# Physics 411: Homework 3

1. **Plotting experimental data:**

   (a) On the web site you will find a file called `sunspots.dat`, which contains the observed number of sunspots on the Sun for each month since January 1749. The file contains two columns of numbers, the first being the month and the second being the sunspot number. Write a program that reads in the data and makes a graph of sunspots as a function of time.

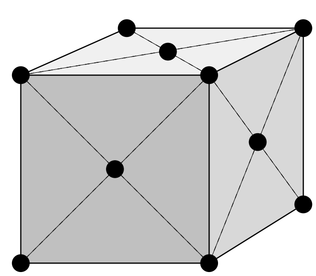
   (b) There is another file on the web site called `stm.dat`, which contains a grid of values from scanning tunneling microscope measurements of the (111) surface of silicon. A scanning tunneling microscope (STM) is a device that measures the surface of a solid at the atomic level by tracking a sharp tip over the surface and measuring quantum tunneling current as a function of position. The end result is a grid of values that represent the height of the surface and the file `stm.dat` contains just such a grid of values. Write a program that reads the data contained in the file and makes a density plot of the values. Use the various options and variants you have learned about to make a picture that shows the structure of the silicon surface clearly.

   ☑ **For full credit** turn in printouts of your two programs and printouts of the plots you created.

2. **Visualizing lattices:** In Example 4.2 we wrote a program that creates a computer visualization of a simple cubic lattice. Using that program as a starting point, or starting from scratch if you prefer, do the following.

   (a) A sodium chloride crystal has sodium and chlorine atoms arranged on a cubic lattice but the atoms alternate between sodium and chlorine, so that each sodium is surrounded by six chlorines and each chlorine is surrounded by six sodiums. Create a visualization of the sodium chloride lattice using two different colors to represent the two types of atoms. (If you print out the result in black-and-white, make sure to use two colors that are clearly distinguishable.)

   (b) The face-centered cubic (fcc) lattice, which is the most common lattice in naturally occurring crystals, consists of a cubic lattice with atoms positioned not only at the corners of each cube but also at the center of each face, like this:

   Create a visualization of an fcc lattice with a single species of atom (such as occurs in metallic iron, for instance).

☑ **For full credit** turn in a printout of your program for part (b) and printouts of the two pictures you created.

Hint: Printing out 3D graphics is a little tricky. The simplest way to do it is to run the program and then take a "screenshot" of the window containing the graphics. On a PC running Windows hold down ALT and then press the "Print Screen" button to take a screenshot of the current active window. On a Mac hold down Command and Shift and press the number 4, then press the space bar, then click on a window to take a screenshot of that window. Once you have your screenshot you can paste it into a document and print it out.

3. **Visualization of the solar system:** The innermost six planets of our solar system revolve around the Sun in roughly circular orbits that all lie approximately in the same (ecliptic) plane. Here are some basic parameters:

| Object | Radius of object (km) | Radius of orbit (millions of km) | Period of orbit (days) |
|---|---|---|---|
| Mercury | 2440 | 57.9 | 88.0 |
| Venus | 6052 | 108.2 | 224.7 |
| Earth | 6371 | 149.6 | 365.3 |
| Mars | 3386 | 227.9 | 687.0 |
| Jupiter | 69173 | 778.5 | 4331.6 |
| Saturn | 57316 | 1433.4 | 10759.2 |
| Sun | 695500 | – | – |

(a) Write down equations for the coordinates $x, y$ of a planet in the plane of the ecliptic at time $t$, assuming that it lies on the $x$-axis at $t = 0$ and travels in a circular orbit with radius $R$.

(b) Using the facilities provided by the `visual` package, create an animation of the solar system that shows the following:

i. The Sun and planets as spheres in their appropriate positions and with sizes proportional to their actual sizes. Because the radii of the planets are tiny compared to the distances between them, represent the planets by spheres with radii $c_1$ times larger than their correct proportionate values, so that you can see them clearly. Find a good value for $c_1$ that makes the planets visible. (You don't need to rescale the size of the Sun—it's large enough to be visible at normal scale.) For added realism, you may also want to make your spheres different colors. For instance, Earth could be blue and the Sun could be yellow.

ii. The motion of the planets as they move around the Sun (by making the spheres of the planets move). In the interests of alleviating boredom, construct your program so that time in the animation runs a factor of $c_2$ faster than actual time. Find a value of $c_2$ that makes the motion of the orbits easily visible but not unreasonably fast. Use the `rate` function to make your animation run smoothly.

☑ **For full credit** turn in a copy of your program and a snapshot showing the animation it produces.

4. **Diffraction gratings:** Light with wavelength $\lambda$ is incident on a diffraction grating of total width $w$, gets diffracted, is focused with a lens of focal length $f$, and falls on a screen. Theory tells us that the intensity of the diffraction pattern on the screen, a distance $x$ from the central axis of the system, is given by

$$I(x) = \left| \int_{-w/2}^{w/2} \sqrt{c(z)}\, e^{i2\pi xz/\lambda f}\, dz \right|^2,$$

where $c(z)$ is the intensity transmission function of the diffraction grating at a distance $z$ from the central axis.

(a) Consider a grating with transmission function $c(z) = \sin^2 \alpha z$. What is the separation of the slits in this grating, expressed in terms of $\alpha$?

(b) Write a Python function `c(z)` that returns the transmission function $c(z) = \sin^2 \alpha z$ as above at position $z$ for a grating whose slits have separation $20\,\mu$m.

(c) Use your function in a program to calculate and graph the intensity of the diffraction pattern produced by such a grating having ten slits in total, if the incident light has wavelength $\lambda = 500\,$nm. Assume the lens has a focal length of 1 meter and the screen is 10 cm wide. You can use whatever method you think appropriate for doing the integral. Once you've made your choice you'll also need to decide the number of sample points you'll use. Choose a value that gives an accurate estimate of the integral in reasonable running time.

Notice that the integrand in the equation for $I(x)$ is complex, so you will have to use complex variables in your program. As mentioned in Section 2.2.5 of the course-pack, there is a version of the `math` package for use with complex variables called `cmath`. In particular you may find the `exp` function from `cmath` useful because it can calculate the exponentials of complex arguments.

(d) Create a visualization of how the diffraction pattern looks on the screen using a density plot (see Section 4.3). Your plot should look something like this:

(e) Modify your program further to make pictures of the diffraction patterns produced by gratings with the following profiles:

i. A transmission profile that obeys $c(z) = \sin^2 \alpha z \sin^2 \beta z$, with $\alpha$ and $w$ as before (ten $20\,\mu$m slits) and $\beta = \frac{1}{2}\alpha$.

ii. Two "square" slits, meaning slits with 100% transmission through the slit and 0% transmission everywhere else. Calculate the diffraction pattern for non-identical slits, one $10\,\mu$m wide and the other $20\,\mu$m wide, with a $60\,\mu$m gap between the two.

☑ **For full credit** turn in your answer to the question in part (a), a printout of your program from part (d), and printouts of your graph from part (c) and the two diffraction patterns from part (e).