# The 2nd Law of Thermodynamics

fusion $2\,{}^{1}_{1}H + 2\,{}^{1}_{0}n \rightarrow 1\,{}^{4}_{2}He$

$\Delta mc^2 = E$

The Second Law of Thermodynamics

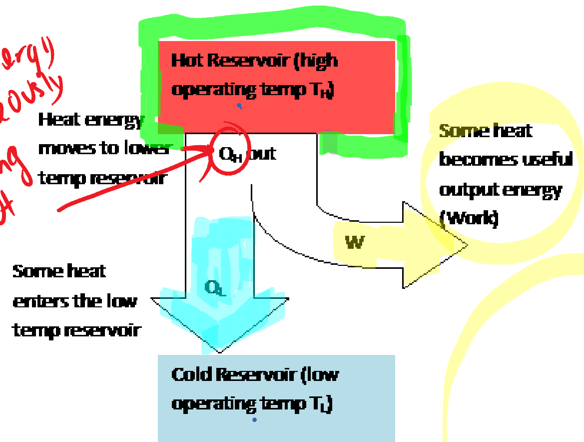
Net

Heat will flow spontaneously from a hot object to a cooler one, it will not flow from a cooler object to a hotter one. (Clausius) This statement is the natural order as energy will flow to reach the lowest possible state. An example of this is rain; water vapour (high kinetic energy)at height in the atmosphere (high potential energy) will first condense to liquid (lower kinetic energy) then fall to earth (lower potential energy). The reverse will not happen without being driven by the addition of heat energy Q. [See also example on p. 451]

The 2nd law of thermodynamics is what makes engines possible. The flow of heat must go from high temperature (recall U $\alpha$ T) to lower T. The fundamental idea of an engine is that during the flow of heat some of the energy can be used to do useful work through the mechanical equivalent of heat. An engine reservoir (storage) diagram shows how this concept works:

Engine uses thermal energy input → mech energy output

Heat energy spontaneously flowing out




$Q_L + W = Q_H$

$W = Q_H - Q_L$

useful output

$\frac{\text{useful out}}{\text{total input}} = \text{eff}$

$\frac{W}{Q_H} = \text{eff}$

$\frac{Q_H - Q_L}{Q_H} = \text{eff} = 1 - \frac{Q_L}{Q_H}$

$= \frac{1_H - Q_L}{Q_H} = \text{eff}$

$1 - \frac{Q_L}{Q_H} = \text{Eff}$

$W +$

$W$

CARNOT Efficiency

idealized max eff.

$\text{eff} = 1 - \frac{T_L}{T_H}$

Low operating temp (exhaust)

high operating temp (engine temp)

Real world

$Q_L = U_L \propto T_L$

$Q_H = U_H \propto T_H$

At what exhaust temp must gas be expelled in order to achieve 100% efficiency (1.000)? 0 K ← not possible

At what operating temp must gas react in an engine to achieve eff = 1? $\infty$

No engine can ever be 100% efficient

~~At the~~ Why are Westinghouse & GE experimenting with liquid Na as coolant in nuclear reactors?

liquid Na as coolant in nuclear reactors?

highly conductive ← rapid heat transfer

low vapour pressure

423

An ideal engine exhaust gas at 150 °C, if the combustion
Occurs at 500 °C determine the maximum possible efficiency
Of the engine

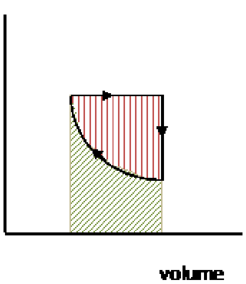
773

$$eff = 1 - \frac{423}{773} = .45 = 45\%$$

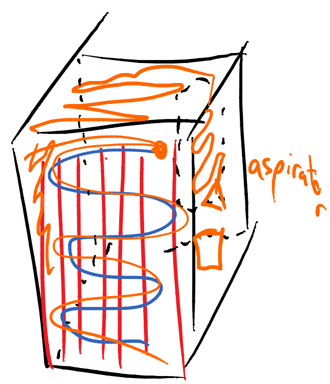
The engine obeys the law of conservation of energy in that:
heat energy flowing out of the hot reservoir = the energy entering the cold reservoir + the useful output

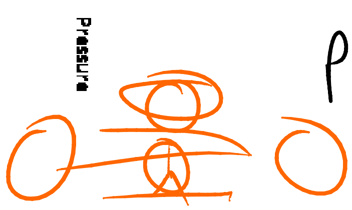
* $(Q_H) = (Q_L) + (W)$

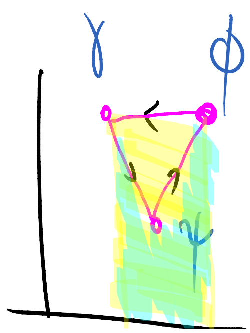
This engine cannot work if $T_H = T_L$ WHY?




**In the PV diagram of an engine cycle the engine must start and stop in the same place. The work done in expansion by the gas is shown as a rectangle. The work done later on the gas during compression is shown in green and is less than the rectangle. The difference in areas is the work available for output. Note the cycle must have net work out therefore it must go in a clockwise cycle so (Work by) > (Work on) the system.**



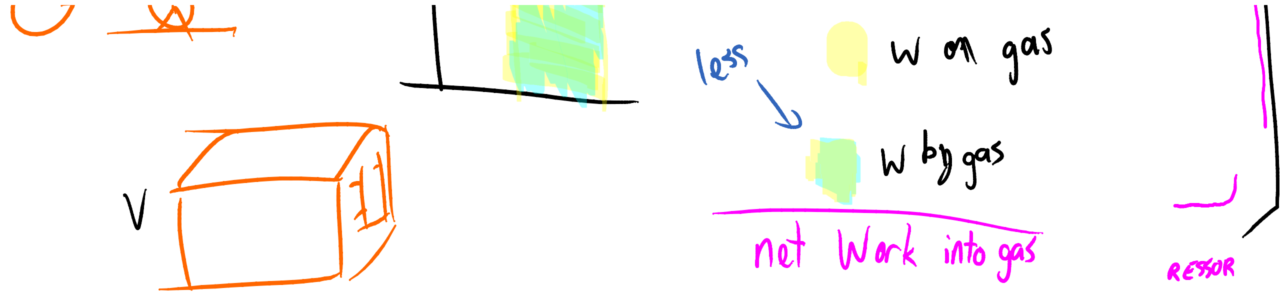




COOLING CYCLE

more

less

W on gas




The efficiency of the engine can be found using eqn. * in terms of the heat energy in the reservoirs,
recall efficiency is the ratio of useful output energy / total input energy so:

Eff = Work / $Q_H$    solving * for W gives: $W = Q_H - Q_L$ and

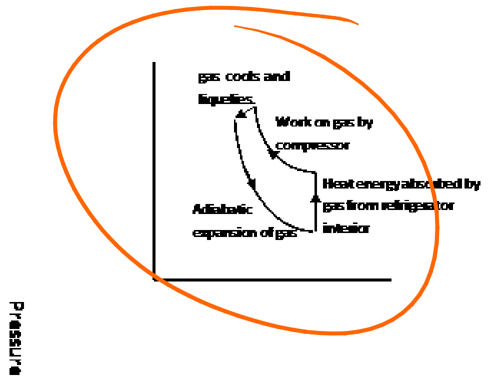
Eff. = $(Q_H - Q_L)/ Q_H$ or

Eff. = $1 - Q_L / Q_H$
The Carnot Engine is the most efficient possible engine. In a Carnot Engine the heat energies( $Q_H$& $Q_L$ )
are directly proportioned to the reservoir temperatures ($T_H$ & $T_L$). This gives the CARNOT EFFICIENCY to
be Eff. = $1 - T_L / T_H$ .

Can a Carnot Engine be 100% efficient? (Hint: what must be the value of $T_L$ for 100% efficiency?)

The Kelvin/Planck statement is an expression of the 2nd law of thermodynamics which states that
NO DEVICE IS POSSIBLE WHOSE SOLE PURPOSE IS TO TRANSFORM
HEAT ENERGY ENTIRELY INTO WORK.
Explain why this is with reference to Carnot efficiency and the low temp reservoir.

A refrigerator or heat pump is essentially the reverse of an engine in that they seek to remove heat from a low temperature environment and exhaust it to higher temp. As this is a violation of the 2nd law there must be work done on the system to allows this. This work is usually done by a compressor on a gas forcing it into a smaller volume (W+). This increases the internal energy ( and temp) of the gas. The gas moves through a series of metal pipes and sheets to conduct heat from the gas cooling it below condensation point. This causes a decrease in volume and pressure and therefore lower internal energy (W neg.). Heat energy is moved into the environment around the refrigerator (Q neg.) and the internal energy (and temp) of the gas decreases. The liquid will then move through a valve which prevents backward flow and is allowed to expand (W neg.) adiabatically (Q = 0) which further lowers it temperature. The gas is circulated through cooling coils inside the fridge and because of its lower temperature heat from the inside of the fridge moves into the gas (Q+). The gas then returns to the compressor. Through the cycle the gas has no net change in its internal energy but the work done by the compressor is used compress the gas allowing it to do work later. The transfer of the energy from the gas to the environment, and the subsequent expansion of the gas brings it to a lower energy state than the inside of the fridge which then provides the heat to bring the gas back to its initial energy level.




**The cycle shown is hypothetical, however all fridge cycles must move counter clockwise on a PV diagram. The area bounded by the path shows the difference between work done on the gas and by the gas. Note that (work on) > (work by) the gas in a refrigerator.**

volume

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