Thermodynamics

I. Internal Energy
- energy of atoms and molecules
- thermal equilibrium
- ideal gas law
- temperature & kinetic theory

II. Heat
- thermal conductivity
- 1st law of thermodynamics
- **heat engines & cycles**
- 2nd law of thermodynamics

	The student will be able to:	HW:
1	Define and apply concepts of internal energy, thermal equilibrium, zeroth law of thermodynamics, and temperature.	✓ 1 – 3
2	State and apply the ideal gas law in terms of Boltzmann's constant and solve related problems with variables pressure, volume, and temperature.	✓ 4 – 7
3	State and apply the stipulations of the kinetic theory of gases and solve related problems involving pressure, force, kinetic energy, Boltzmann's constant, temperature, and speed distributions of particles	✓ 8 – 13
4	Define and apply the concept of thermal conductivity and solve related problems involving heat flow.	✓ 14 – 19
5	State and apply the first law of thermodynamics and solve related problems including work, heat, heat engines & cycles, *P*-*V* diagrams.	20 – 26
6	Define and describe entropy; state and apply qualitatively the second law of thermodynamics.	27 – 30

1st Law of Thermodynamics

Recognizing that heat is the transfer of internal energy and work is also a form of energy transfer, a useful form of conservation of energy becomes:

$$\Delta U = Q + W$$

where: U = internal energy
Q = heat (into the system)
W = work done *on* the system

1st Law of Thermodynamics

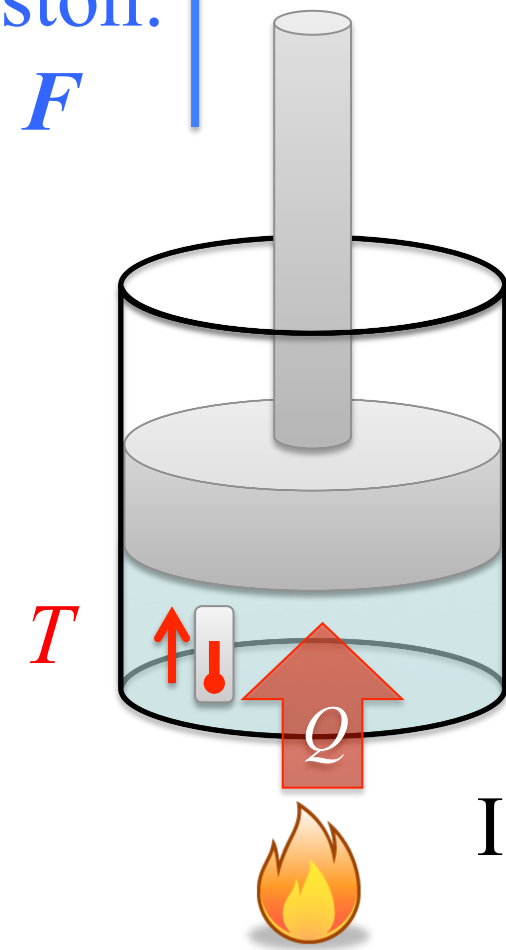
Recognizing that heat is the transfer of internal energy and work is also a form of energy transfer, a useful form of conservation of energy becomes:

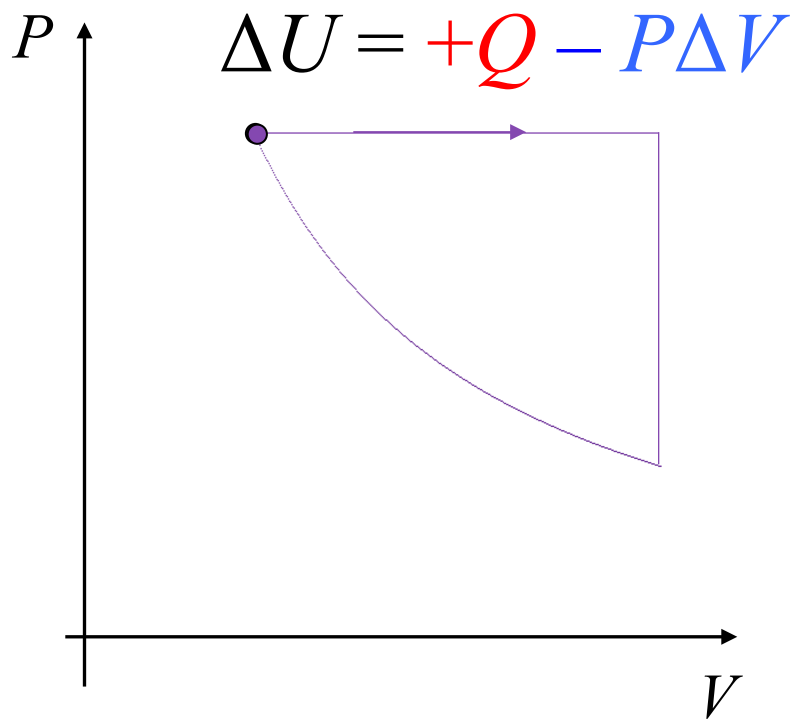
$$\Delta U = Q - W$$

where: U = internal energy
Q = heat (into the system)
W = work done *by* the system

Isobaric Process: pressure is constant. Work equals pressure times change in volume.

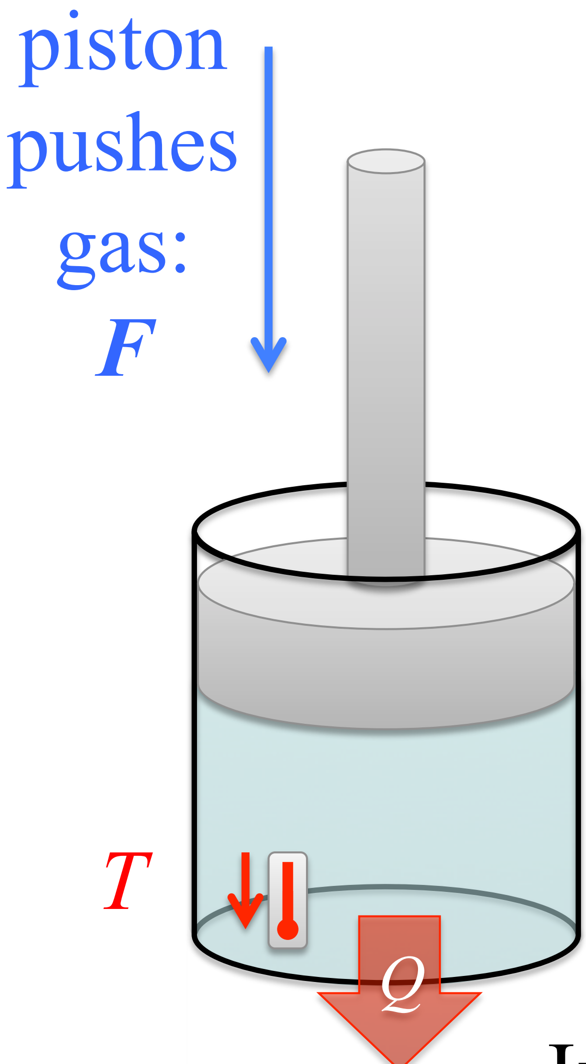
gas pushes piston: F



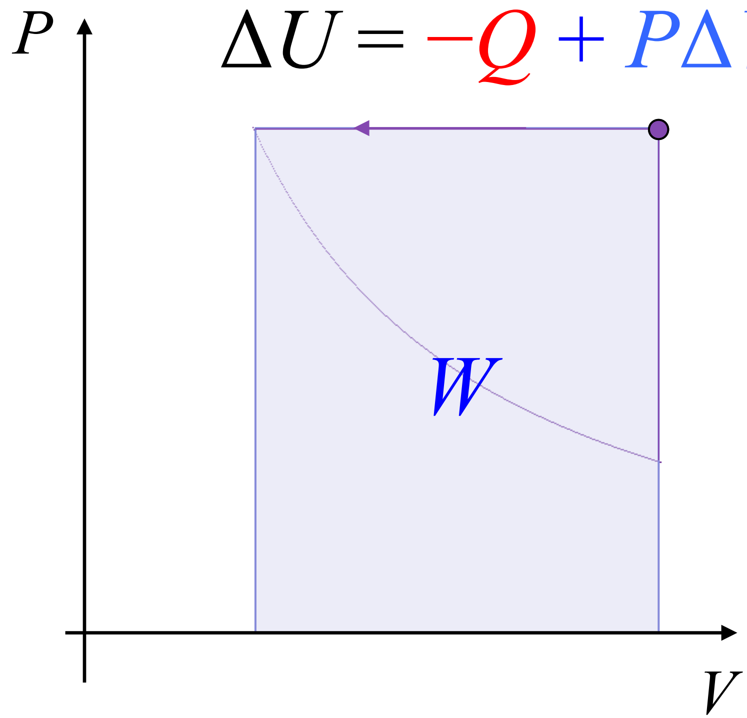


If gas is heated and pressure remains constant, volume, temperature, and internal energy all increase.

Work equates with area under the curve – signs depends on direction.



$$\Delta U = -Q + P\Delta V$$

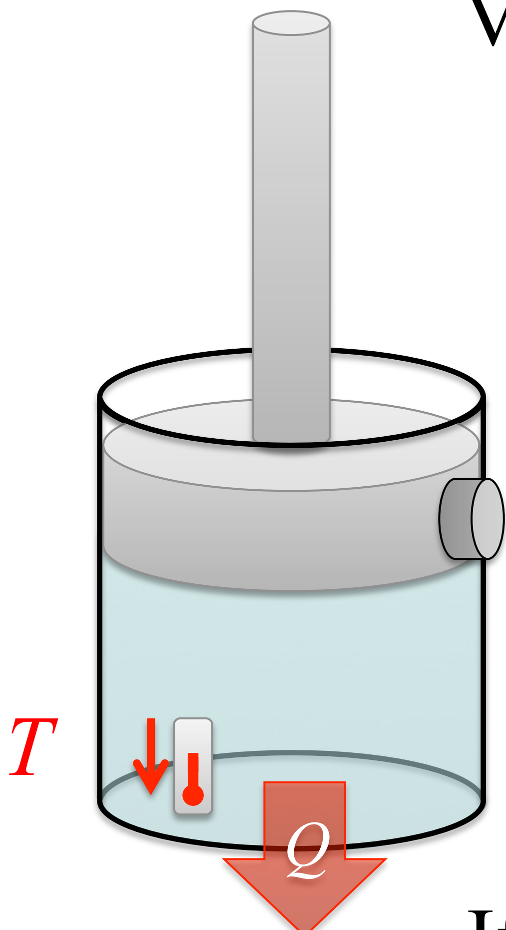


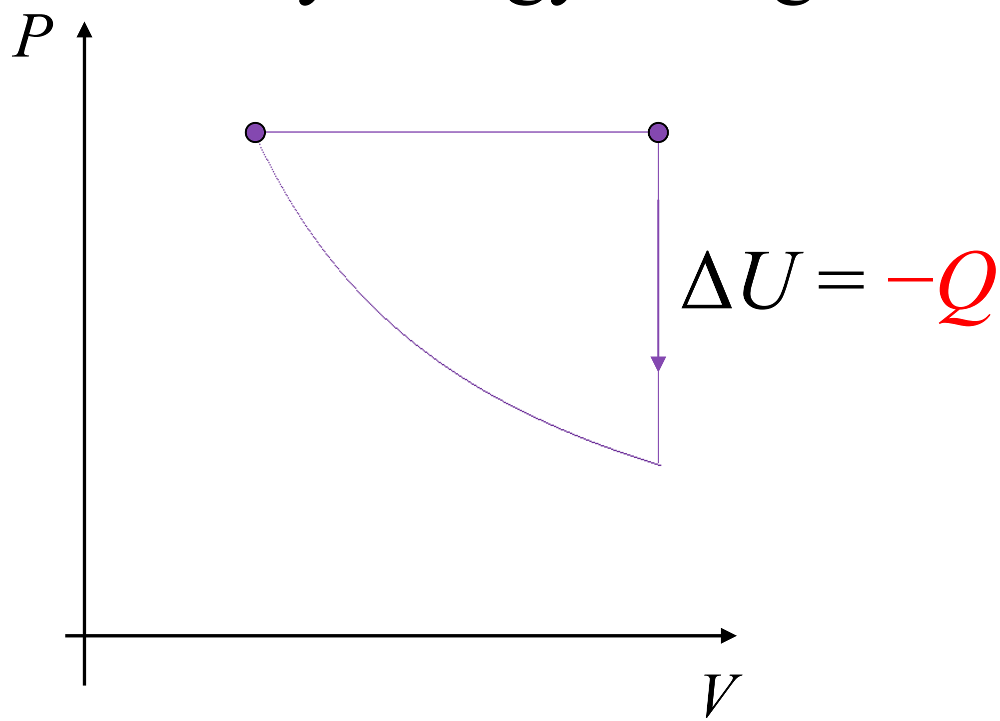
Note: in this hypothetical case the pressure is steady at atmospheric (plus a small amount related to the weight of piston).

If gas is cooled and pressure remains constant, volume, temperature, and internal energy all decrease.

Isochoric (or Isovolumetric) Process

Volume is constant, so work is zero.
Heat is the only energy change.



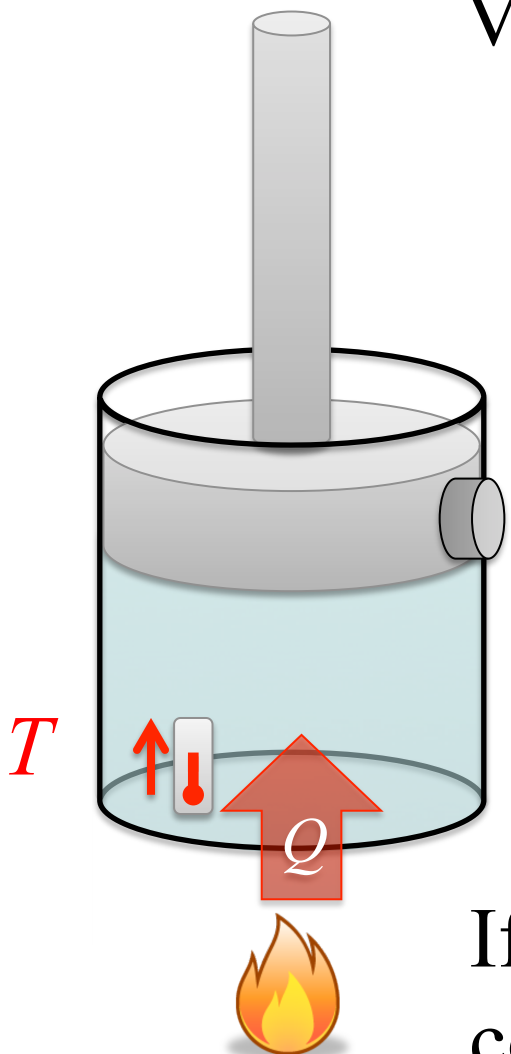


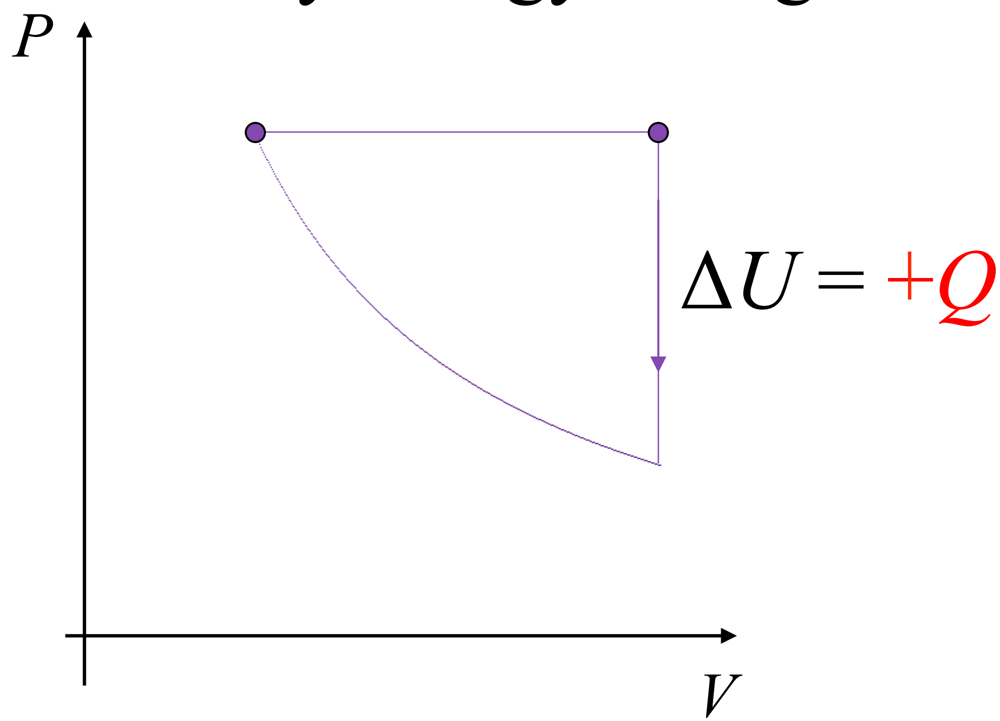
Note: in this hypothetical the piston is now locked in place by a pin. This would keep the volume from changing.

If gas is cooled and volume remains constant, pressure, temperature, and internal energy all decrease.

Isochoric (or Isovolumetric) Process

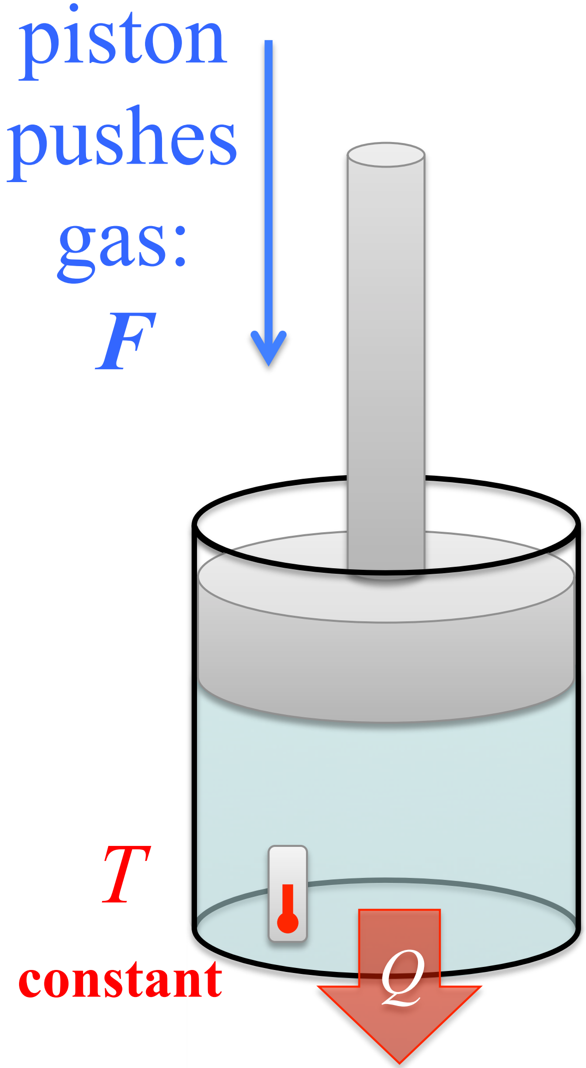
Volume is constant, so work is zero.
Heat is the only energy change.





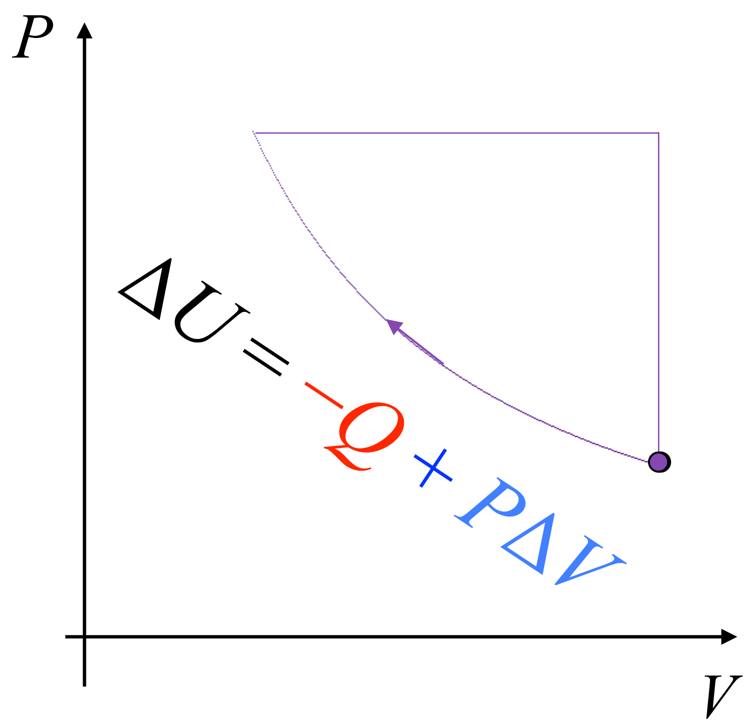
If gas is heated and volume remains constant, pressure, temperature, and internal energy all increase.

Isothermal Process



Note: in this hypothetical the piston is moved slowly to allow thermal equilibrium with surroundings at all times.

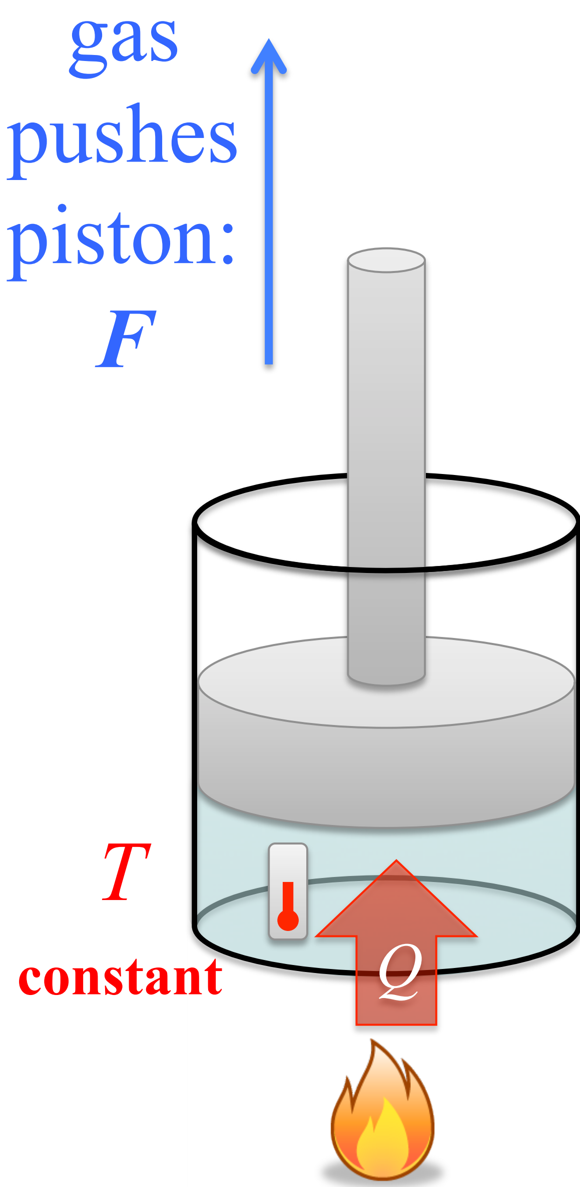
Temperature is constant so PV = constant also.



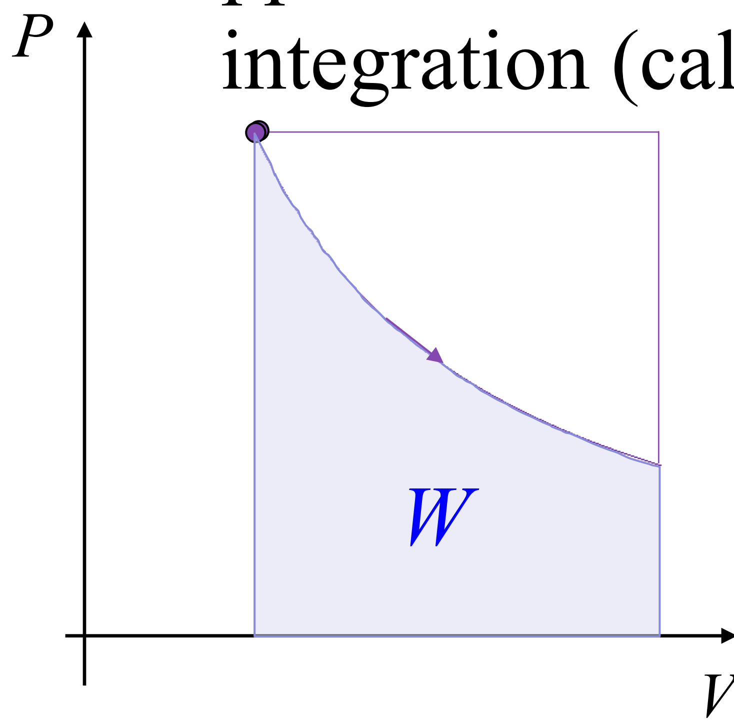
Temperature and internal energy are *both* constant! $\Delta U = 0$, $|Q| = |W|$

$$Q = P_{avg}\Delta V$$

Isothermal Process

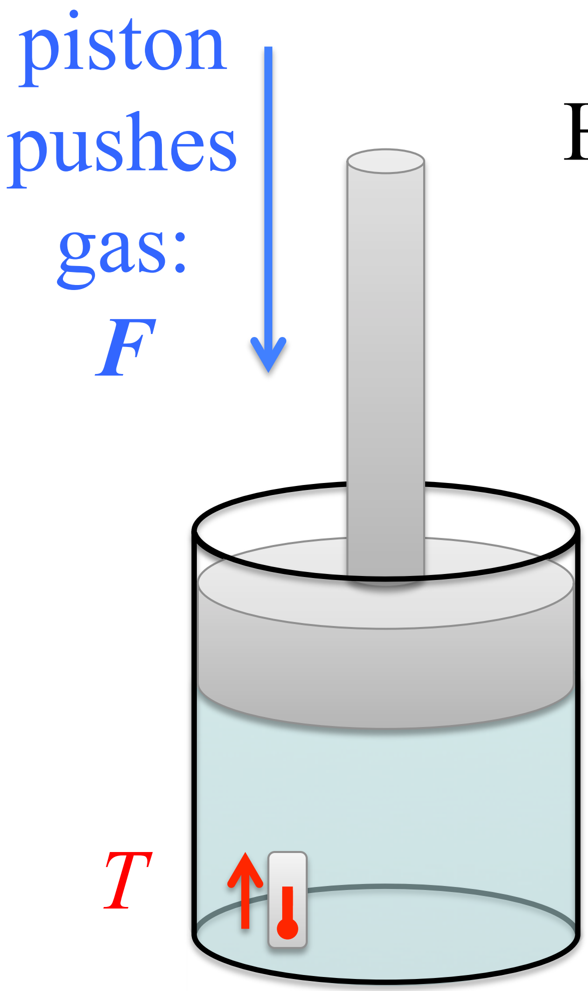


Work is still area under the curve – can approximate or find by integration (calculus).

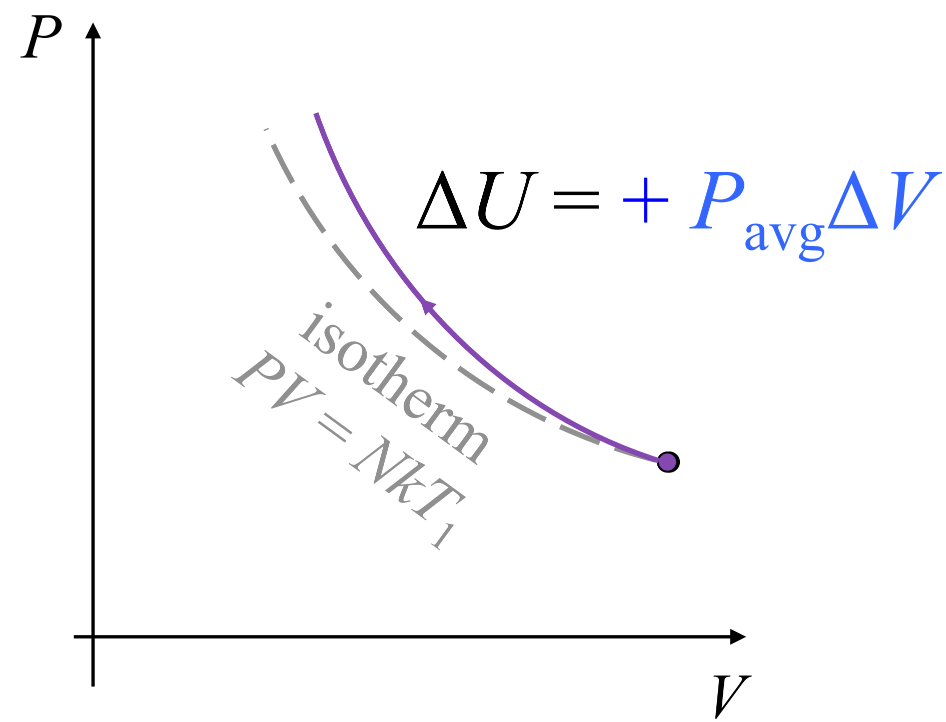


Volume is inversely proportional to pressure. Work done by gas equals heat gained at constant temperature.

Adiabatic Process



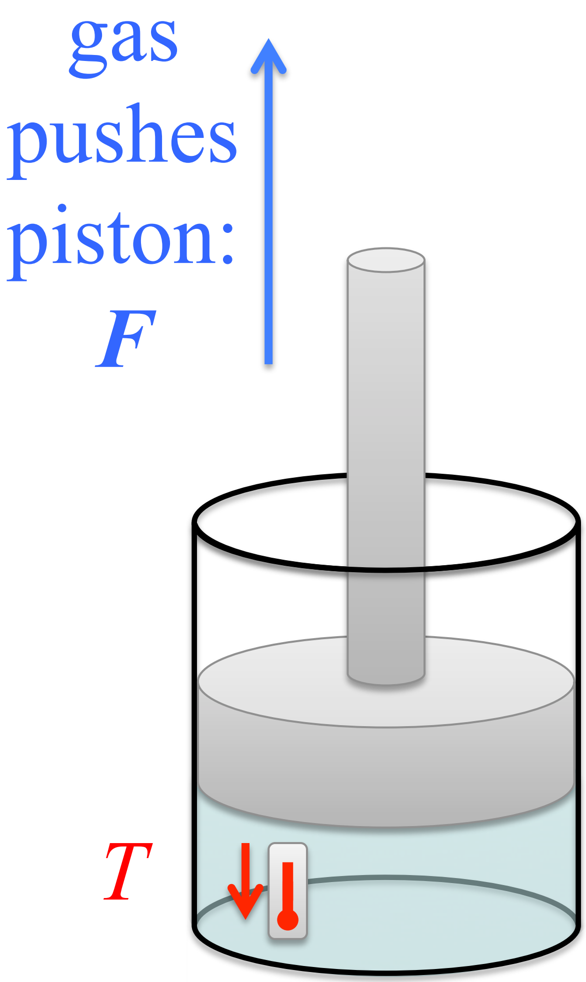
Heat is zero so the work done equates with a change in internal energy.



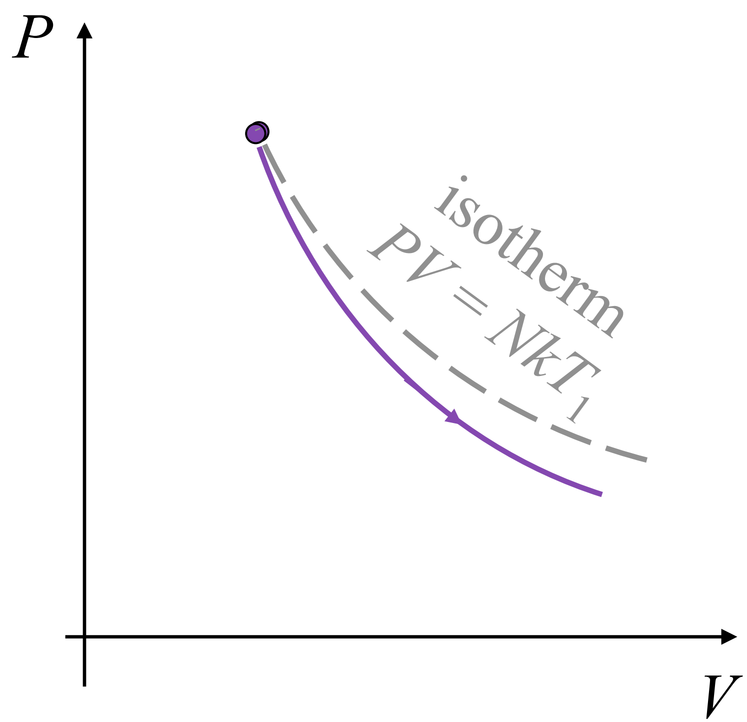
Work done *on* the gas equates with an *increase* in temperature, pressure, and internal energy as volume decreases.

Note: in this hypothetical the piston is either thermally insulated or moved so quickly there is no time for heat to flow.

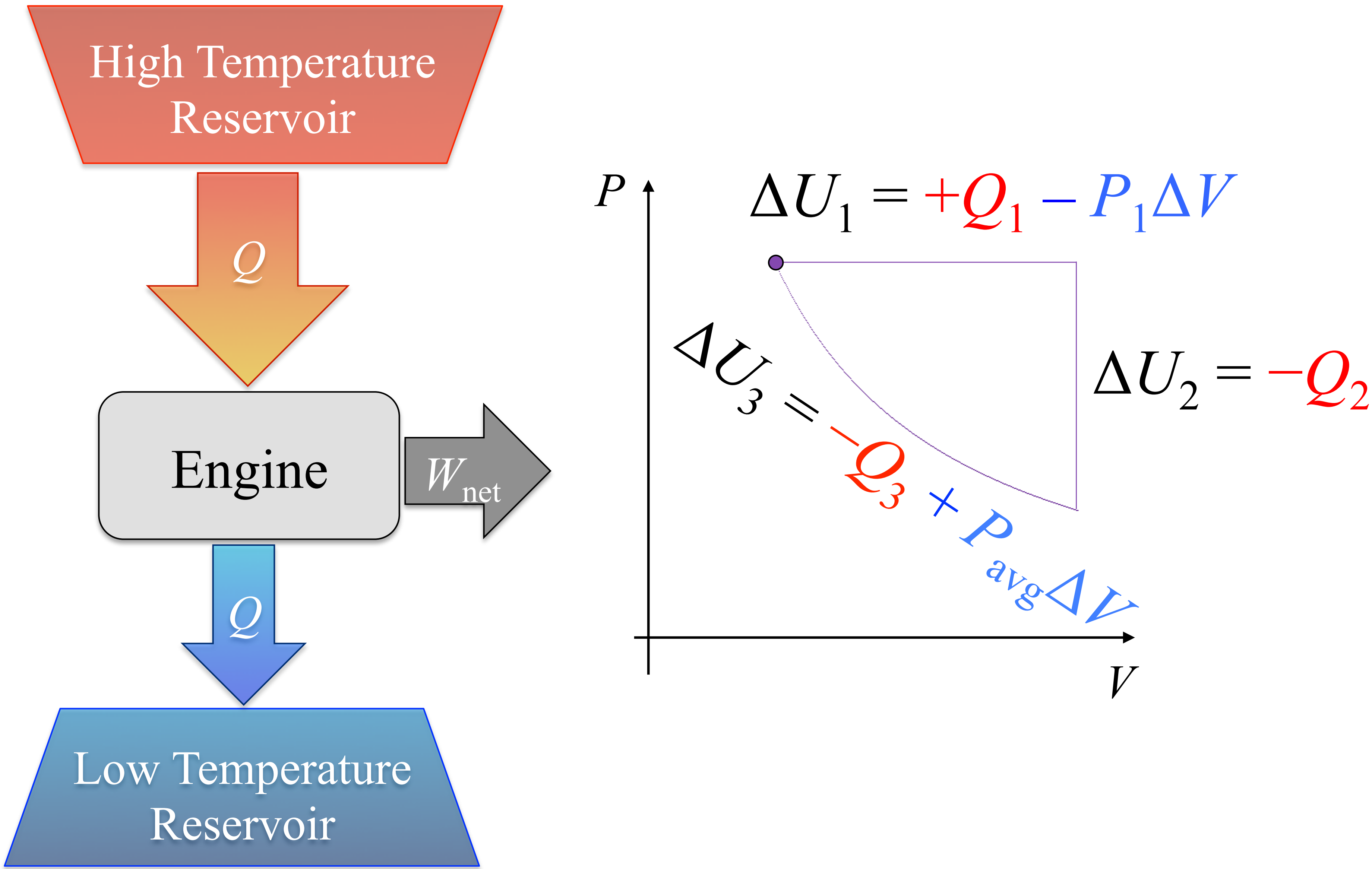
Adiabatic Process

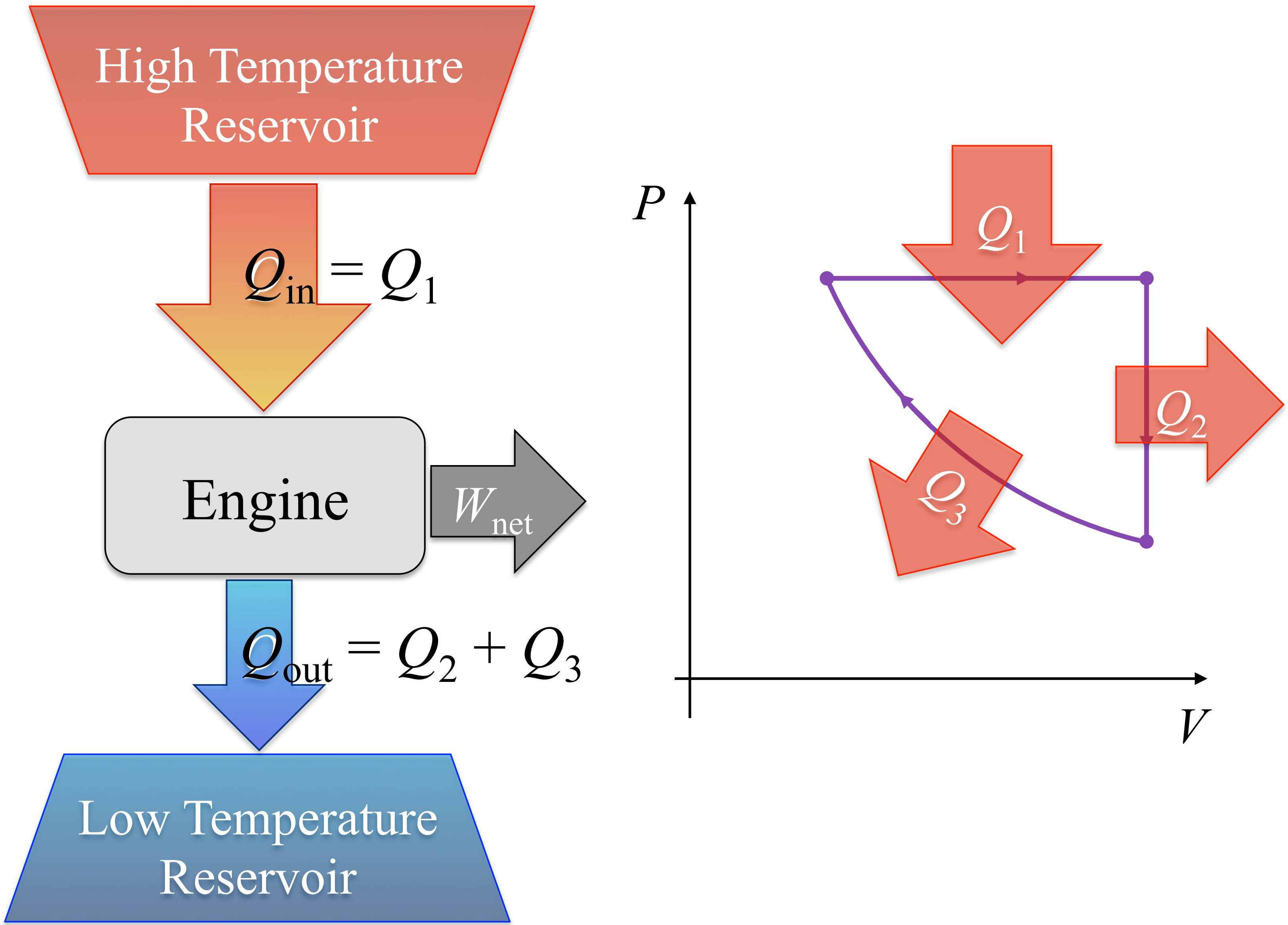


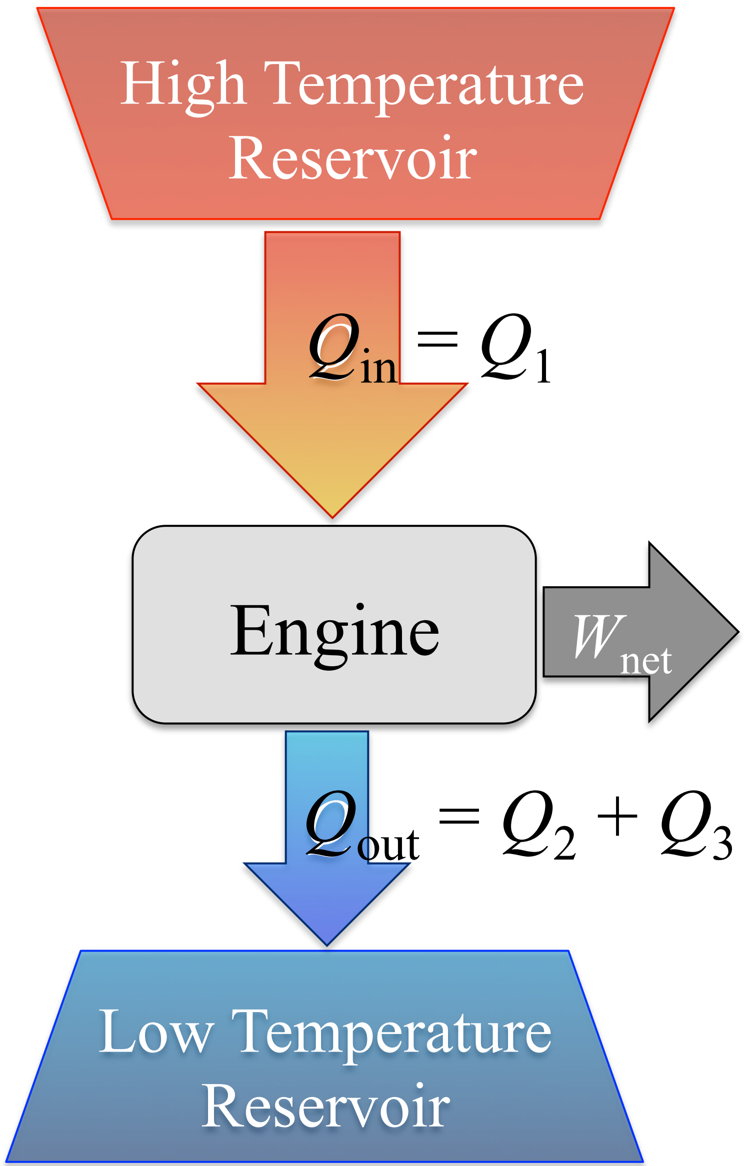
As before, work equates with area under the curve.

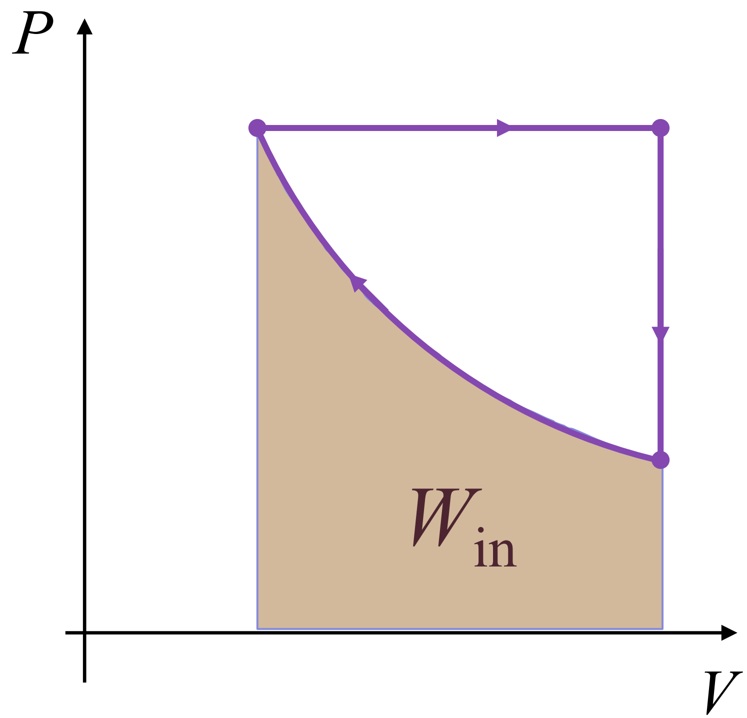


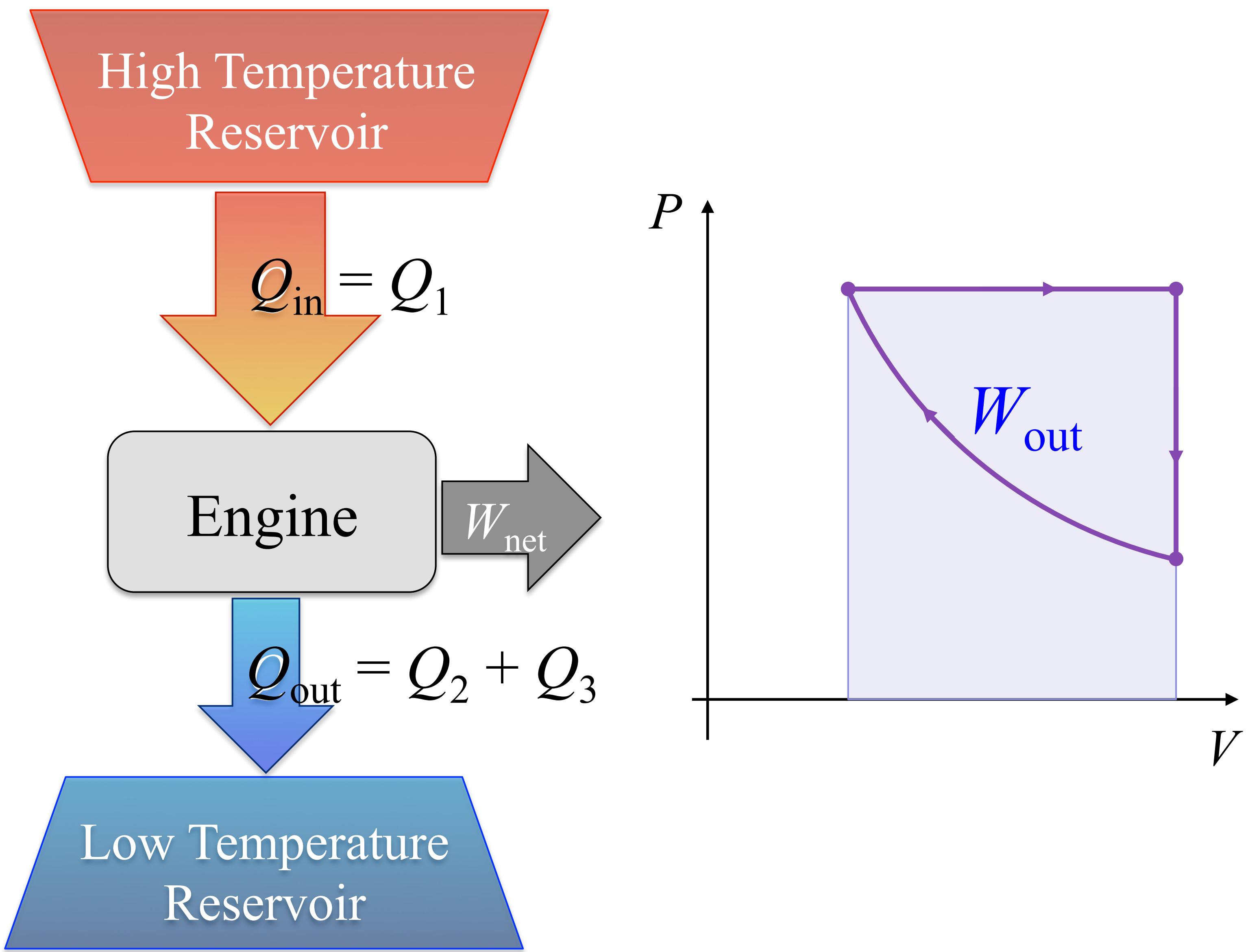
Work done *by* the gas equates with an *decrease* in temperature, pressure, and internal energy as volume increases.

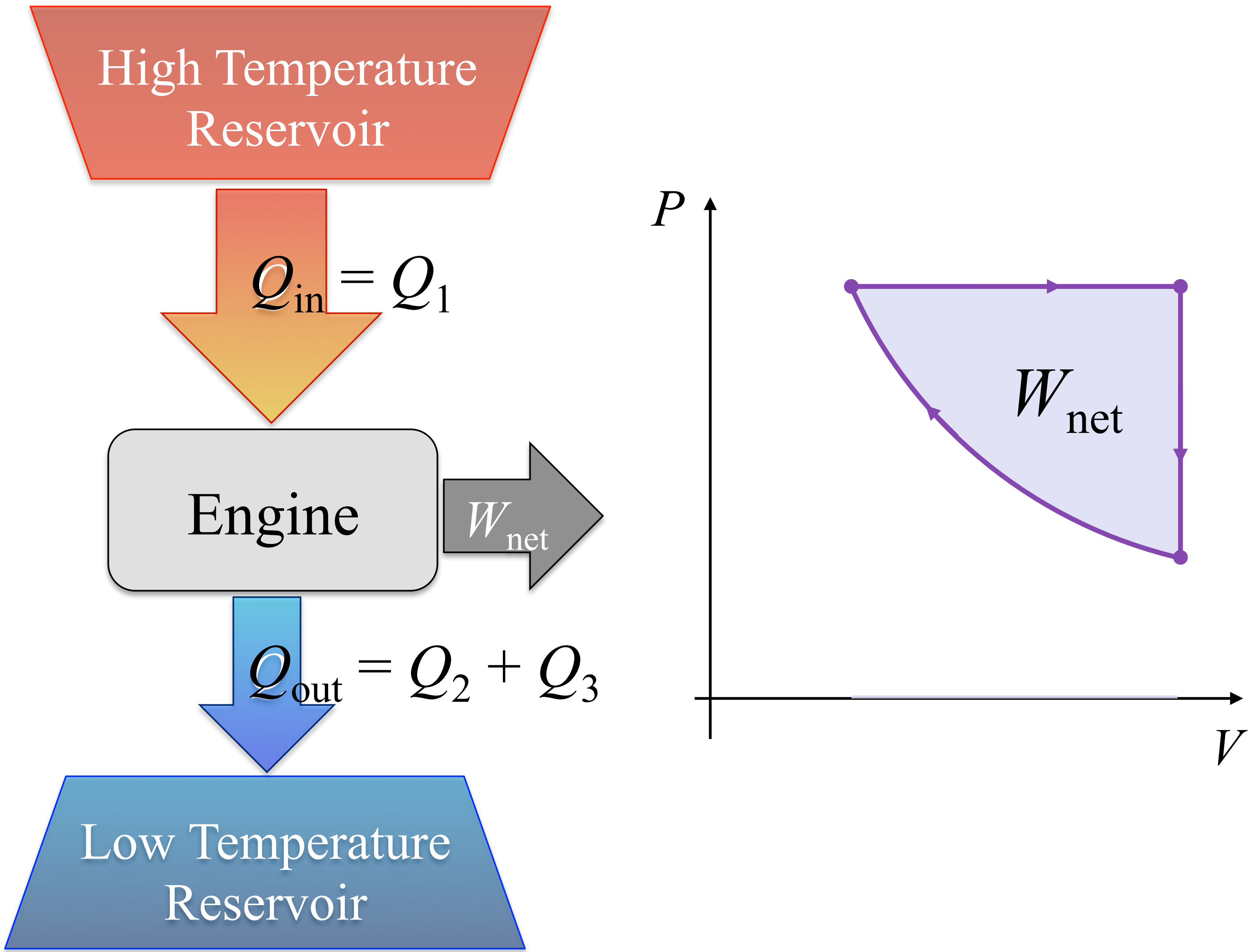

High Temperature Reservoir
Q
Engine
W_{net}
Q
Low Temperature Reservoir
P
V
$\Delta U_1 = +Q_1 - P_1 \Delta V$
$\Delta U_2 = -Q_2$
$\Delta U_3 = -Q_3 + P_{avg} \Delta V$

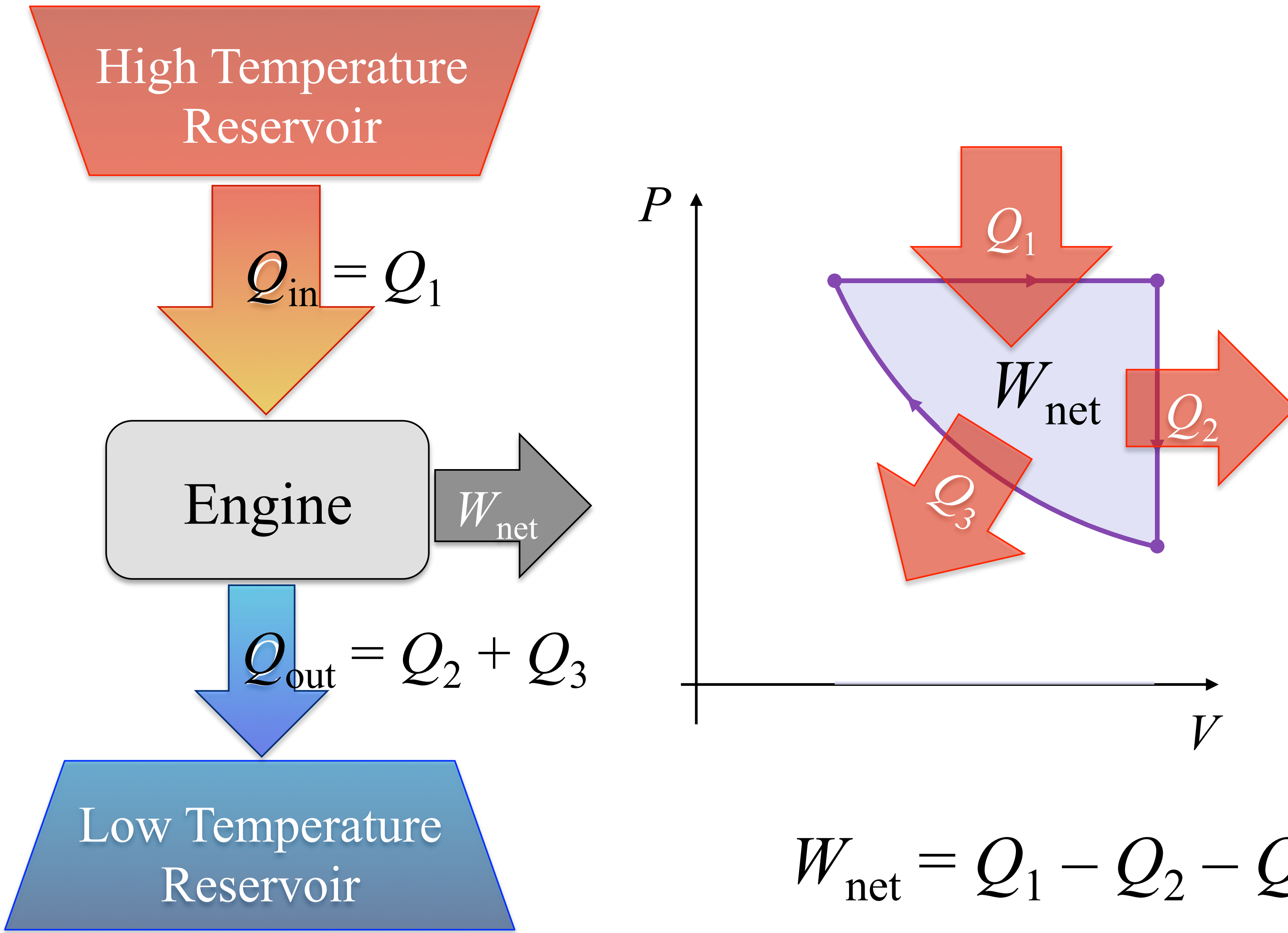

High Temperature Reservoir
$Q_{in} = Q_1$
Engine
W_{net}
$Q_{out} = Q_2 + Q_3$
Low Temperature Reservoir
P
V
Q_1
Q_2
Q_3


High Temperature Reservoir
$Q_{in} = Q_1$
Engine
W_{net}
$Q_{out} = Q_2 + Q_3$
Low Temperature Reservoir

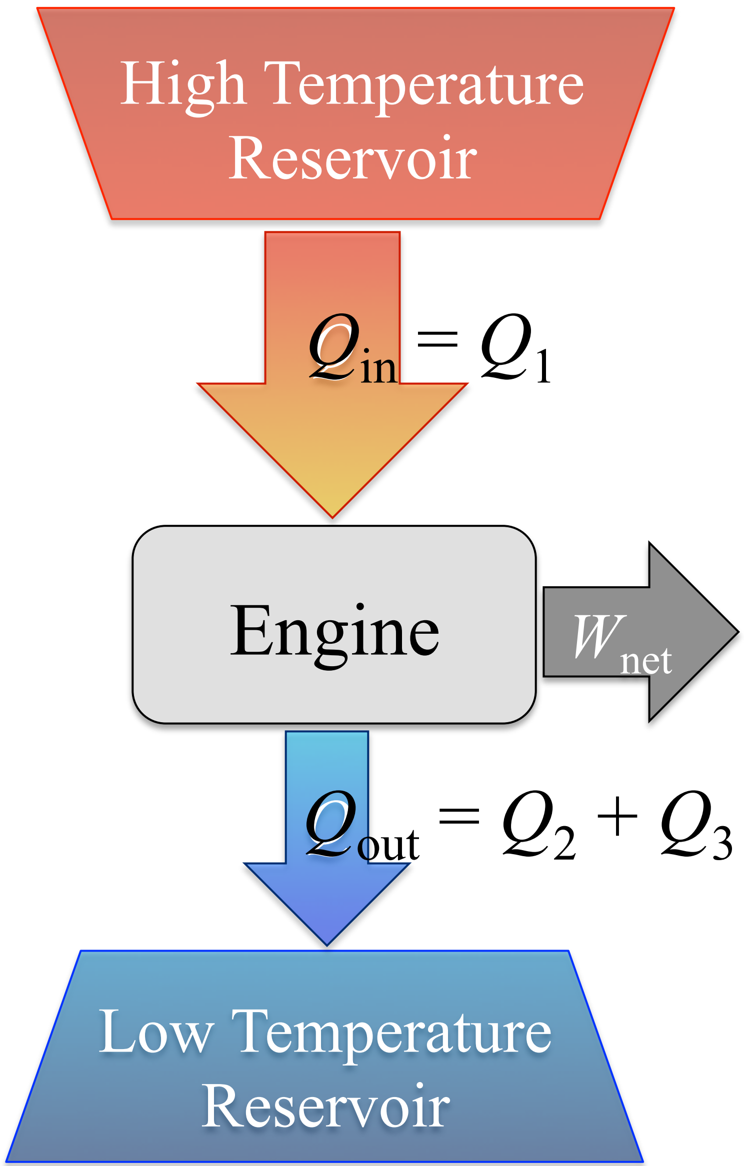

P
V
W_{in}

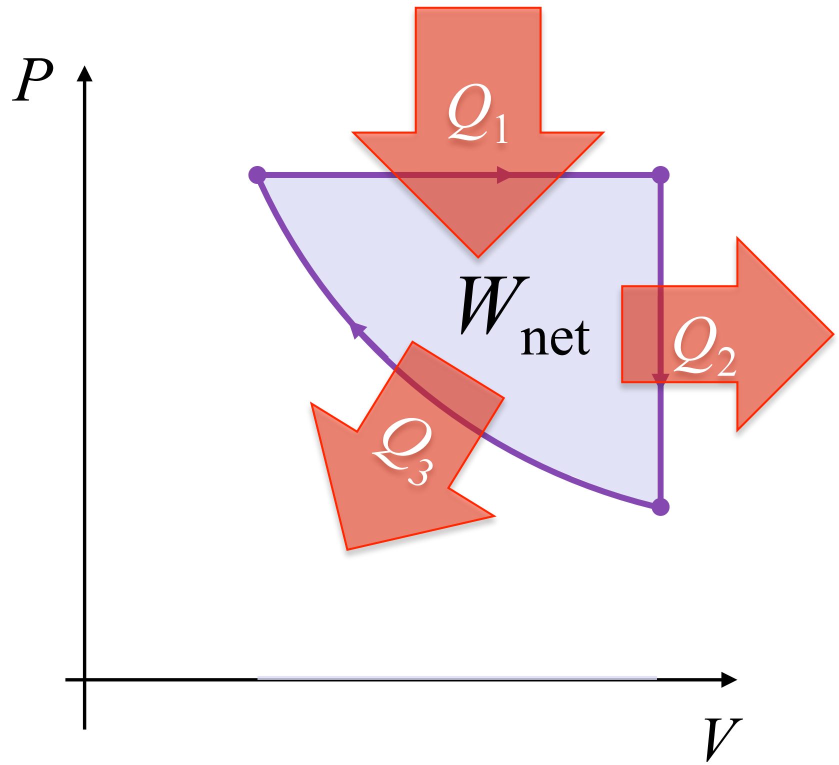

High Temperature Reservoir
$Q_{in} = Q_1$
Engine
W_{net}
$Q_{out} = Q_2 + Q_3$
Low Temperature Reservoir
P
W_{out}
V


High Temperature Reservoir
$Q_{in} = Q_1$
Engine
W_{net}
$Q_{out} = Q_2 + Q_3$
Low Temperature Reservoir
P
W_{net}
V


High Temperature Reservoir
$Q_{in} = Q_1$
Engine
W_{net}
$Q_{out} = Q_2 + Q_3$
Low Temperature Reservoir
P
V
Q_1
W_{net}
Q_2
Q_3

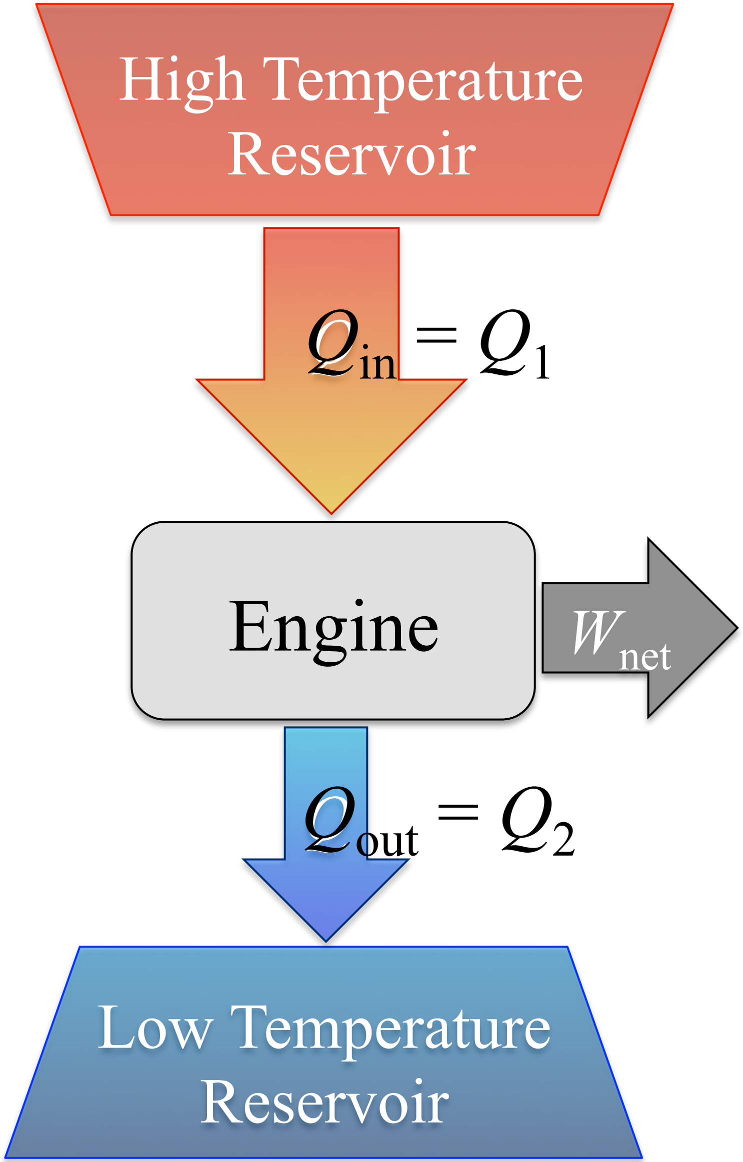
$$W_{net} = Q_1 - Q_2 - Q_3$$

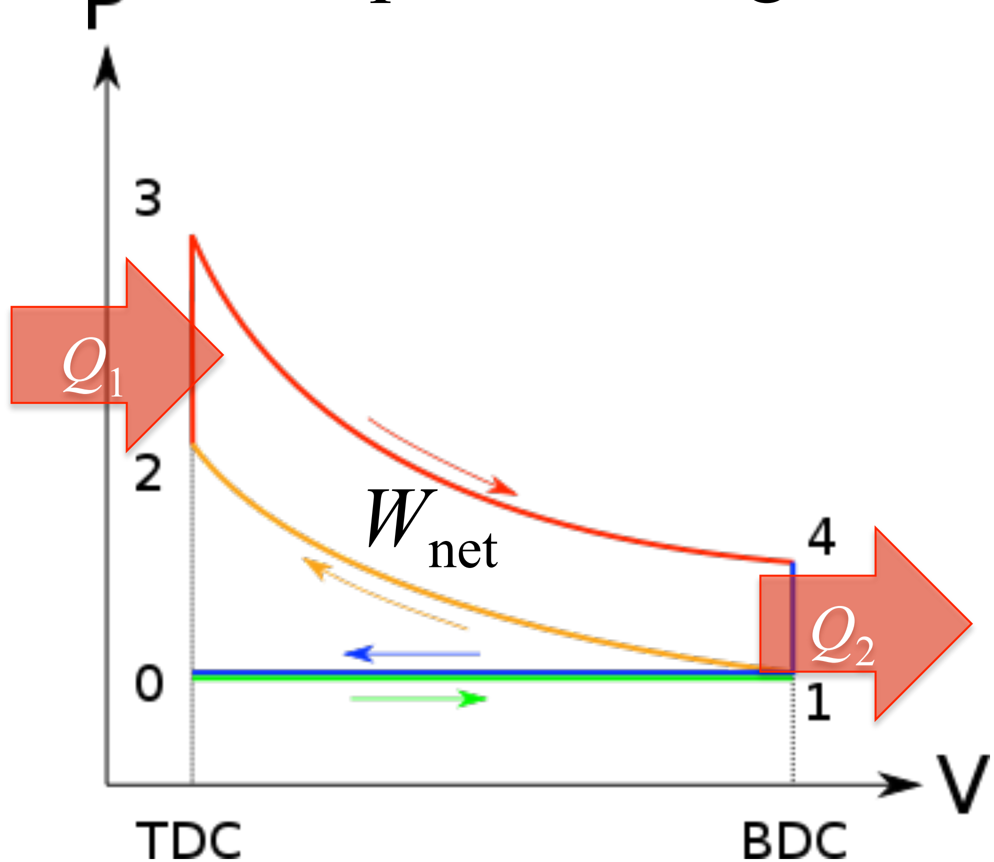




$$eff = \frac{W_{net}}{Q_1}$$

Otto Cycle
example: car engine

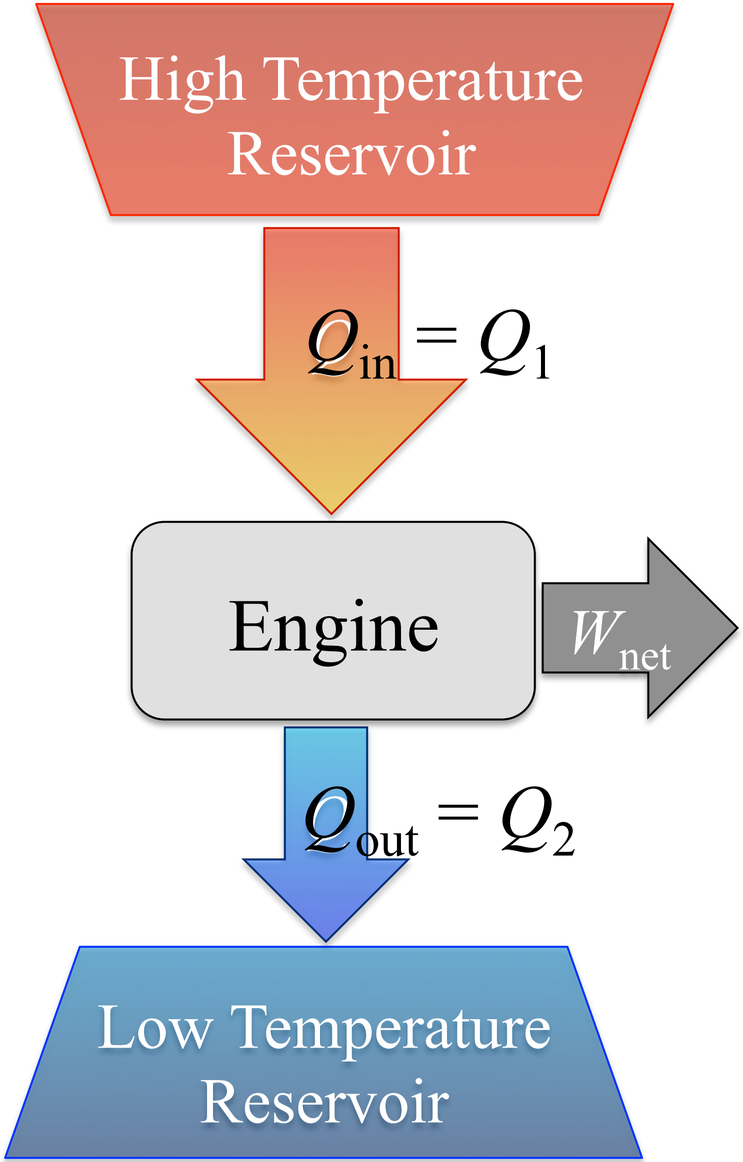


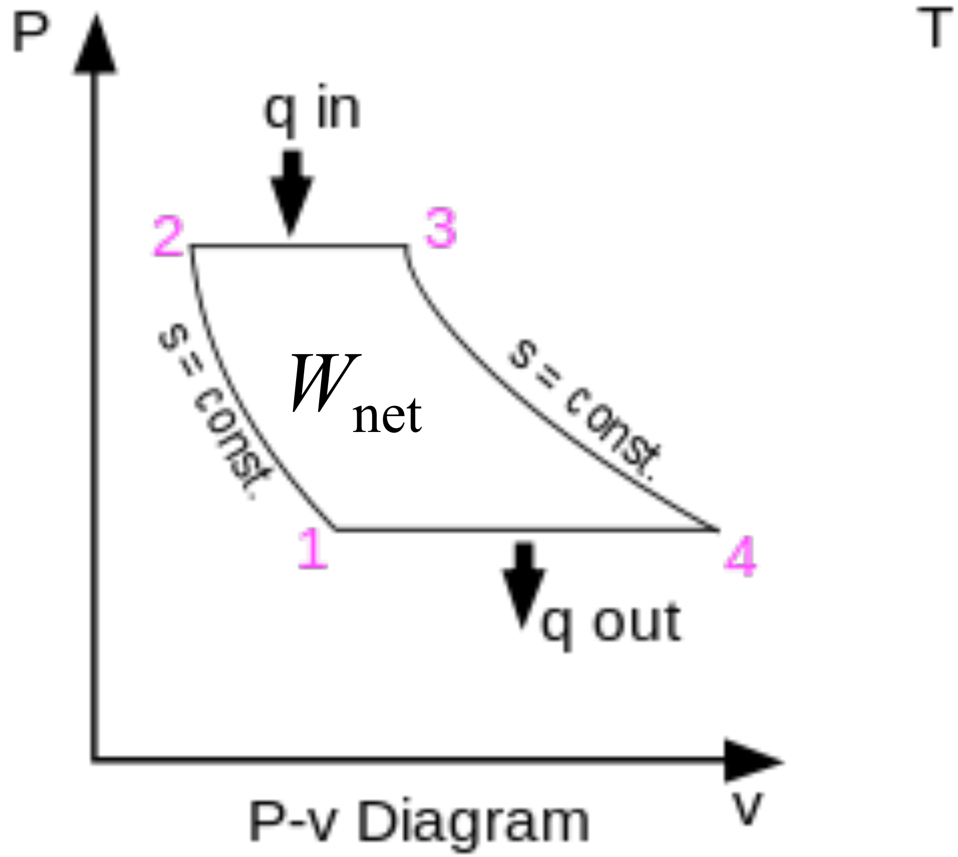


$$eff = \frac{W_{net}}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

image credit: Luc1992, Wikipedia

Brayton Cycle
example: gas turbine

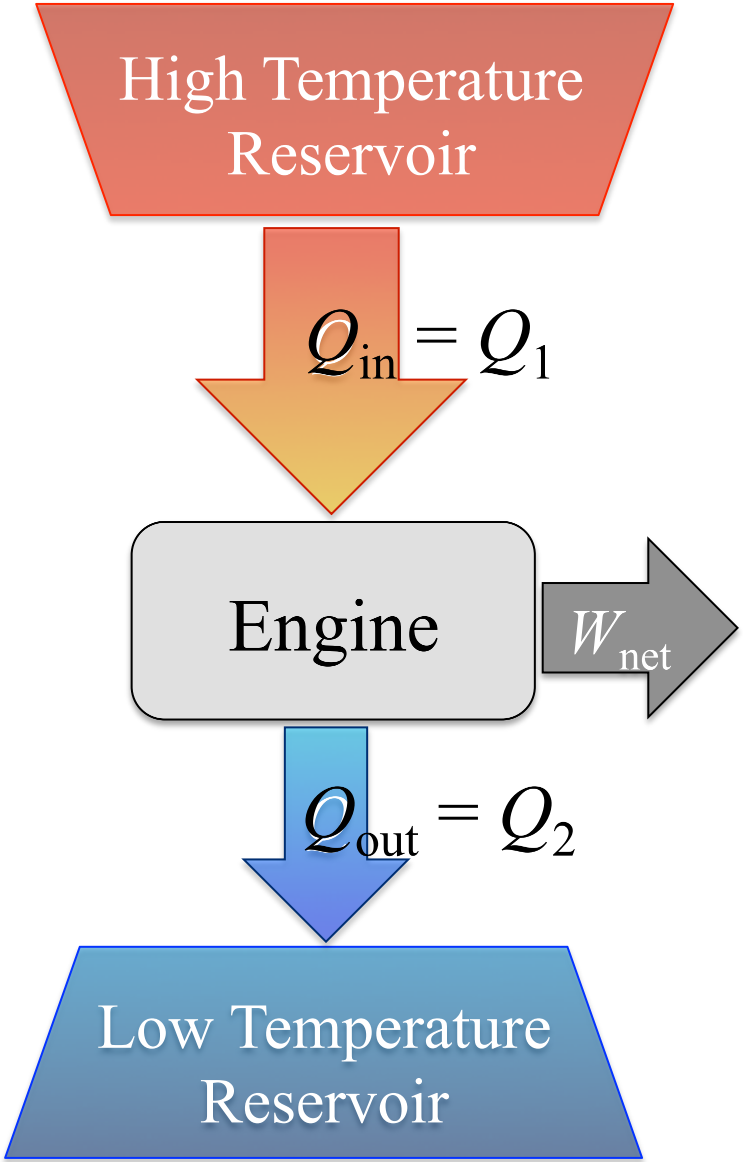


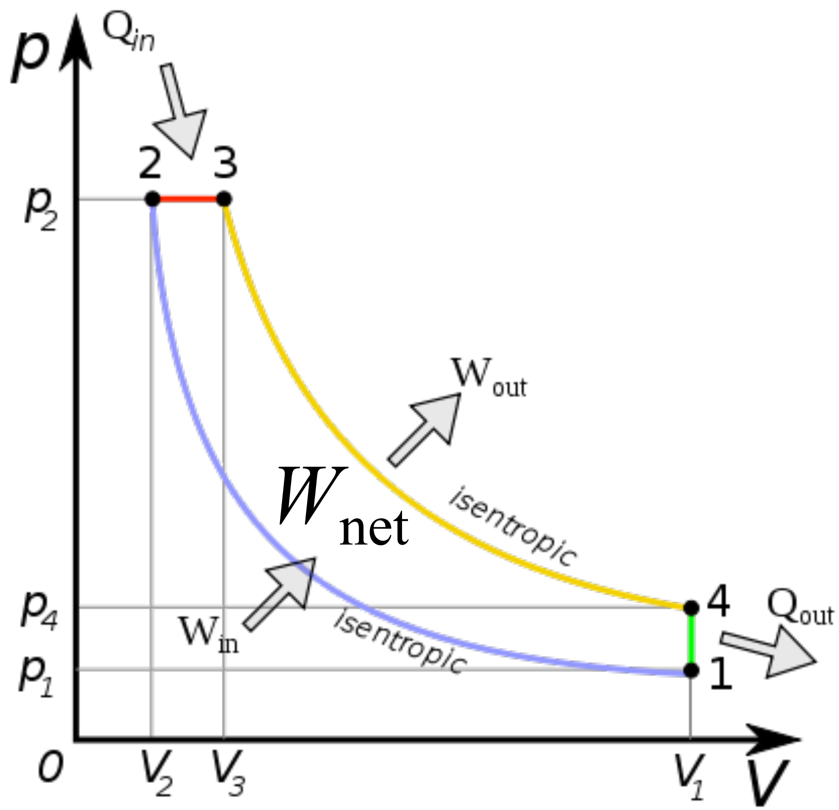


$$eff = \frac{W_{net}}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

image credit: en.User.Duk, Wikipedia

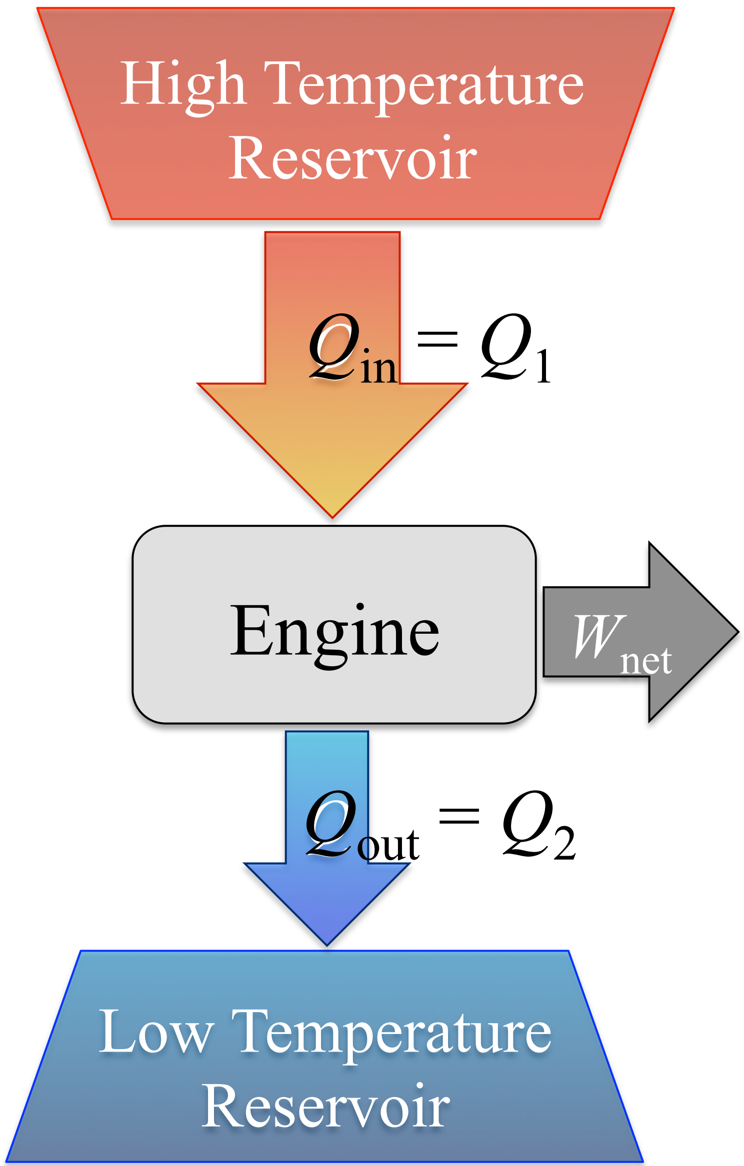
Diesel Cycle
example: truck engine

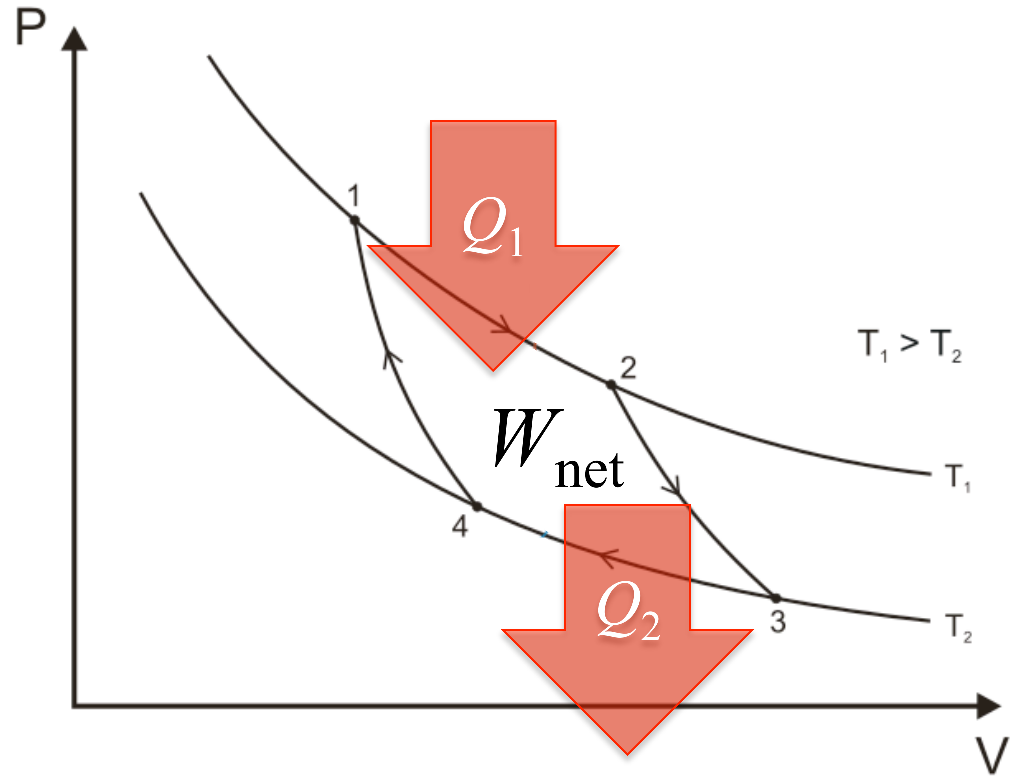




$$eff = \frac{W_{net}}{Q_1} = \frac{Q_1 - Q_2}{Q_1}$$

Carnot Cycle maximizes efficiency

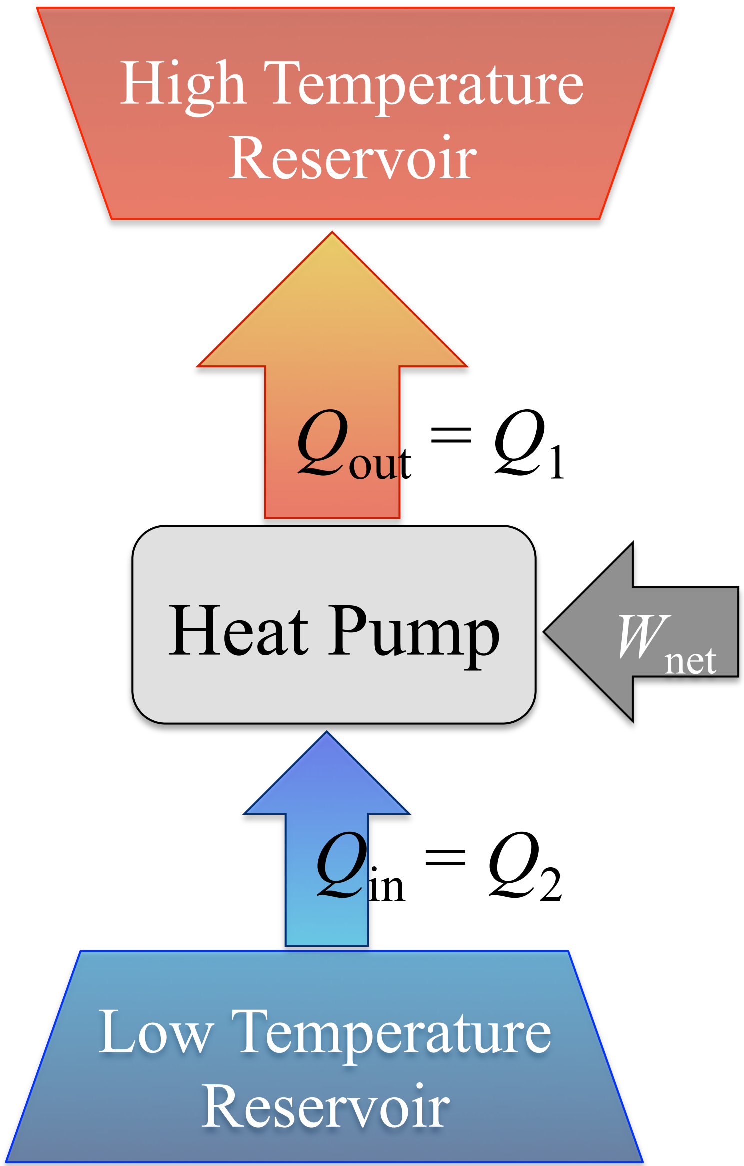




$$eff = \frac{W_{net}}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

image credit: Keta, Wikipedia

Reversed Carnot Cycle
air conditioner, refrigerator



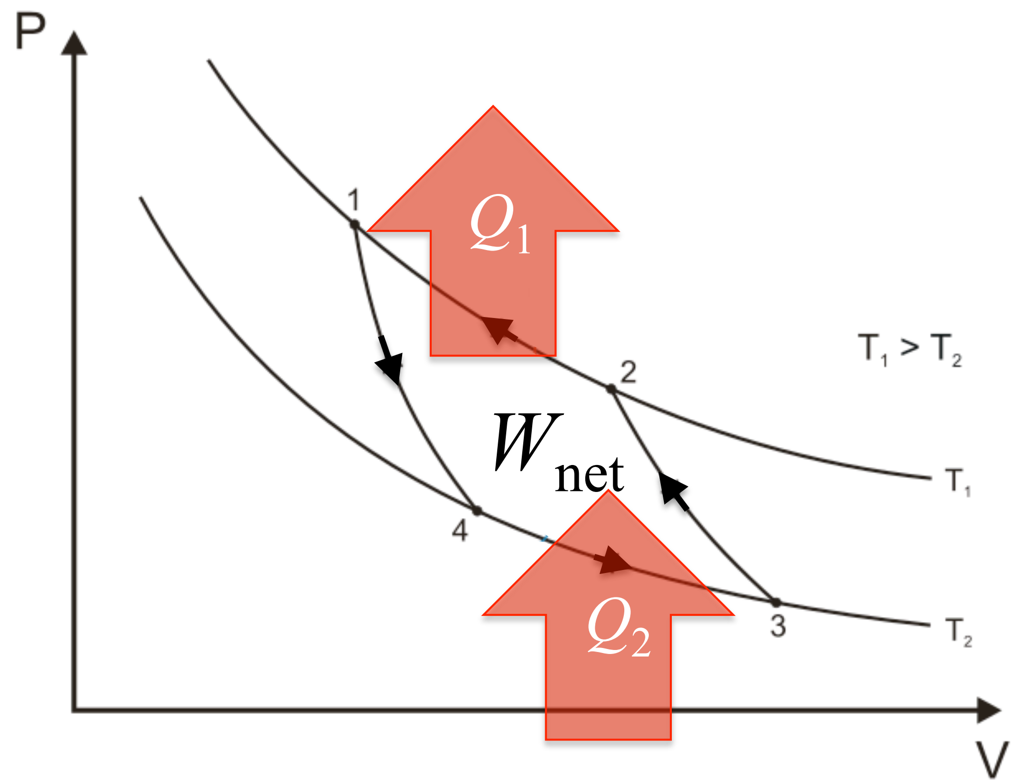


image credit: Keta, Wikipedia