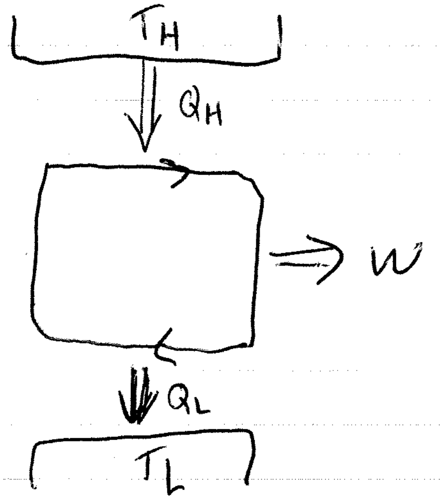
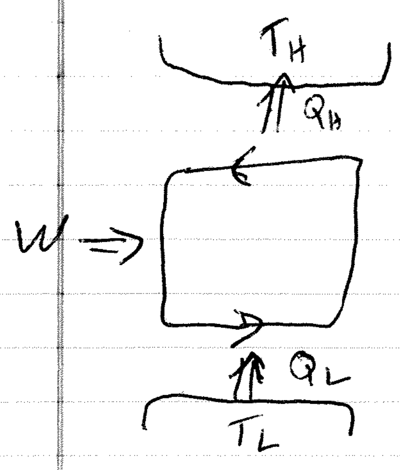
Lecture 9

We can depict Carnot engine abstractly as



using heat to generate work, where some heat gets discarded to cold bath/reservoir.

A Carnot refrigerator is the opposite process.



it uses work to transfer energy from a low-temperature reservoir to a high-temp reservoir

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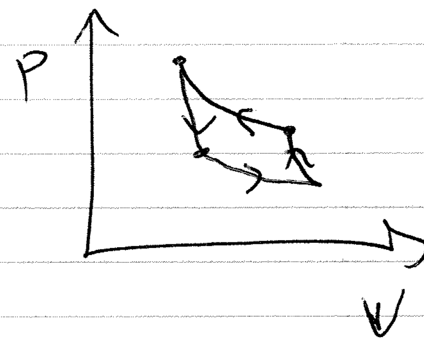
So Carnot refrigerator is just opposite to Carnot engine in all aspects. i.e., p-V diagram is



Measure of performance for refrigerator is coefficient of performance

$$K = \frac{\text{what we want}}{\text{what we pay for}} = \frac{|Q_L|}{W}$$

goal is to get as much energy as possible from low-temp reservoir using as little work as possible

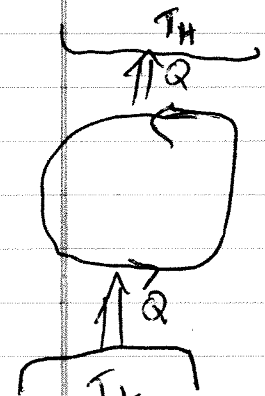
for Carnot fridge, $W = |Q_H| - |Q_L|$

$$\Rightarrow K_C = \frac{|Q_L|}{|Q_H| - |Q_L|}$$

using $\frac{|Q_H|}{T_H} = \frac{|Q_L|}{T_L}$ for Carnot

$$\Rightarrow K_c = \frac{T_L}{T_H - T_L}$$

Is it possible to have a "perfect refrigerator"?
(for which no work would be necessary to invest)



Answer is "no"!

Why? Let's do an entropy analysis

Consider one cycle:

1) Entropy change for working substance is zero b/c cycle
2) Entropy change for cold reservoir is $-|Q|/T_L$ & for hot reservoir is $|Q|/T_H$

$\Rightarrow$ entropy change for whole system would be

$$\Delta S = \frac{-|Q|}{T_L} + \frac{|Q|}{T_H}$$

Since $T_H > T_L$, this would imply $\Delta S < 0$ in violation of 2nd law!!!

So perfect refrigerators cannot exist!

- We now complete our study of thermodynamics by proving that Carnot engine has the maximum possible efficiency of any heat engine.

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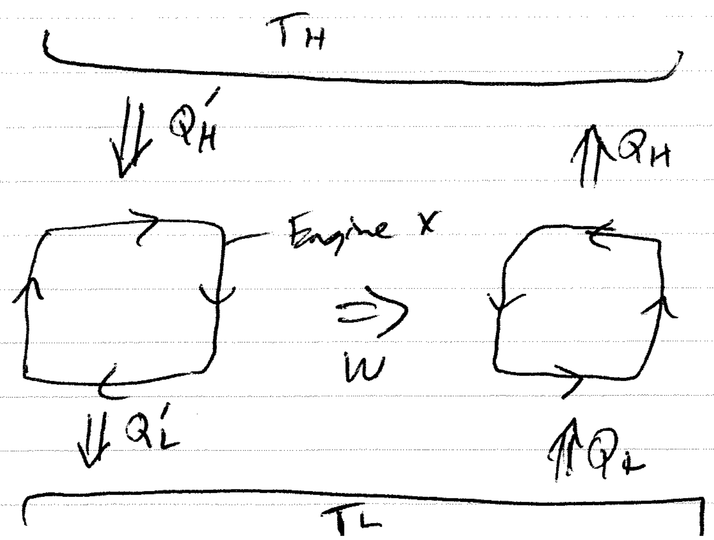
Suppose ε_c is the efficiency of a Carnot engine operating between T_H + T_L:

$$\varepsilon_c = 1 - \frac{T_L}{T_H}$$

Now suppose someone else claims to have an engine X operating @ same temperatures such that its efficiency $\varepsilon_X > \varepsilon_c$

We can then take engine X + couple it to a Carnot fridge w/ same reservoirs



we tune Carnot fridge such that it requires work W as input

If engine X has greater efficiency, then

$$\varepsilon_X = \frac{|W|}{|Q_H'|} > \varepsilon_C = \frac{|W|}{|Q_H|}$$

$$\Rightarrow \quad |Q_H| > |Q_H'|$$

Since work done by engine

= work done on Carnot fridge

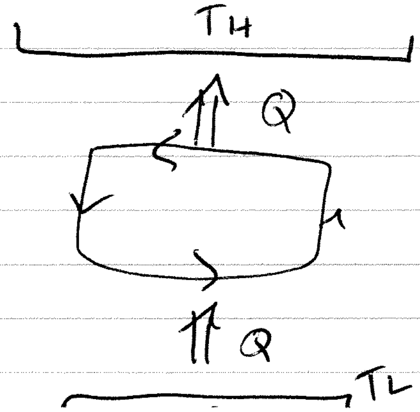
$$\Rightarrow \quad W = |Q_H| - |Q_L|$$

$$= |Q_H'| - |Q_L'|$$

$$\Rightarrow \quad |Q_H| - |Q_H'| = |Q_L| - |Q_L'|$$

$$= Q > 0$$

$\Rightarrow$ device is equivalent to



which is a perfect fridge!

But this cannot exist!

$\Rightarrow$ assumption $\varepsilon_x > \varepsilon_c$

must have been wrong

Conclusion: no engine can have efficiency greater than a Carnot engine

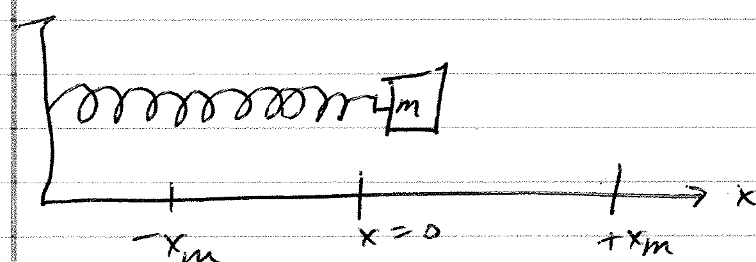
Chap. 15

Simple Harmonic Motion

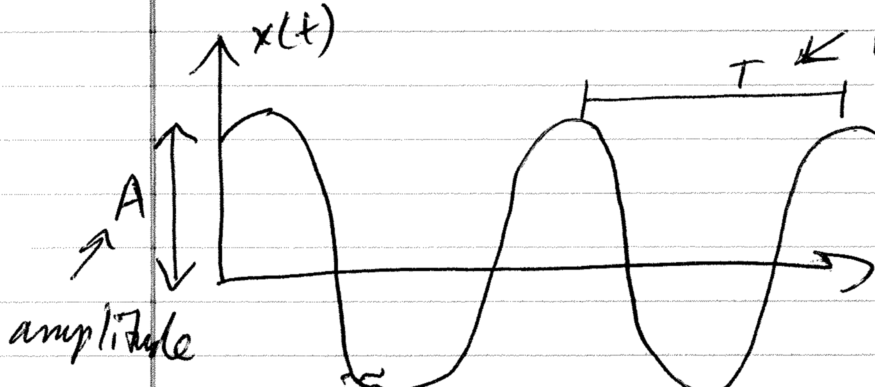
study of oscillations

occurs in waves, pendulum, springs, etc.

Imagine a spring attached to a wall



motion over time is characterized by



displacement @ time t

$$x(t) = x_m \cos(\omega t + \phi)$$

amplitude

angular freq.

time

phase angle

$$\omega = \frac{2\pi}{T}$$

period of oscillations

From this, we can get velocity & acceleration

take $x(t) = x_m \cos(\omega t)$

$$v(t) = \frac{dx(t)}{dt} = -\omega x_m \sin(\omega t)$$

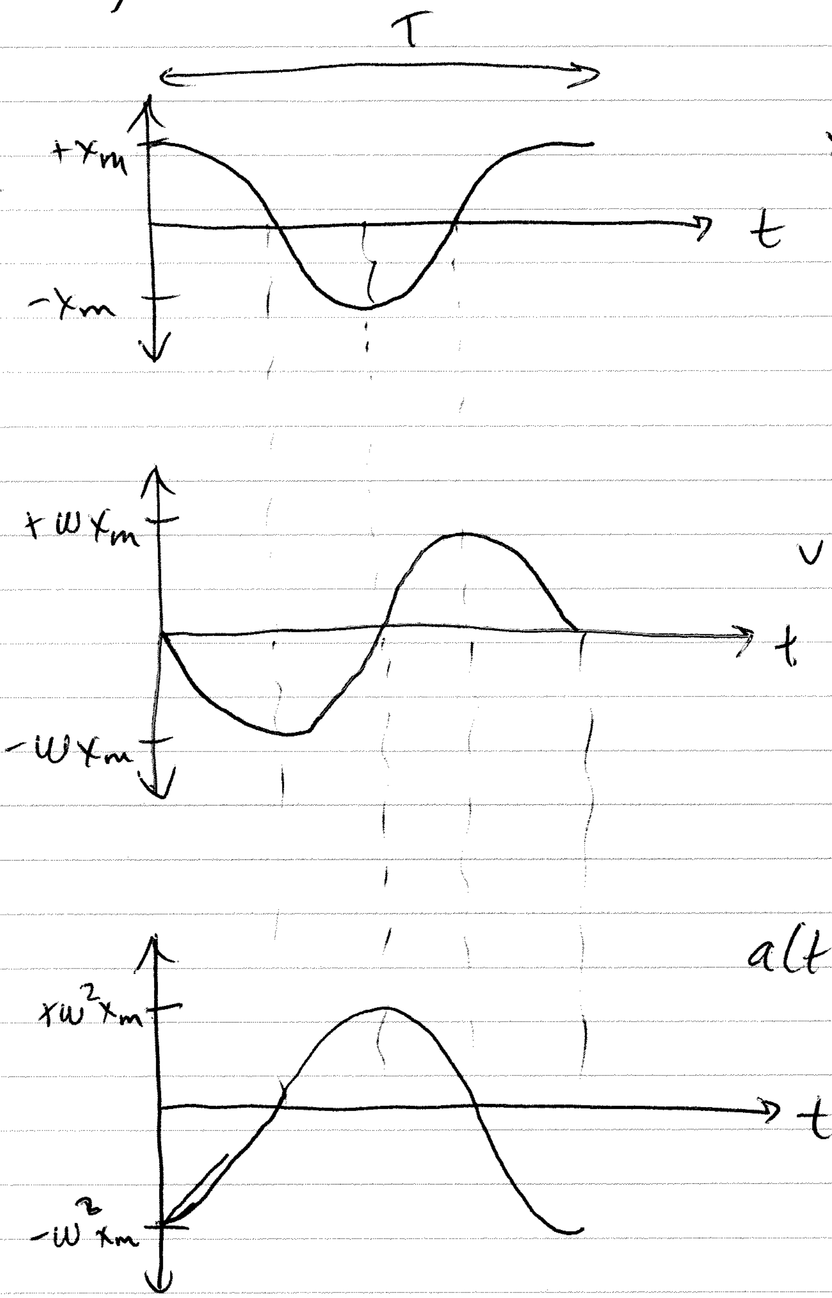
$$a(t) = \frac{dv(t)}{dt} = -\omega^2 x_m \cos(\omega t)$$

Plotting these

Displacement $x_m \cos(\omega t)$

Velocity $v(t) = -\omega x_m \sin(\omega t)$

Acceleration $a(t) = -\omega^2 x_m \cos(\omega t)$



Question

Mass suspended from spring is oscillating up & down

i) @ some point during oscillation, mass has zero velocity but is accelerating

ii) @ some point ...,
mass has zero velocity & zero acceleration

a) both occur

b) neither occurs

c) only i) occurs ✓

d) only ii) occurs