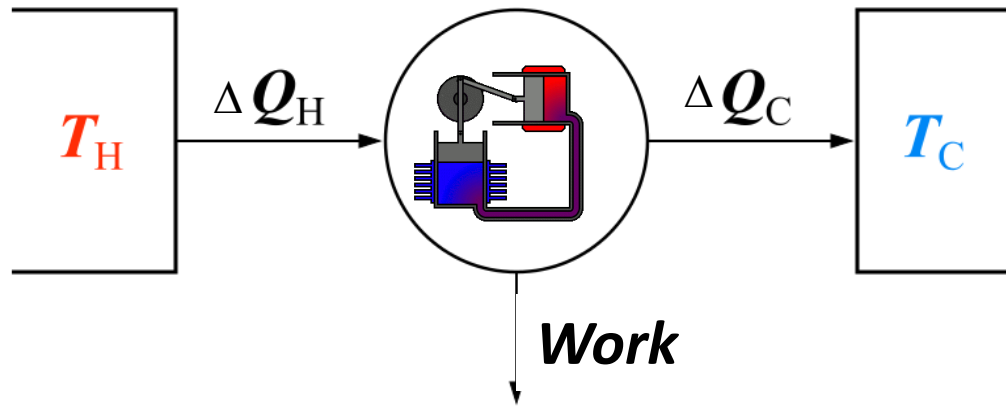


Efficiency of Heat Engine



Heat Engine has to take heat Q_H from “heater”, and return heat Q_C to a “cooler”.

$$Work = \Delta Q_H - \Delta Q_C$$

Efficiency of a heat engine is $\frac{Work}{Q_H} = \frac{\Delta Q_H - \Delta Q_C}{\Delta Q_H} = 1 - \frac{\Delta Q_C}{\Delta Q_H}$

Perpetual motion

- First kind: Motion with no energy source. Impossible because of energy conservation (*The First Law of Thermodynamics*).



- Second kind: converting the heat of an environment to work.

NOPE!

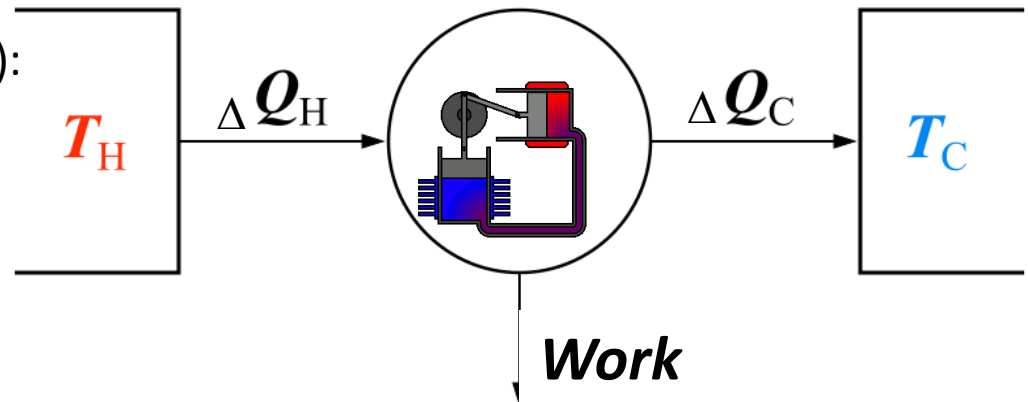
“It is impossible to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects.”

Lord Kelvin's version of *the Second Law of Thermodynamics*

Second Law of Thermodynamics and Entropy

Change in entropy (Clausius definition):

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



If $Work=0$, $\Delta Q_C = -\Delta Q_H = \Delta Q$

$$\Delta S_{total} = \frac{\Delta Q_C}{T_C} - \frac{\Delta Q_H}{T_H} = \Delta Q \left(\frac{1}{T_C} - \frac{1}{T_H} \right) \geq 0$$

Clausius version of **the Second Law** :

“In an isolated system, the total **entropy** cannot decrease over time”

$$\Delta S_{total} = \Delta Q_H \left(\frac{1}{T_C} - \frac{1}{T_H} \right) - \frac{Work}{T_C} \geq 0$$

$Work \leq \Delta Q_H \left(\frac{T_H - T_C}{T_H} \right)$, so the maximum efficiency of a heat engine is $\frac{\Delta T}{T_{max}}$

Homework

Problem 1

Modify our derivation of the maximum efficiency of a heat engine to determine

- a) The maximum efficiency of A/C or refrigerator, i.e. find the minimal work W needed to remove heat Q from the cooler.
- b) Efficiency of a heat pump: calculate the minimal work W needed to add heat Q to the heater.

In both cases, assume $T_C < T_H$ be temperatures of the cooler and the heater, respectively.

Problem 2

Based on the result on Problem 1b, calculate the power of the most efficient heat pump that could replace a traditional 3 kW heater (i.e. the heater that directly converts 3kW of electric power to heat).

Assume room temperature to be 20°C, and the outside temperature to be 0°C (treat the outside as a cooler). Remember that to convert temperature from Celsius to Kelvin you need to add 273K.