1) a) Consider an argon-ion laser runing at 514.5nm with a minimum beam waist (radius) of $w_o = 0.6$ mm, where the minimum waist is located at the flat front mirror of the laser. You measure the beam waist some distance away from the front of the laser. The beam waist measure 0.8mm. How far are you away from the laser? What is the radius of curvature at this location? What is the value of the q parameter? (5 points)
b) Exercise 3.1-4 (page 84, page 91 of 1st Ed.) (5 points)

2a) Problem 3.1-6 (page 100). (1st Ed. problem 3.1-1 page 106) (5 points)
b) Exercise 3.2-5 (page 94 of the text book). (1st Ed. exercise 3.2-5 page 100) (10 points)

3) Reproduce 3 of the higher order Hermite-Guassian and Laguerre-Guassian modes intensity pattern (i.e. not the TEM$_{0,0}$ pattern) in summary of Oct. 16
http://scylla.ceas.uwm.edu/890/summary/pdf/hermite_gaussian.jpg   and
http://scylla.ceas.uwm.edu/890/summary/pdf/Laguerre-gaussian.jpg
Assume z=0 and that the w$_o$=5mm. You should submit answers (in gray scale images) as well as your program. Each image should be printed with gray colormap as well as graylog colormap (see below) (10 points).
The purpose of this exercise is to demonstrate the use of colormap to visualize data and get familiar with matlab. The example here are in matlab command. The colormap assigns certain color to a value. For example, a gray scale map of 256 levels will assign black to level 0 and white to level 256. This gray scale is provided in matlab and has brightness increasing linearly as the level ramping up. To generate other variation in brightness, you can define your own colormap. For instance, you can have log variation called graylog,with the following commands that replace "colormap(gray(256));" in the example:

```
for n = 1:256
g(n) = log(n)/log(256);
graylog(n,:) = [ g(n) g(n) g(n) ];
end
colormap(graylog);
```
The following example generates a Gaussian beam (TEM$_{0,0}$ mode) with min. spot size of 1. The xy plane image has 256×256 sampling points with the ranges for x and y being the same, from –7.5 to 7.5. The key steps are:
a. Create a vector x with values running from –7.5 to 7.5 with 256 point.
b. Copy x to y
c. Create mesh points with x,y and the command 'meshgrid'
d. Generate the field of a beam Z from the formula and mesh points
e. Normalize the intensity by its maximum and multiplied by 256
f. Install a 256 levels colormap with command 'colormap'
g. Display and print the intensity image.

Actual matlab program:
```
x=-7.5:0.0586:7.5;
y=x;
[X,Y] = meshgrid(x,y);
R=X.^2+Y.^2;
Z=exp(-R);
Inten=Z.*conj(Z);
norm=256/max(max(Inten));
image(x,y,Inten*norm);
colormap(gray(256));
axis('square');
print -dps filename
```

For graylog colormap, use "colormap(graylog)" after graylog is defined.
Note: Matlab perform vector operation (such as *, /,^) by default. To force scalar operation, you need to put a dot in front, e.g. .*, \./, \.^.

Regular problems for graduate students (bonus for undergraduate students)
4) Generate the far field patterns of the modes in question 3 and plot out their images with gray colormap. Hint: for the best result, use the display window size about 5 times of w_o. (10 points)
The purpose of this exercise is to show the equivalent of uncertainty principle in optics. From this principle, we should predict the beam of high order modes expanding faster. The far field can be computed by taking the Fourier transform of the initial field with the 'fft2' function in matlab. The following code segment for far field of the $TEM_{0,0}$ mode should be entered after the example in question 3.

```
U=fft2(Z);
Intenf=U.*conj(U);
Intenf=fftshift(Intenf);
xf=-8.533:0.06667:8.533;
yf=xf;
norm=256/max(max(intenf));
image(xf,yf,intenf*norm);
colormap(gray);
axis('square');
```

Note: the maximum range of xf is equal to $1/ (2\times$ grid spacing in x) by Nyquist theorem and we use Fast Fourier transform to approximate Fourier transform. Fast Fourier transform requires a shift ('fftshift') in its period to center the pattern.

Extra=credit
5) Consider the optical cavity shown in the diagram on the right. Assume that it is stable.
  a) Sketch the equivalent lens diagram.
  b) Identify the place in the cavity where the beam achieves its minimum.
  c) What is the formula for the minimum spot size at the location in b)?
  d) Show that this formula is valid for stable cavities only. (i.e. does the formula hold if the cavity is unstable?) (10 points)