5.0: Overview of Flow, Transport and Exponential

In Physics 7A, Chapters 1 and 2, we explored a very general and universally applicable model based on conservation of energy: the *Energy-Interaction Model*. The approach of focusing on initial and final values was extended in Chapter 4 about thermodynamics, to include all state variables. We now turn back to energy conservation, but with a significant difference. Up to now the changes in energy and other variables occurred over time. We focused on an initial time and a final time and looked at how indicators of various energies changed between those two times. We begin Chapter 5 by looking at phenomena that occur in a *steady-state* fashion. *Steady-state* refers to systems that do not change with time. In particular, we will study the steady-state flow of fluids and electric charge in electrical circuits. In these phenomena the change in energy occurs over *position*, but is constant in time. We will *not* be starting from scratch, however, since we will be able to use many of the ideas and constructs we previously developed when working with the Energy-Interaction Model.

We begin by focusing on phenomena that involve flow of fluids in fluid systems and charge in electric circuits. The effect of resistance in both kinds of flow means that energy will be reduced in the fluid system while thermal energy will increase. Frequently the flow is described as being *dissipative*. We call the model/approach we use to make sense of dissipative flow, the *Steady-State Energy Density Model*.

Later in the chapter we generalize the underlying ideas about flow to flow phenomena in which changes in energy are not of paramount importance. Rather, the focus is simply on the “fluid” and medium properties and the “driving force” that keeps the flow going. The “thing” that flows can be a real fluid, electric charge, energy, or other things that diffuse – in short, any phenomenon in which the flow of something becomes constant can be understood with this approach/model, which we call the *Linear Transport Model*.

Frequently in science the same basic relationship is rediscovered by practitioners in different disciplines. Usually a different name is given to the relationship and different symbols are used to express it in each different discipline. These historical differences manage to last through multiple generations of textbooks. This is certainly true of the linear transport equation we develop in this chapter. As an example, some of you will study environmental science or soil and water science. You may have come across Darcy’s law, describing the flow of water in soils. After studying this chapter, Darcy’s law should seem pretty familiar to you, even if some of the symbols that are used are different. Practitioners in other branches of science, technology, medicine and engineering, will use different laws relating to transport, each with its different name and specialized symbols, but all referring to the same basic underlying transport model. Hopefully, you will develop expertise in “reading past the particular symbols” and recognize the fundamental content expressed by the relationship, which, after all, is independent of which letters of the alphabet we choose to use.

The kinds of phenomena we can make sense of using the *Steady-State Energy Density Model* or the *Linear Transport Model* do not change in time. That is, the transport phenomena remain constant for the time interval of interest. For example, once a resistor network has been arranged and a battery connected, the current very quickly comes to its steady-state values in the various parts of the circuit and then remains constant. Or, when there is a constant temperature difference from one end of a bar of metal to the other, the rate of heat flow is constant along the bar. These two powerful models, though broadly applicable to many real situations, exclude any situation where the amount of something transported changes with time. There are certainly many physical systems where the rate of change is not constant.

A very common “non-steady state” phenomenon in nature is exponential growth or decay. You might have seen discussions of exponential growth in biology classes, or perhaps in a business or economics class when discussing compound interest. You may also have seen *exponential decay* in chemistry when exploring radioactivity and nuclear decay. Many of the physical systems that exhibit steady-state flow also exhibit exponential behavior as they evolve to a steady-state condition. The “charging up” of an electrical circuit, the heat flow from a hot cup of coffee or tea, the draining of a container of liquid through a small hole all exhibit exponential behavior. In the last part of this chapter we develop a model that that provides the foundation for understanding this kind of exponential-change phenomena. We include exponential change in this chapter, because all of the physical systems that exhibit steady-state behavior and to which the *Steady-State Energy Density Model* and the *Linear Transport Model* apply, also exhibit exponential change under different circumstances.