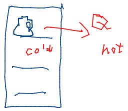
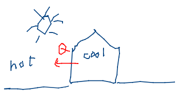
Sometimes you want heat to flow from cold to hot

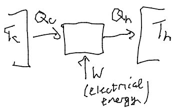
e.g. refrigerator



e.g. heat pump

air conditioner





coefficient of performance

$$C.O.P. = \frac{\text{what you want}}{\text{what you pay}}$$

for cooling,

$$C.O.P. = \frac{Q_c}{W}$$

for heating,

$$C.O.P. = \frac{Q_h}{W}$$

ideally we want W to be tiny & C.O.P. to be huge

$$\cancel{\frac{Q_c}{Q_h} > \frac{T_c}{T_h}}$$

due to 2nd Law of Thermodynamics

cooling

$$C.O.P. = \frac{Q_c}{W}$$

$W + Q_c = Q_h$

$W = Q_h - Q_c$

$$= \frac{Q_c}{Q_h - Q_c} = \left(\frac{Q_h - Q_c}{Q_c}\right)^{-1}$$

$$= \left(\frac{Q_h}{Q_c} - 1\right)^{-1}$$

$$\frac{Q_c}{Q_h} > \frac{T_c}{T_h}$$

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

$$\left(\frac{Q_h}{Q_c} - 1\right)^{-1} > \left(\frac{T_h}{T_c} - 1\right)^{-1}$$

and then a miracle happens

cooling

$$C.O.P. < \frac{T_c}{T_h - T_c}$$

e.g. refrigerator

$T_c = 5°C = 278K$ $T_h = 20°C = 293K$

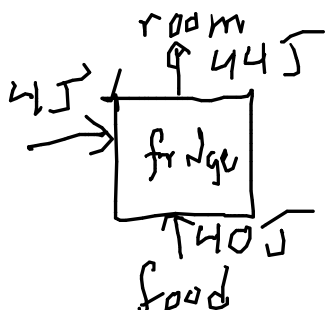
$$cop < \frac{278}{293 - 278} = 18.5$$

$$\rightarrow \frac{Q_c}{W} < 18.5 \rightarrow W > \frac{Q_c}{18.5}$$

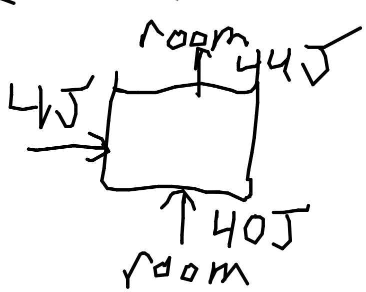
If COP = 10

$$\frac{Q_c}{W} = 10 \rightarrow W = \frac{Q_c}{10}$$

to remove 40 J of heat from fridge, I do 4 J of work



use fridge as A/C? –



room gets warmer – more heat out than in

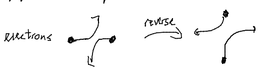
Irreversible Process

only happens in one direction in time – reverse the video & it looks unnatural

e.g. break a cup, spill paper-clips

heat flow hot $\xrightarrow{Q}$ cold

At (subatomic) microscopic level, processes are reversible



At macroscopic level, objects tend towards equilibrium

e.g. ~~heat~~ thermal energy spreads out in a room

equilibrium is the most probable state system can be in

What's the chance the particles line up?

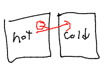
Very low!

There are a lot more ways to make a mess

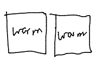
The probability that a system can end up in a state is characterized by its <u>entropy</u>

disordered systems have higher entropy than ordered systems, and are more probable

Equilibrium: state of maximum entropy



fairly organized



less organized
more entropy

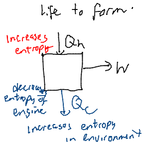
2nd Law of Thermodynamics:

entropy of an isolated system never decreases.

Entropy can decrease in one system if it increases somewhere else.

e.g. when I clean my office, I convert food energy into thermal energy, increasing my entropy

e.g. Sun's entropy is increasing as it ~~burn~~ "burns" which allows life to form.



you have to get rid of excess entropy or engine won't be cyclic – it stops

~~heat~~

Energy "conservation" = entropy minimization

Universe is gaining entropy all the time & approaching equilibrium

"heat death of the Universe"

unless - -

another Big Bang?