Optics and Thermodynamics, Fall and Spring 2001

Useful constants:

$$
\begin{aligned}
e &= 1.60 \times 10^{-19}\ \mathrm{C} \\
hc &= 1240\ \mathrm{eV} \cdot \mathrm{nm} \\
c &= 3.00 \times 10^{8}\ \frac{\mathrm{m}}{\mathrm{s}} \\
m_e &= 0.511\ \frac{\mathrm{MeV}}{\mathrm{c}^2} \\
k &= \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^{9}\ \frac{\mathrm{Nm}^2}{\mathrm{C}^2} \\
\epsilon_0 &= 8.85 \times 10^{-12}\ \frac{\mathrm{C}^2}{\mathrm{Nm}^2}
\end{aligned}
$$

1. **Part 1:**
   Consider a reversible isothermal expansion of an ideal gas (the system) in contact with a heat reservoir at a temperature T, from an initial volume V_1 to a final volume V_2.

   (a) What is the change of the internal energy of the system?

   (b) Obtain the amount of work performed by the system.

   (c) What is the amount of heat absorbed by the system?

   (d) What is the change of entropy of the system?

   (e) What is the change of the entropy of the system plus the reservoir?

   Part 2:
   Next consider a free expansion of the above ideal gas from an initial volume V_1 to a final volume V_2.

   (a) What is the change of temperature of the system?

   (b) Does the internal energy change?

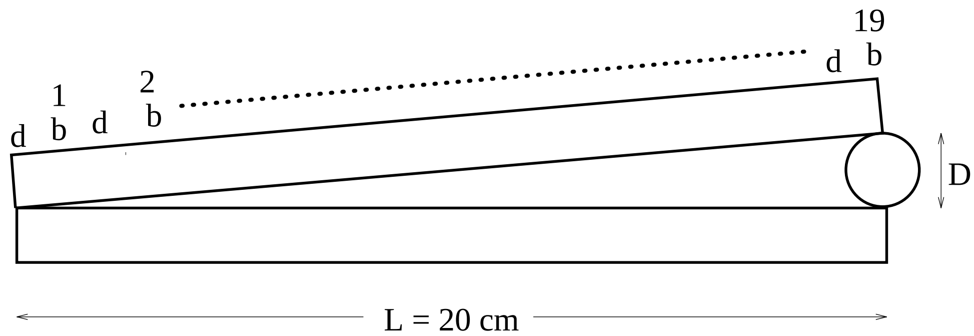
   (c) Obtain the amount of work performed by the system.

   (d) Obtain the absorbed amount of heat.

   (e) Obtain the change of entropy of the system and that of the reservoir.

2. The diameters of fine wires can be accurately measured using interference patterns. Two optically flat pieces of glass of length L are arranged with a wire between them as shown in the figure. The setup is illuminated with normally incident yellow light of wavelength $\lambda = 590$ nm. The length is $L = 20$ cm, and 19 bright fringes are seen along this length.

   (a) Find the diameter of the wire.



(b) If the 19th fringe is not quite at the end, but there is no 20th fringe, give an estimate of the possible relative error in the measurement of the diameter.

3. The operation of a gasoline engine is approximately represented by the Otto cycle. This cycle consists of four different processes:

$A \to B$ The gas is compressed adiabatically from volume V_A to volume V_B (compression stroke).

$B \to C$ The gas is heated at constant volume V_B (combustion of the gasoline mixture).

$C \to D$ The gas expands adiabatically from volume V_B to volume V_A (power stroke).

$D \to A$ The gas is cooled at constant volume V_A (exhaust stroke).

(a) Compute the thermodynamic efficiency of the Otto cycle as a function of the compression ratio V_A/V_B and the heat capacity per particle at constant volume, c_V. Assume that the gas is ideal with temperature-independent heat capacities.

(b) Do higher or lower compression ratios give higher efficiency?

4. A loop of wire is dipped into soapy water and forms a soap film when removed. The loop is held so the film is vertical. The index of refraction of the film is 1.4 and the light incident on the film has a wavelength of 560 nm in vacuum.

a. What is the wavelength of the light inside the film?

b. If the thickness of the film is $t = 10^{-6}$m, find the number of wavelengths contained in a thickness $2t$.

c. What happens to the phase of a light wave when it is reflected from
i) the front of the film, and
ii) the back of the film?

d. As time progresses, the film becomes thinner due to evaporation. The film then appears black in reflected light. Briefly explain why this occurs.