Heat, Thermal Energy, Temperature

- Thermal Energy: total amount of kinetic and spring energy in the random motion of molecules in an object
- Temperature: a measure of average thermal energy per particle

same temperature
more thermal energy

$E_{th} = \underbrace{\left(\frac{f}{2}k\right)}_{}NT$ in many cases

depends on type of molecule & other things

Heat: flow of energy from high T to low T spontaneously

Thermal energy can change without heat.

e.g. rubbing hands together

1) pot on stovetop: heat
2) a wire attached to a battery gets warm: work (no hotter source)
3) cup of water in a microwave: work
chicken in a microwave: combination

A) heat
B) work

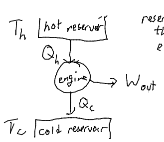
$\Delta E_{th} = Q + W$
1st Law of Thermodynamics

$W, Q > 0$ if flow into system
$W, Q < 0$ if flow out

Heat can be converted into work, to a certain extent

e.g. hot air balloon rises
engine burns gasoline, drives car

A heat engine is a cyclic process that changes thermal energy into useful energy (heat into work)

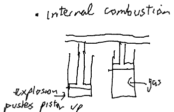


reservoir: big enough that its T stays constant even when heat flows out/in

Some heat must be released as "exhaust"

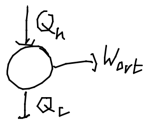
e.g. steam engine (coal plants, natural gas, nuclear)
hot reservoir: steam
cold reservoir: surrounding air, river,

- internal combustion engine (car)



hot res.: burning gas
cold res.: air

Cyclic process: $\Delta E_{th} = 0$
(same thing over & over again)



$$\underbrace{Q_h}_{\text{energy in}} = \underbrace{W_{out} + Q_c}_{\text{energy out}}$$

$$W_{out} = Q_h - Q_c$$

$$e = \frac{\text{what you get}}{\text{what you pay}} = \frac{W_{out}}{Q_h} = \frac{Q_h - Q_c}{Q_h} =$$

$$= 1 - \frac{Q_c}{Q_h}$$

$e = 1$ if $Q_c = 0$: impossible!

2nd law of thermodynamics says, in cyclic process,

$$\frac{Q_c}{Q_h} > \frac{T_c}{T_h}$$ in Kelvin!

$$1 - \frac{Q_c}{Q_h} < 1 - \frac{T_c}{T_h}$$

$$\boxed{e < 1 - \frac{T_c}{T_h}}$$

eg! gasoline engine

$T_h = 500K$ (232°C)

$T_c = 300K$ (warm summer day)

$$e < 1 - \frac{300k}{500k} = 0.4 = 40\%$$

improve limit with hotter hot reservoir
or a colder cold reservoir

$$1 - \frac{T_c}{T_h} = \frac{T_h - T_c}{T_h} \leftarrow \Delta T$$

Diesel engine: $T_h = 1000K$

$$e < 1 - \frac{300k}{1000k} = 70\%$$