Sheet 9

Please hand in your solutions before the *Wednesday* *lecture at 10:15.*

Problem 1 : Thermodynamic laws (10 points)

a) (2 points) Write down a mathematical expression for the first law of thermodynamics, and explain it in one sentence.

b) (2 points) Write down a mathematical expression for the second law of thermodynamics, and explain it in one sentence.

c) (2 points) Write down a mathematical expression for the third law of thermodynamics, and explain it in one sentence.

d) (4 points) Write down a mathematical expression by combining the first law and the second law without the chemical energy.

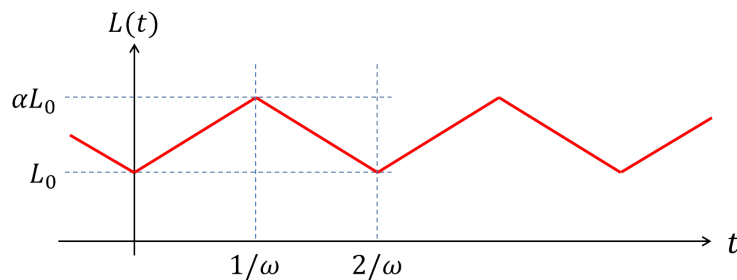## Problem 2 : Oscillating Piston (10 points)

Fig. 1: An oscillating piston.

Consider an oscillating piston with an amplitude $L(t)$ as in Fig. 1, filled with ideal gas, where the average velocity of the gas particles in the piston is $\langle v \rangle$, and α is a non-zero real number. The oscillation is sufficiently slow such that the piston expansion-compression process can be considered reversible, however it is fast enough, compared to the particles velocity, such that the process is also non quasi-static.

a) (5 points) Calculate the relative energy $E(t = 2/\omega)/E(t = 0)$ over one period.

b) (5 points) Sketch a plot of the relative energy change as a function of $0 \leq \alpha \leq 4$ using $L_0 \omega / \langle v \rangle = 1$.

Problem 3 : Thermodynamic Cycles (30 points)

Consider an ideal gas confined in a piston, that is used to operate a heat engine. The thermodynamic cycle in the system is represented by a closed loop of paths in the pressure-volume (p-V) phase space (also kown as (p-V) diagramme).

Draw the thermodynamic cycles in p-V phase space and calculate the cycles' efficiency η for the following cases. In the phase space use V as abscissa ("$x-$axis") and p as ordinate ("$y-$axis"), and use the specific heat ratio γ if needed.

a) (10 points) A path with two isotherms $(T, 2T)$ and two isochores $(V, 2V)$.

b) (10 points) A path with two adiabats and two isochores $(V, 2V)$.

c) (10 points) A path with two adiabats, one isobar $(V \to 2V)$, one isochore $(3V)$.