Physics 4311: Thermal Physics - Homework 5

due date: Tuesday, Feb 27, 2024, please upload your solution as a pdf on Canvas

Problem 1: Diesel engine (6 points)

A Diesel engine takes in air at ambient conditions (room temperature, 1 atm pressure) and compresses it rapidly to about 5% of its original volume.

a) Calculate the temperature of the air at the end of the compression. Assume that the compression is so fast that it can be assumed to be adiabatic. The adiabatic index for air is about 1.4.

b) Explain why a Diesel engine does not need spark plugs.

Problem 2: Surface tension of a droplet (12 points)

The surface tension σ of an interface between two substances is defined in terms of the work required to increase the interface area by an infinitesimal amount dA via $\delta W = \sigma dA$. Consider a spherical droplet of radius a of a fluid embedded in air at ambient pressure p_0. This problem aims at finding the pressure p inside the droplet.

a) Compute the work due to the volume expansion if the radius of the droplet is increased by an infinitesimal da.

b) Compute the work due to the increase in surface area if the radius of the droplet is increased by da.

c) In equilibrium, the work due to the pressure and the work due to the surface tension should cancel. Use this to find the difference between p and p_0.

Problem 3: Rubber elasticity (6 points)

The equation of state of a rubber band can be modeled by the so-called Guth-James equation

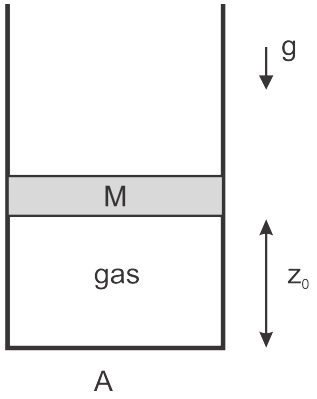
$$F = aT \left[\frac{L}{L_0} - \frac{L_0^2}{L^2} \right] .$$

Here F is the tension force, L is the length of the rubber band (with L_0 being the unstretched length). T is temperature, and a is a constant.

a) The rubber band is held at fixed (stretched) length. Will the tension increase as the temperature increases?

b) When the rubber band is heated at fixed tension, will its length increase or decrease with temperature?

Problem 4: Movable piston (16 points)



An ideal gas of N atoms is contained in a cylindrical vessel of cross section A with a piston of mass M on top. The piston can move up and down, keeping the pressure constant, but the gas cannot escape. The device is surrounded by vacuum. Initially, the cylinder is at rest, the gas is in equilibrium at temperature T_0, and the vertical position of the cylinder is z_0.

a) Consider the forces acting on the piston, and find the initial pressure inside the gas.

b) The gas is now heated up slowly, lifting the piston. Find the temperature T of the gas, when the height of the cylinder reaches $z = 2z_0$.

c) Compute the work done by the gas during the expansion. (Does the pressure change in this process?)

d) Find the change in the internal energy of the gas in this process.

e) How much heat has to be provided to the gas in this process? Express the answer in terms of N and T_0.