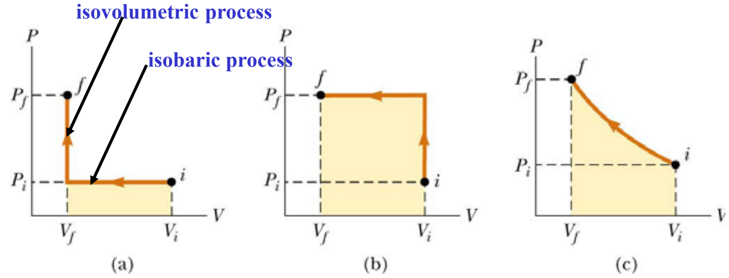
Chap. 15, Thermodynamics

Work in Thermodynamic Processes

Mechanical work done on a system is

$W = -P \Delta V$

For a gas, the work done can be determined from a PV diagram.



First Law of Thermodynamics

First Law of Thermodynamics

The internal energy of a system changes from an initial value U_i to a final value of U_f due to heat Q and work W:

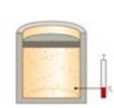
$\Delta U = U_f - U_i = Q + W$

The internal energy depends only on the state of a system, not on the method (path) by which the system arrives at a given state.

For an isolated system, for a cyclic process, or for an isothermal (constant temperature) process,

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

Work
Isothermal



Ideal Gas

monatomic molecules

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

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

molar specific heat at constant volume

$$C_v \equiv \frac{3}{2} R$$

$$\Delta U = nC_v\,\Delta T$$

Ideal Gas At Constant Pressure

isobaric

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

$$\Delta U = \frac{3}{2} nR\Delta T \qquad P\Delta V = nR\Delta T$$

$$Q = \frac{5}{3} nR\Delta T$$

molar specific heat at constant volume

$$Q = nC_p\,\Delta T$$

$$C_v \equiv \frac{3}{2} R$$

$$C_p = C_v + R$$

$$\gamma = \frac{C_p}{C_v}$$

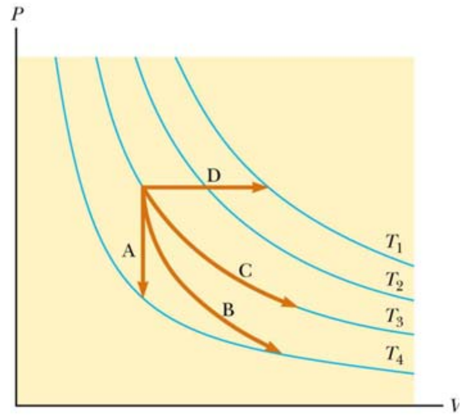
Adiabatic Process

An adiabatic process is one which involves no heat flow with the outside environment.

Q = 0

ΔU = W

$PV^{\gamma} = const.$



Adiabatic Process

Step #1: Isobaric

$$P, V, T\ (= PV/nR) \Rightarrow P, V+\Delta V, T+\Delta T_1$$

$$\Delta U_1 = nC_p\Delta T_1 - P\Delta V \qquad nC_v\Delta T_1 = nC_p\Delta T_1 - P\Delta V$$

$$P\Delta V = n(\gamma - 1)C_v\Delta T_1$$

Step 2: Lose the same Heat at Constant Volume

$$P, V+\Delta V, T+\Delta T_1 \Rightarrow P+\Delta P, V+\Delta V, T+\Delta T_1+\Delta T_2$$

$$\Delta U_2 = nC_v\Delta T_2 = -nC_p\Delta T_1$$

$$\Delta T = \Delta T_1 + \Delta T_2 = (1-\gamma)\Delta T_1$$

$$\Delta U = \Delta U_1 + \Delta U_2 = -P\Delta V$$

$$(P+\Delta P)(V+\Delta V) = nR(T+\Delta T_1+\Delta T_2)$$ ← **Gas Law**

$$V\Delta P + P\Delta V = nR(1-\gamma)\Delta T_1 = -\frac{R}{C_v}P\Delta V \qquad \gamma P\Delta V = -V\Delta P$$

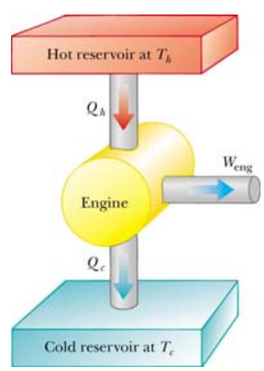
$$\frac{\gamma\Delta V}{V} = -\frac{\Delta P}{P} \rightarrow PV^{\gamma} = const.$$

Reversible and Irreversible Processes

A reversible process is one in which every state along some path is an equilibrium state. The system can be returned to its initial conditions along the same path.

A process that does not satisfy these requirements is irreversible.

Heat Engines

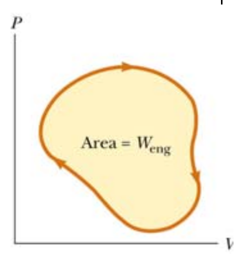


A heat engine is a device that converts internal energy to other useful forms of energy.

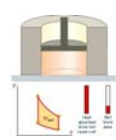
In a complete cycle

$W = |Q_h| - |Q_c|$

Efficiency $$e = \frac{W}{|Q_h|} = 1 - \frac{|Q_c|}{|Q_h|}$$



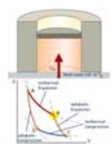
second law of thermodynamics: it is impossible to construct a heat engine that is 100% efficient.

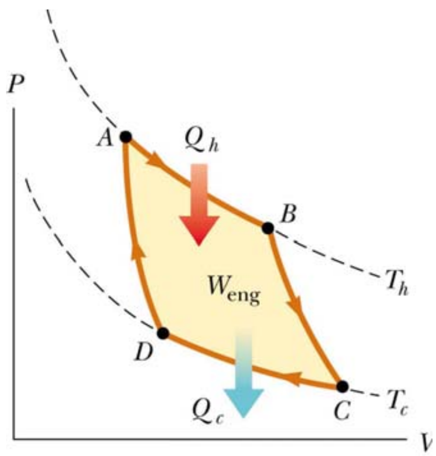


Carnot Engine

No real engine operating between two energy reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs.

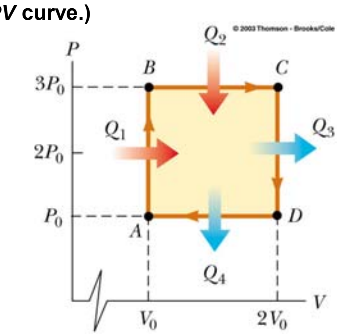
$$e = 1 - \frac{T_C}{T_H}$$





Example Problem

58. One mole of an ideal gas is taken through the cycle shown in Figure P12.58. At point *A*, the pressure, volume, and temperature are P_0 , V_0 , and T_0. In terms of *R* and T_0 , find
(a) the total energy entering the system by heat per cycle,
(b) the total energy leaving the system by heat per cycle,
(c) the efficiency of an engine operating in this cycle, and
(d) the efficiency of an engine operating in a Carnot cycle between the temperature extremes for this process. (*Hint:* Recall that work done on the gas is the negative of the area under a *PV* curve.)



Entropy And Disorder

The change in entropy for reversible processes is $\Delta S = Q/T$ with T expressed in Kelvin scale. Entropy is a measure of the "disorder" of a system. It is related to the number of possible ways the total energy of a system can be subdivided into its individual components.

$$S = k_B \ln W$$

Another version of the second law of thermodynamics

The total entropy of the universe does not change when a reversible process occurs ($\Delta S_{universe} = 0$) and increases when an irreversible process occurs ($\Delta S_{universe} > 0$).

Third Law of Thermodynamics

Third Law of Thermodynamics

It is not possible to lower the temperature of any system to absolute zero in a finite number of steps.

Wise Guy's Interpretation of Thermodynamics Laws

Zeroth Law: Everyone is treated the same way. No exceptions.
First Law: You can't win.
Second Law: You must lose.
Third Law: You can't get out of the game.