

Questions/problems

Diffusion/conduction processes

Use the Diffusion Processes simulation in the Virtual Lab for these problems.

1. Diffusion 1: Diffusion is a time-dependent process, i.e., a concentration distribution will change over time. But eventually this distribution will come into equilibrium with its boundary conditions and it will no longer change. This situation is called “steady-state”. Here, the time-dependent term in the diffusion equation is zero. Perform the following experiment: Configure the concentration field with a narrow strip of constant concentration (=1000) along the entire left edge, and with a narrow strip of constant concentration (=0) along the entire right edge. Then configure the diffusivity field as having uniform high diffusivity (the default). Since the concentrations and diffusivities do not depend on x , this is a one-dimensional problem.

The concentration is fixed at 1000 on the left and is fixed at 0 on the right, so only the concentrations in the middle (initially at zero) will change. Run the simulation and monitor the concentration distribution over time. Describe what happens. Describe the steady-state distribution. Could you have predicted the steady-state result by analyzing the steady-state diffusion equation?

2. Diffusion 2: redo Diffusion problem 1. But this time create a diffusivity field that is entirely low diffusivity. How does the time-dependent behavior of this problem differ from that of the former problem? What about the steady-state configuration?

3. Diffusion 3: redo Diffusion problem 1 again, this time creating a diffusivity field that is half high diffusivity (on the left) and half low diffusivity (on the right). What is the steady-state distribution? Look at the steady-state diffusion equation and try to figure out why you obtain this result.

4. Diffusion 4: In Diffusion 3, you observed a concentration distribution coming to equilibrium in a two-part diffusivity field. If you think about it and you use data from Diffusion 3, you should be able to deduce the ratio of the high to the low diffusivities. What value do you obtain? [Hint: diffusivity (conductivity) is the equivalent of the reciprocal of resistivity or resistance. How do you evaluate the voltage distribution in a circuit consisting of a voltage source V being grounded through two resistors in series?]

5. Diffusion 5: Chemical production plants are built only after small-scale pilot plants demonstrate the viability of the process. But sometimes a process that works fine in small scale has a catastrophic outcome when it's rescaled upward. An example of such a process is one that is exothermic, i.e., one that generates heat. Demonstrate that phenomenon here. Create a simulation in which the diffusivity field is uniformly high and the concentration field is everywhere fixed at zero except for a small circle where the concentration field is incremented by 10 at each timestep. This is equivalent to an

exothermic reaction taking place within a circular area where the circular area is being cooled by a surrounding constant-temperature equal.

Run the experiment for a number of circle sizes; then plot the maximum temperature as a function of circle size. What is going on? What is the largest circle that can be used such that the temperature does not exceed 500 anywhere within the reaction? How might you design a larger reactor area and still not exceed a 500 maximum? Do it.

Use the simulation on Heat Conduction in the Virtual Laboratory for this problem

6. Conduction. The flow of heat in a uniformly conducting material is affected by its cross-sectional area. Suppose you were required to infer the cross-sectional area of a heated rod just by analyzing the propagation of heat along its length. How would you approach the problem? That's the subject of this problem. You'll find instructions in the simulation preface.