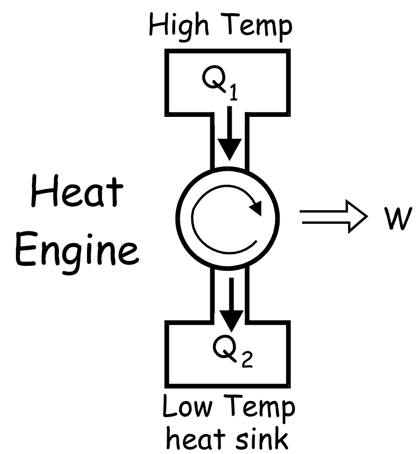
# AP Physics -- Heat Engines 4 LP

## *Thermodynamic cycle*.




***All heat engines produce waste heat***

Waste heat goes to heat sink

first law -- engine can never produce more work than the work that went into it.

heat engines can never produce more work than the thermal energy which was provided to them.

ratio of output work/energy to input work/energy is called efficiency

$$e = \frac{W_{out}}{W_{in}} \qquad = \frac{W}{Q_H}$$

$$e = \left| \frac{W}{Q_H} \right|$$

***Ideal Steam Engines:***

1824 -- Nicolas-Leonard-Sadi Carnot

"Sadi Carnot

***Ideal engine***

Efficiency -- depends on temperature difference between the heat source and the heat sink

Ideal engine ignored real world factors

***ideal heat engine -- no change in its internal energy.***

$$\Delta U = Q + W$$

for ideal engine, $\Delta U = 0$

$$Q = -W$$

$$W = Q_{hot} - Q_{Cold}$$

thermal forumla: $$e = \frac{W \text{ in one cycle}}{Q \text{ added in one cycle}}$$

$$e = \frac{W_{Out}}{Q_{In}}$$

$W = Q_h - Q_c$ so

$$e = \frac{Q_h - Q_{Ch}}{Q_h}$$

$Q$ proportional to $T$ so:

$$e = \frac{T_{Hot} - T_{Cold}}{T_{Hot}}$$

Ideal Efficiency:

$$e = \frac{T_h - T_C}{T_h}$$

***Must use T in Kelvins***

***absolute best efficiency that engine can have.***

ignores friction, heat loses, and other real world factors

real engines are less efficient

- A steam engine operates on a warm 28.0 °C day. The saturated steam operates at a temperature of 100.0 °C. What is the ideal efficiency for this engine?

$T_{hot}$ = 100.0 °C + 273 = 373 K

$T_{cool}$ = 28.0 °C + 273 = 301 K

$$e = \frac{T_h - T_C}{T_h} \qquad e = \frac{373\ K - 301\ K}{373\ K}$$

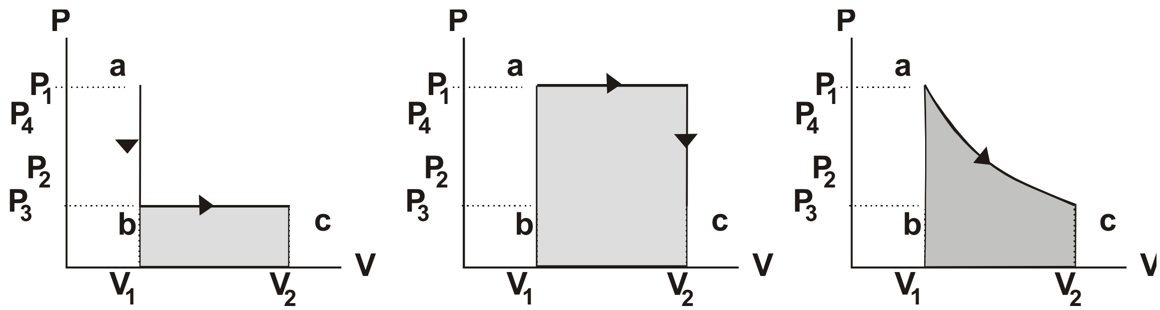
$e =$ 0.193

To increase efficiency

high temperature must be increased

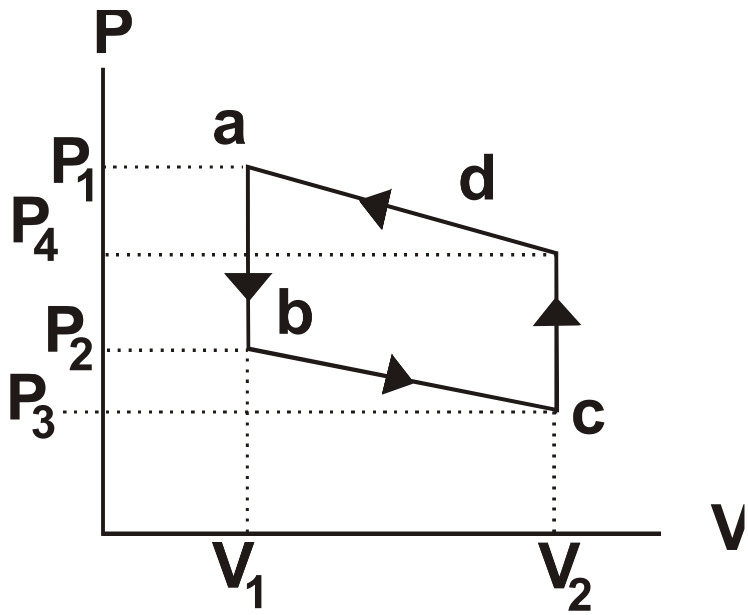
heat sink temperature decreased

superheating the steam




Work done on gas depends on path

## *PV diagram for Thermo Cycle:*




***ab -- no work*** ***PV =0***

***P decreases at Constant volume***

***bc -- work*** ***Area under curve***

$$W = P_3\left(V_2 - V_1\right) + \frac{1}{2}\left(V_2 - V_1\right)\left(P_2 - P_3\right)$$

***Expansion -- P decreases as V increasess***

***cd – no work, PV = 0***

***da -- work***

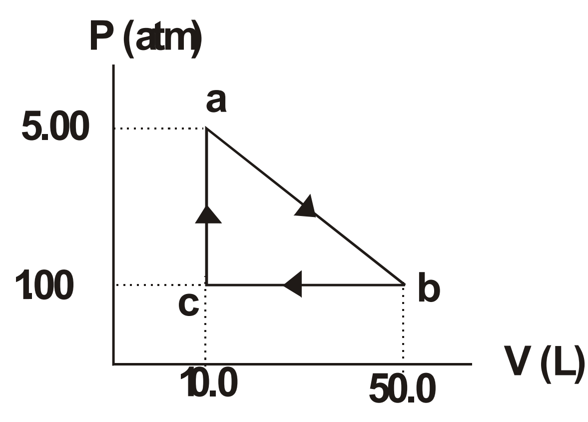
$$W = P_4\left(V_2 - V_1\right) + \frac{1}{2}\left(V_2 - V_1\right)\left(P_1 - P_4\right)$$

***Area inside the curve is the net work done.***

$$W_{net} = P_4\left(V_2 - V_1\right) + \frac{1}{2}\left(V_2 - V_1\right)\left(P_1 - P_4\right) - \left(P_3\left(V_2 - V_1\right) + \frac{1}{2}\left(V_2 - V_1\right)\left(P_2 - P_3\right)\right)$$

$$W_{net} = \left(V_2 - V_1\right)\left(P_4 - P_3 + \frac{1}{2}\left(P_1 - P_4 - P_2\right)\right)$$

- A substance undergoes a cyclic process shown in the graph. A work output occurs along path ab, a work input is required along path bc, and no work is involved in constant volume process ca. Heat transfer occurs during each process in the cycle. (a) what is the work output during process ab? (b) how much work input is required during process bc? (c) What is the net heat input during the cycle?




***(a)*** $W$ = area of rectangle + area of triangle

$$W = \left(1.013\, x\, 10^5\, Pa\right)\left(40\ \cancel{L}\right)\left(\frac{10^{-3} m^3}{1\ \cancel{L}}\right) + \frac{1}{2}(4)\left(1.013\, x\, 10^5\, Pa\right)\left(40\ \cancel{L}\right)\left(\frac{10^{-3} m^3}{1\ \cancel{L}}\right)$$

$$W = 122\, x\, 10^2\, J \quad = \quad \boxed{1.22\, x\, 10^4\, J}$$ Expansion process, pos work

(b) Negative work. $W$ = area of rectangle

$$W = -\left(1.013\, x\, 10^5\, Pa\right)\left(40\ \cancel{L}\right)\left(\frac{10^{-3} m^3}{1\ \cancel{L}}\right) \quad = -40.5\, x\, 10^2\, J \quad = \quad \boxed{-4.05\, x\, 10^3\, J}$$

(c)

$$Q_{net} = W_{net} \quad = W_{ab} + W_{bc} + W_{ca}$$

$$W_{net} = 1.22\, x\, 10^4\, J - 0.405\, x\, 10^4\, J + 0 \quad = \quad \boxed{8.15\, x\, 10^3\, J}$$

## ***Carnot Cycle** -- thermo cycle for ideal engine*

1: Isothermal expansion

cylinder on high temperature heat sink $T_{hot}$.

gas absorbs $Q_{in}$ and expands

moves piston upward

curve ***AB*** (on the PV diagram below).

2: Adiabatic expansion:

cylinder on insulated stand

gas expands adiabatically

pressure drops to lowest value

***BC*** on PV diagram.

3: Isothermal compression:

cylinder on low temperature heat sink

$Q_{out}$ flows from cylinder to heat sink

volume decreases

gas compressed isothermally

curve ***CD***.

4: Adiabatic compression:

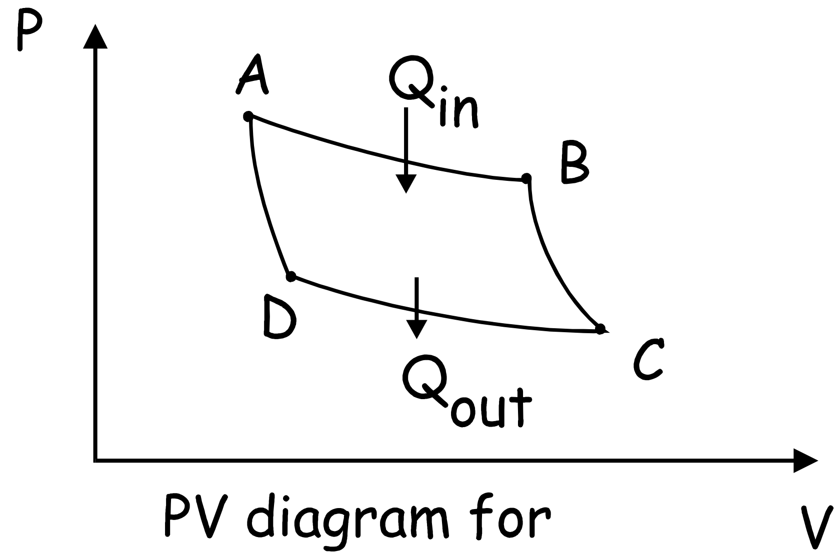
cylinder -- insulated stand

adiabatically compressed to original state along the curve ***AD***

ready to undergo another cycle.

***A*** to ***B*** -- isothermal expansion

V increases and P decreases




PV diagram for the Carnot cycle

***B*** to ***C*** -- adiabatic expansion

***C*** to ***D*** -- system is compressed isothermally

***D*** to ***A*** -- adiabatic compression

Sadi Carnot -- energy conserved, not all energy appears in forms that are useful.

Some energy -- converted to heat

exhausted to low temperature heat sink

Rudolf Julius Emanuel Clausius

any energy transformation - some energy would always be lost as heat universe --  energy constantly being converted to heat

amount of useful work in universe constantly decreasing

ratio of heat content of system to absolute temperature would always increase.

Entropy $$\Delta S = \frac{\Delta Q}{T}$$

entropy constantly increasing

Entropy measure of disorder

predicts that someday all energy in the universe will be converted to heat

none will be left over to do any work.

second law:

Heat will never flow from a cold object to a hot object, but only from a hot object to a cold object.

***Second law of thermodynamics ≡ It is impossible to build a heat engine that can produce work equivalent to the input heat.***

If $\Delta E$ is zero

$$W_{out} = Q_{in} - Q_{out}$$

$Q_{out}$ is exhaust heat

Always have exhaust heat

***work out can never equal the heat in.***

***Order and Disorder:***

first law -- energy can neither be created nor destroyed

can be transformed from one type of energy to another

organized energy -- unorganized state

Gasoline -- organized energy

Combustion products -- unorganized

Second law of thermodynamics ≡ A natural processes takes place in a direction that increases the disorder of the universe.

second law not limited to thermal systems

affects entire universe.

nonthermal things go from ordered state to disordered state

sandcastle on beach

would tide build sandcastle?

egg is highly ordered -- broken egg disordered

"Humpty Dumpty"

universe state of order $\rightarrow$ state of disorder

Infinite number of monkeys at infinite number of typewriters

grains of sand won't form Notre Dame Cathedral

cooked egg won't turn itself back into a raw egg

Disordered things can become ordered

Requires energy input

Deck of cards - order

Entropy -- formalized measure of disorder.

As disorder increases, entropy increases second law says that entropy tends to increase in all natural processes

$$\Delta S = \frac{\Delta Q}{T}$$

Where ***ΔS*** is the change in entropy, ***ΔQ*** is the input heat, and ***T*** is the temperature of the system in Kelvins.

The change in entropy in an isolated system can never decrease. It can only be zero or positive. $\Delta S \geq 0$.

We can define the second law in terms of entropy:

***Second law of thermodynamics ≡ A natural process always takes place in a direction that increases the entropy of the universe.***

Natural processes are irreversible and increase entropy.

Las Vegas built on the idea of entropy

gullible tourists do not understand the second law

Foolish people bet their money that entropy won't increase

***Perpetual Motion Machines:***

***Entropy and Evolution***

universe is going from ordered state to disordered state

for life to have evolved requires that life goes from disorder state to ordered state

Violates second law

fertilized ovum - being born - growing to adulthood also seems to violate second law

Disorganized CCHS student takes physics – becomes organized

second law has to do with natural random events and actions

Probabilities rule

Throw cards & pick up -- they could be in order

You could pick winning lotto number

Just unlikey

Life does not violate second law

Takes energy to organize life

Done at expense of environment, it becomes more disordered.

"pollution".

organism dies becomes disordered

decay

Second law of thermodynamics powerful

we are playing a game -- life

can never get more out of life than we put in

first law

best that we can do -- break even

second law -- you can't even win your money back

In every transaction, you will lose some of your energy to disorder.

you can't even quit the game

It's the only game in town

Actually, you can quit the game, but when you do this, you have ***really quit the game***.

So here's the beastly message:

***You can't win.***

***You can't break even.***

***You can't even quit the game.***

***You can only lose.***