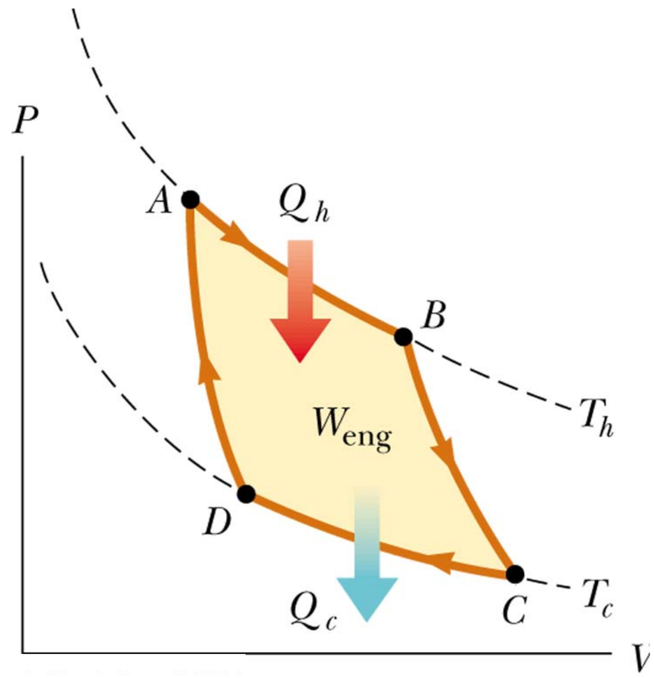
“Another way of stating the Second Law then is: the universe is constantly getting more disorderly! Viewed that way, we can see the Second Law all about us. We have to work hard to straighten a room, but left to itself, it becomes a mess again very quickly and very easily .... How difficult to maintain houses, and machinery, and our own bodies in perfect working order; how easy to let them deteriorate. In fact, all we have to do is nothing, and everything deteriorates, collapses, breaks down, wears out, all by, itself . . . and that is what the Second Law is all about." – Isaac Asimov

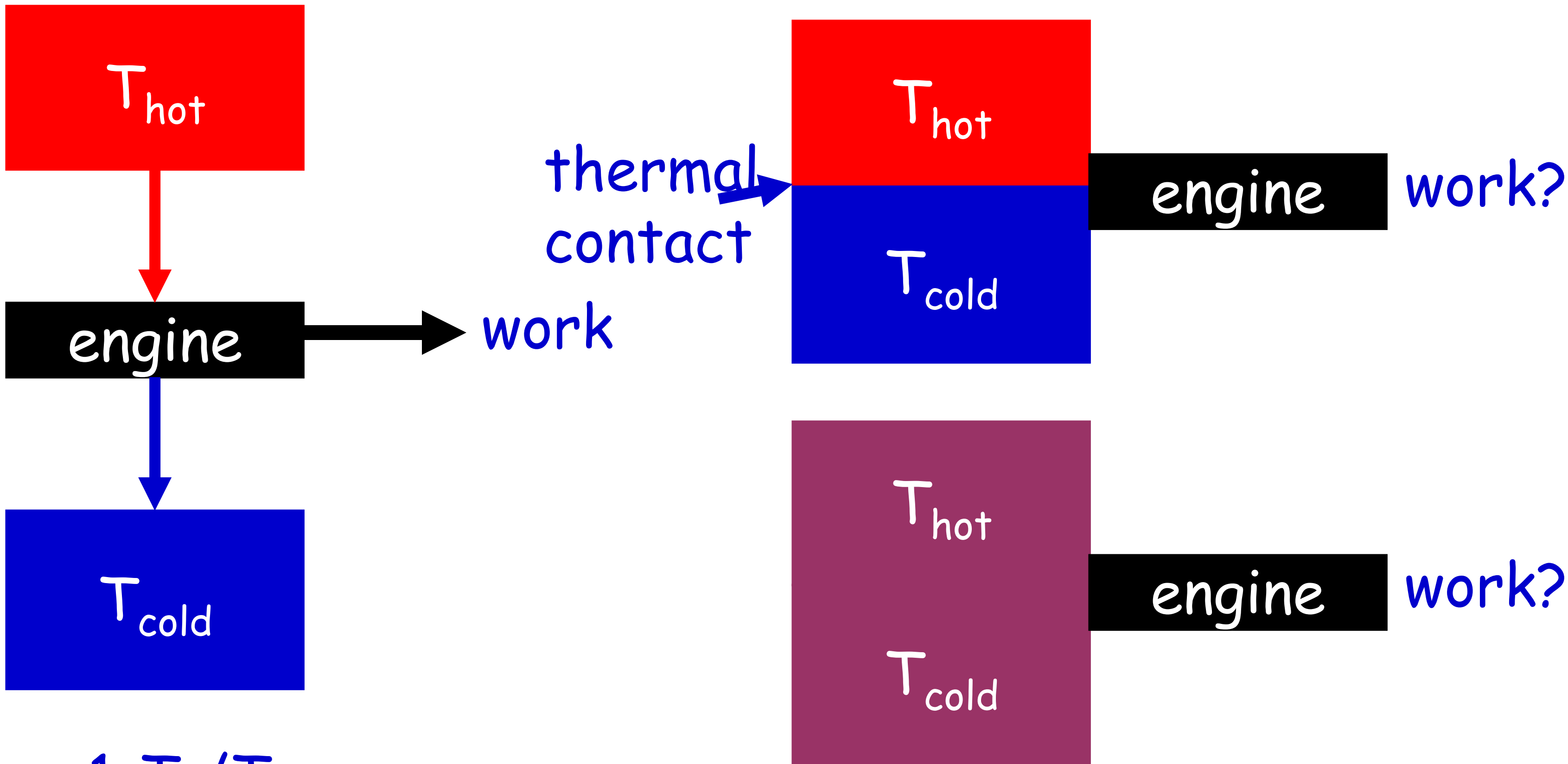
Carnot engine



efficiency=1-T_{hot}/T_{cold}

The Carnot engine is the most efficient way to operate an engine based on hot/cold reservoirs because the process is **reversible.**

Irreversible process



$e=1-T_c/T_h$

$e=1-T_c/T_h=0$

The transport of heat by conductance is irreversible and the engine ceases to work.

The (loss of) ability to do work: entropy

entropy: $\Delta S = Q_R/T$ R refers to a reversible process
The equation ONLY holds for
a reversible process.

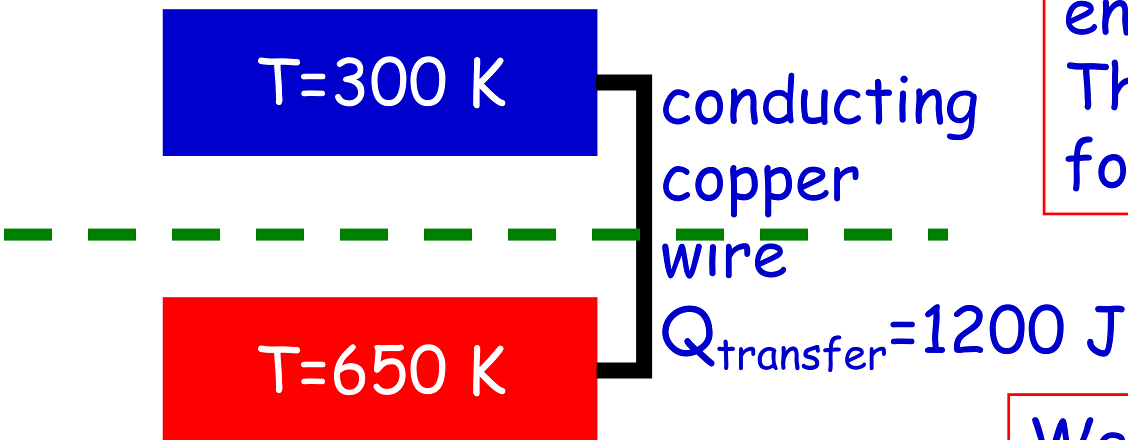
example: Carnot engine:
Hot reservoir: $\Delta S_{hot} = -Q_{hot}/T_{hot}$ (entropy is decreased)
Cold reservoir: $\Delta S_{cold} = Q_{cold}/T_{cold}$

We saw: efficiency for a general engine: $e = 1 - Q_{cold}/Q_{hot}$
efficiency for a Carnot engine: $e = 1 - T_{cold}/T_{hot}$
So for a Carnot engine: $T_{cold}/T_{hot} = Q_{cold}/Q_{hot}$
and thus: $Q_{hot}/T_{hot} = Q_{cold}/T_{hot}$
Total change in entropy: $\Delta S_{hot} + \Delta S_{cold} = 0$

For a Carnot engine, there is no change in entropy

The loss of ability to do work: entropy

Now, consider the following irreversible case:



entropy: $\Delta S = Q_R/T$
This equation only holds for reversible processes.

We cut the irreversible process up into 2 reversible processes

$$\Delta S_{hot}+\Delta S_{cold}=Q_{hot}/T_{hot}+Q_{cold}/T_{cold}=-1200/650+1200/300=$$
$$=+1.6\ J/K$$

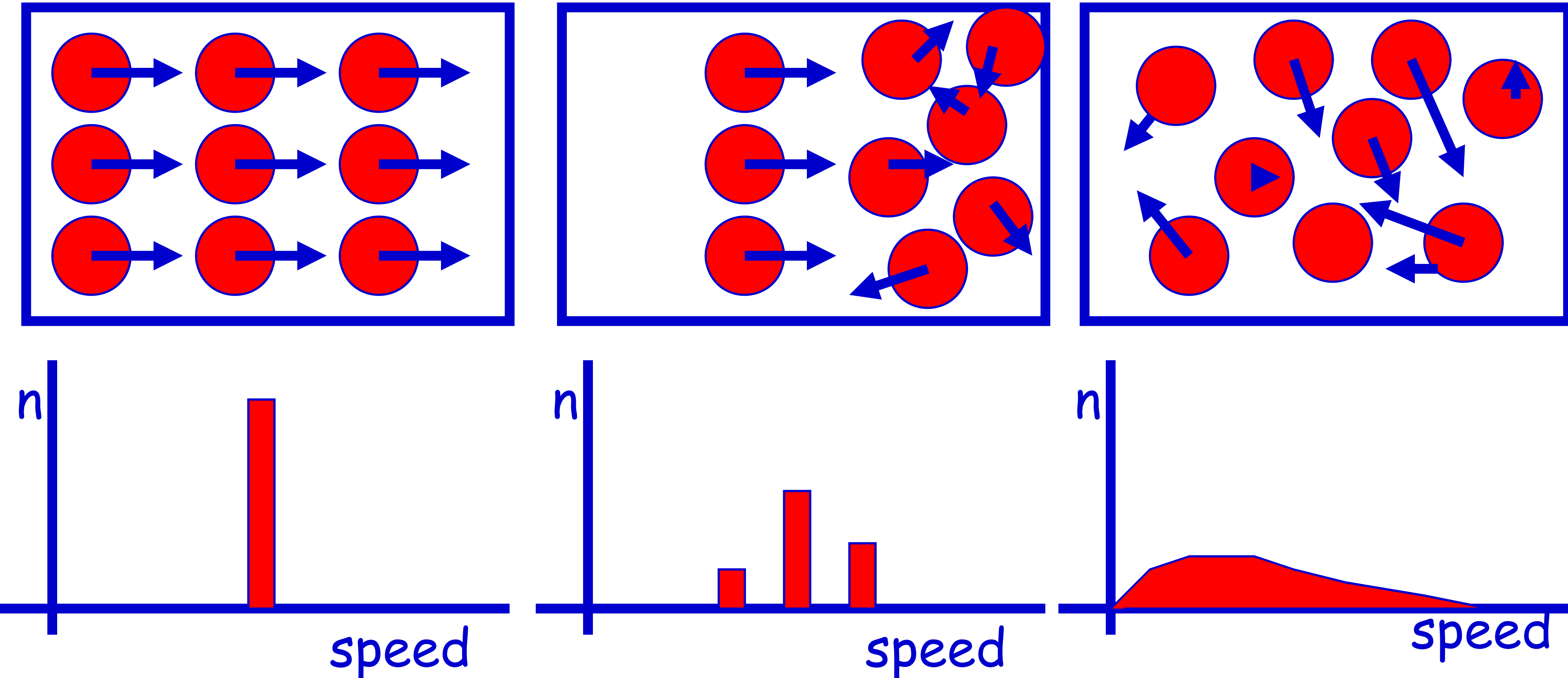
The entropy has increased!

2nd law of thermodynamics rephrased

2nd law: It is impossible to construct an engine that, operating in a cycle produces no other effect than the absorption of energy from a reservoir and the performance of an equal amount of work: we cannot get 100% efficiency

2nd law rephrased: The total entropy of the universe increases when an irreversible process occurs.

Entropy in terms of disorder



In an isolated system, disorder tends to grow and entropy is a measure of that disorder: the larger the disorder, the higher the entropy.

The laws of thermodynamics & symmetry

1st law: energy is conserved. This law indicates symmetry; we can go any direction (for example in time) as long as we conserve energy.

2nd law: entropy increases. This law gives asymmetry; we can not go against the flow of entropy (time can only go in one way).

Examples for this chapter

One mole of an ideal gas initially at 0 ^{0}C undergoes an expansion at constant pressure of one atmosphere to four times its original volume.

a) What is the new temperature?
b) What is the work done on the gas?

a) PV/T=constant so if V x4 then T x4 273K*4=1092 K
b) $W=-P\Delta V$

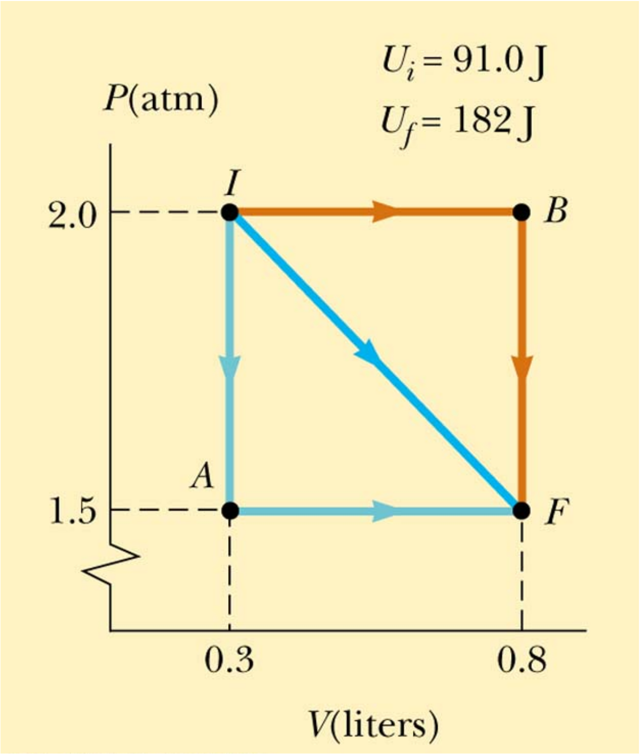
use PV=nRT

before expansion: PV=1*8.31*273=2269 J

after expansion: PV=1*8.31*1092=9075 J

$W=-P\Delta V=-\Delta(PV)=-[(PV)_f-(PV)_i]=-(13612-3403)=-6805$ J

-6805 J of work is done on the gas.



Example

A gas goes from initial state I to final state F, given the parameters in the figure. What is the work done on the gas and the net energy transfer by heat to the gas for:

a) path IBF b) path IF c) path IAF

(U_i=91 J U_f=182 J)

a) work done: area under graph:

$W=-(0.8-0.3)10^{-3}*2.0*10^5=-100$ J

$\Delta U=W+Q$ 91=-100+Q so Q=191 J

b) $W=-[(0.8-0.3)10^{-3}*1.5*10^5 + \frac{1}{2}(0.8-0.3)10^{-3}*0.5*10^5]=-87.5$ J

$\Delta U=W+Q$ 91=-87.5+Q so Q=178.5 J

c) $W=-[(0.8-0.3)10^{-3}*1.5*10^5]=-75$ J

$\Delta U=W+Q$ 91=-75+Q so Q=166 J

Example

The efficiency of a Carnot engine is 30%. The engine absorbs 800 J of energy per cycle by heat from a hot reservoir at 500 K. Determine a) the energy expelled per cycle and b) the temperature of the cold reservoir. c) How much work does the engine do per cycle?

a) Generally for an engine: efficiency: $1-|Q_{cold}|/|Q_{hot}|$
$0.3=1-|Q_{cold}|/800$, so $|Q_{cold}|=-(0.3-1)*800=560$ J

b) for a Carnot engine: efficiency: $1-T_{cold}/T_{hot}$
$0.3=1-T_{cold}/500$, so $T_{cold}=-(0.3-1)*500=350$ K

c) $W=|Q_{hot}|-|Q_{cold}|=800-560=240$ J

A new powerplant

A new powerplant is designed that makes use of the temperature difference between sea water at 0 m (20^0) and at 1 km depth (5^0). A) what would be the maximum efficiency of such a plant? B) If the powerplant produces 75 MW, how much energy is absorbed per hour? C) Is this a good idea?

a) maximum efficiency=Carnot efficiency=$1-T_{cold}/T_{hot}$= 1-278/293=0.051 efficiency=5.1%
b) $P=75*10^6$ J/s $W=P*t=75*10^6*3600=2.7\times10^{11}$ J
   efficiency=$1-|Q_{cold}|/|Q_{hot}|=(|Q_{hot}|-|Q_{cold}|)/|Q_{hot}|= W/|Q_{hot}|$ so $|Q_{hot}|=W/\text{efficiency}=5.3\times10^{12}$ J
c) Yes! Very Cheap!! but... $|Q_{cold}|= |Q_{hot}|-W=5.0\times10^{12}$ J every hour 5E+12 J of waste heat is produced: $Q=cm\Delta T$ 5E+12=4186*m*1 m=1E+9 kg of water is heated by 1 ^{0}C.

Example

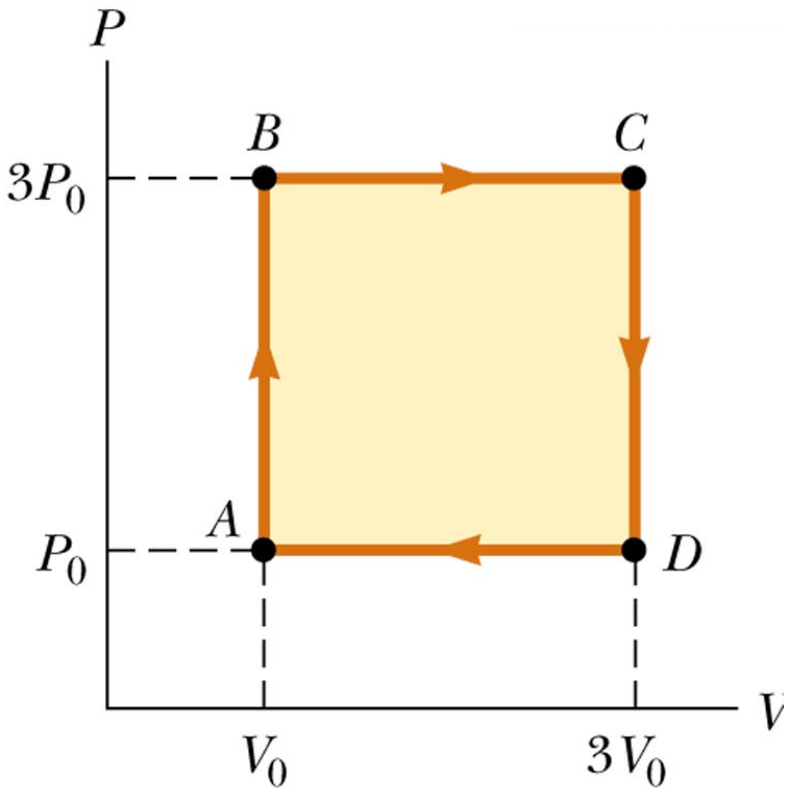
What is the change in entropy of 1.00 kg of liquid water at 100 ^0C as it changes to steam at 100 ^0C?

$L_{vaporization}$=2.26E+6 J/kg

$Q=L_{vaporization}m$=2.26E+6 J/kg * 1 kg= 2.26E+6 J

$\Delta S=Q/T$=2.26E+6/(373)=6059 J/K

A cycle



Consider the cycle in the figure.

A) what is the net work done in one cycle?

B) What is the net energy added to the system per cyle?

A) Work: area enclosed in the cycle:
$W=-(2V_0 2P_0)+(2V_0 P_0)=-2V_0 P_0$ (Negative work is done on the gas, positive work is done by the gas)

b) Cycle: $\Delta U=0$ so $Q=-W$ $Q=2V_0 P_0$ of heat is added to the system.

adiabatic process

For an adiabatic process, which of the following is true?

A) $\Delta S<0$
B) $\Delta S=0$
C) $\Delta S>0$
D) none of the above

Adiabatic: $Q=0$ so $\Delta S=Q/T=0$