Transfer matrix Exercises

Write two programs to implement the Transfer matrix method for an arbitrary number of multilayers.

Program 1 should be able to calculate the reflectivity and transmission as a function of varying incident angle for a single incident wavelength.

Program 2 should calculate the reflectivity and transmission as a function of varying wavelength at a single fixed incident angle of incidence.

Each program should ask the user if they want p-polarized or s-polarized incident light.

I want you to examine a variety of multilayer structures. For each you should enter the array of refractive index and thickness values for the multilayer like this:

```
n = [1.5 1 1.5]
d = [0 1200e-9 0]
```

Note that the first and last thickness values, d, are input as zero. The number does not really matter as these are in first and last media and they are semi-infinite in extent. These values of d never show up in the calculation they are just placeholders.

When you finish with one multilayer example just comment out the n and d for that example and enter the next pair, for example:

```
% n = [1.5 1 1.5]
%d = [0 1200e-9 0]
n = [1 2.2 1.5 1]
d = [0 78e-9 105e-9 0]
```

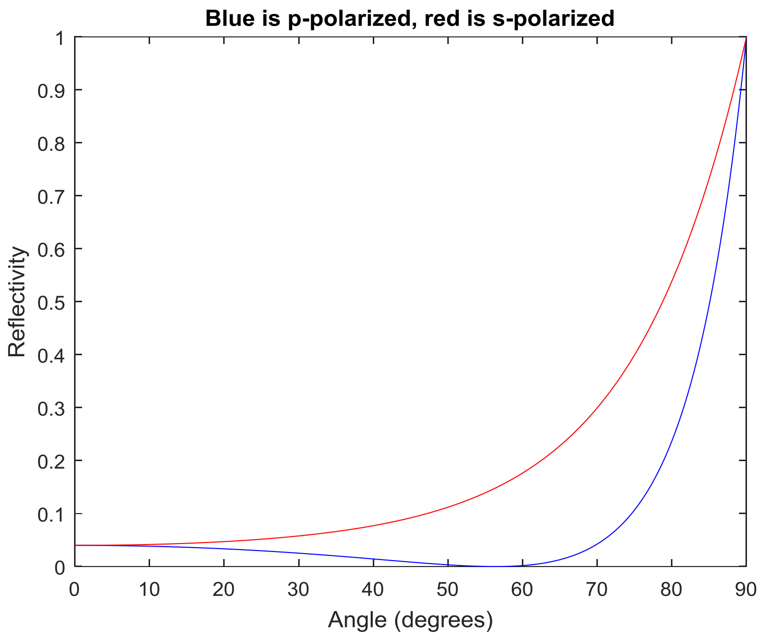
In that way you can comment out appropriately and repeat any calculation.

Exercise 1: Reflectivity as a function of angle from a glass surface.

Look at both p-polarized and s-polarized reflection from an air glass interface as a function of angle.

```
n = [1 1.5]
d = [0 0]
lam=600e-9 %This is the wavelength of 600 nm
```

This exercise does not use a layer at all. It really just tests if the basic program surrounding the matrix part is working. You should get something like this:



What is the physics here? Note that the p-polarized reflectivity goes to zero at just under 60 degrees. That is Brewster's angle. Thus, un-polarized light reflected from glass at 60 degrees becomes s-polarized on reflection because none of the p-polarized light is reflected.

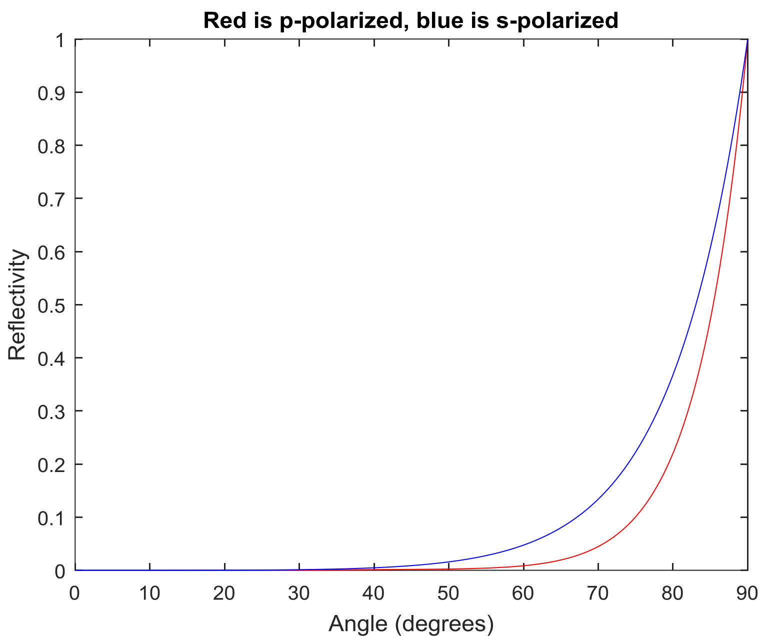
Exercise 2. Anti-reflection coating at a single wavelength

Now do a 3 layer run with:

```
n = [1 1.225 1.5];
d = [0 123e-9 0];
```
lam = 600e-9 %This is the wavelength of 600 nm

This simulates light in air reflecting off a glass surface which is covered by an anti-reflection coating. The antireflection coating has a lower index than the glass. The thickness of the antireflection coating is a quarter wavelength in the material of index 1.225 i.e d(2)=600nm/(4*1.225)=123 nm.

Note in the plot that at angles up to about 30 degree both s- and p-polarized reflectivity is zero. Compare to the plot in the first exercise which shows reflectivity of about 4% at angle up to 30 degrees.

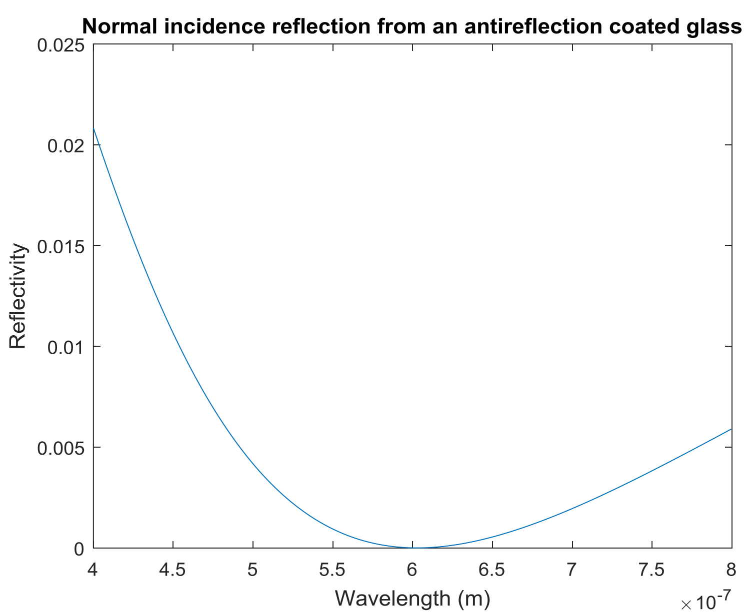


Exercise 3. Anti-reflection coating as a function of wavelength

Now try your reflectivity versus wavelength program on the same antireflection coating:

```
n = [1 1.225 1.5];
d = [0 123e-9 0];
th = 0   %angle for normal incidence.
```

Go from a wavelength of 400 nm to 800 nm. You should get a plot like this:



From this plot you can see that the zero reflectivity condition is only true around 600 nm. A lens with this antireflection coating would look bluish because when hit with white light more blue is reflected than red light. You can see this effect on high quality camera lenses.

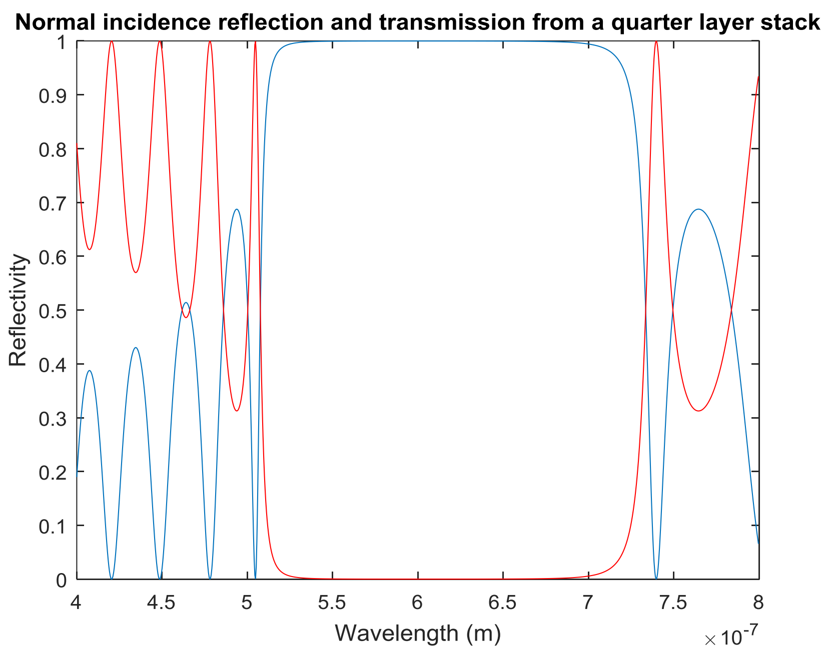
Exercise 4. A simple one-dimensional photonic band gap system—the Bragg stack

Last system to try is a multilayer with many layers.

```
n = [1 1.5 2.5 1.5 2.5 1.5 2.5 1.5 2.5 1.5 2.5 1.5 2.5 1.5 2.5 1.5 2.5 1.5 2.5 1.5 2.5 1];
d = [0 100 60 100 60 100 60 100 60 100 60 100 60 100 60 100 60 100 60 100 60 0]*1e-9;
```

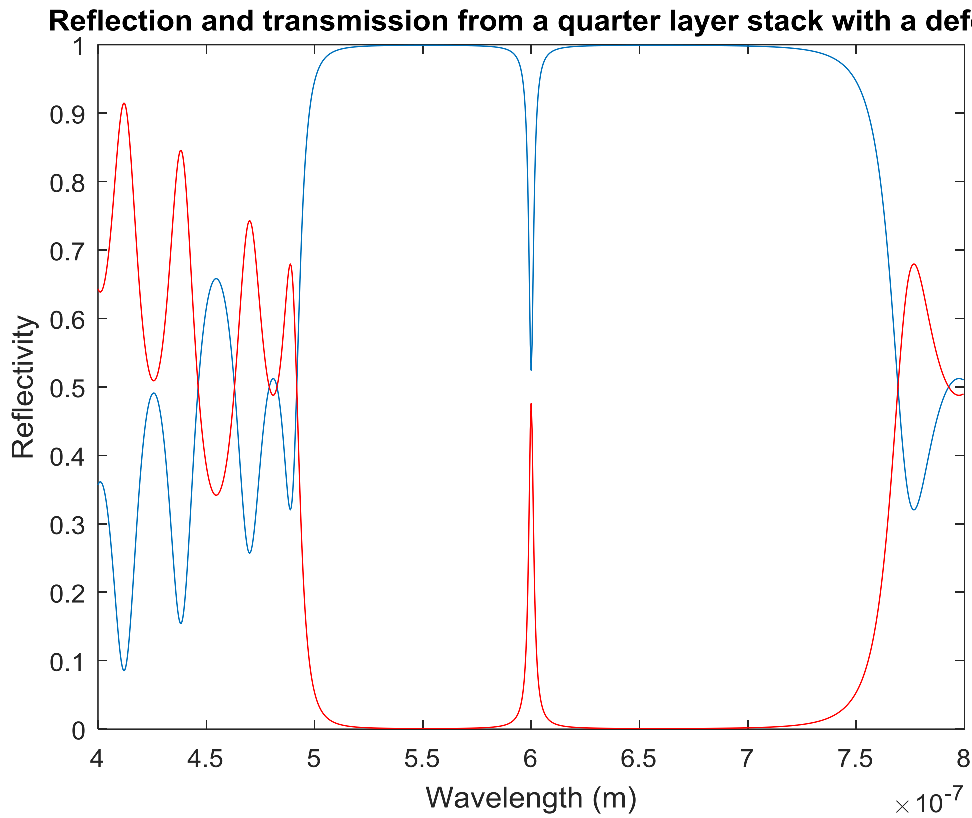
th = 0 %angle for normal incidence.

This system has 20 layers of alternating high refractive index, low refractive index. Each layer is a quarter wavelength in thickness (accounting for the refractive index in the layer). The reflection and transmission should look like this:



The blue curve is the reflection. It is almost perfectly reflecting from 525 nm to 700 nm. As expected, the transmission (red curve) in this range is essentially zero. This system is a simple photonic band gap structure. The photonic band gap refers to the range of wavelengths over which light is forbidden to propagate through the multilayer. Here the band gap is between 525 nm and 700 nm.

Finally, try doubling the thickness of one center layers in the stack i.e. d(11) = 120 (instead of 60 as above). Run again. You should get this:



By breaking the symmetry of the regular multilayer array creates a narrow defect state in the center of the band gap.

Deliverables:

The code for your 2 programs.
The plots for the 4 exercises.