_C = |Q_H| - |Q_C|$$

Work Done in Stirling Cycle

- $W_{12} = nRT_H \ln(V_{23}/V_{14}) = Q_H$
- $W_{34} = nRT_C \ln(V_{14}/V_{23}) = Q_C$
- $W_{tot} = W_{12} + W_{34} = |Q_H| - |Q_C|$
- $W_{tot}/Q_H = (|Q_H| - |Q_C|)/Q_H$
- $W_{tot}/Q_H = (T_H - T_C)/T_H$