1. (4 pts.) Catheters that are placed in arteries and veins will alter the flow through the vessel. Consider a catheter of radius $\varepsilon R$ that is placed in a blood vessel. What are the boundary conditions? What is the velocity profile? Determine the reduction in flow rate relative to a vessel of the same radius without a catheter. Compute the spatial average velocity and use this to find a friction factor-Reynolds number relation using the definition for hydraulic diameter. How does this compare with $f = 16/Re$ for laminar flow in a tube (Recall problem 3 on homework set 2). Assume steady flow and assume that the pressure drop is the same with and without the catheter; treat blood as a Newtonian fluid.

2. (3 pts.) Denn 8.1

3. (3 pts.) A vertical tube is filled with a Bingham fluid and a plate is held over the lower end. (See the figure below). When the plate is removed, the fluid may or may not flow out of the tube by gravity. Explain this and establish a criterion for flow in such an experiment. Recall that a Bingham fluid behaves in the following way: $\tau_{xy} = -\tau_0 + \eta dv_x/dr$. Hint: Solve for flow rate using the spatial average velocity profile.