Physics 7B

DLM 15 Overview

Model/Approach: Linear Transport Model

AC6.3.1 Linear Transport Model (DLM 14 FNT) (~ 40 min)

Learning Goals:

- Understand the meaning of the constructs that appear in the linear transport model
- Understand the meaning of the linear transport model relationship, $j = -k\, d\phi/dx$
- Understand how to use the linear transport model to make sense of phenomena involving fluid flow, electric charge flow, heat flow, and diffusion

Act-6.3.2 Voltage Drops and Heat Transfer (~ 60 min)

Learning Goals:

- Practice applying the linear transport equation to electrical and thermal phenomena.
- Practice identifying the appropriate $d\phi/dt$ in a particular phenomenon

Model: Exponential Change

AC7.1.1 Water flowing out of a standpipe (~ 40 min)

Learning Goals:

- Experience a phenomena that changes exponentially
- Get better understanding of what exponential change means and how it appears graphically
- Get better understanding of half-life
- Get better understanding of what it mean for a rate of change to be proportional to the amount

Announcements

- **Reading Assignment** - Read Summary and Review pages 133-136.

- You should be use the resources on the web page to improve your understanding of the course materials and prepare you for the exams and the final.

Linear Transport Model

A) **On the board** you will make a chart of the defining properties of the linear transport model for the four phenomena from the FNTs. Draw a chart of four columns and four rows. Label each column for one of the phenomena.

Label the first row *quantity transported* and the second row *flux* and **in your small group:** Come to a consensus on your answers to **FNT 1, parts a & b** and put these answers in the chart. Put up any questions you have about these on the board.

B) **FNT 1, part c**

1) **In your small group:** Come to a consensus on your answers to this part.

Note that we use the generic variable, ϕ, to refer generally to any or all of these physical quantities that changes along the direction of the flow. We then divide the change in this physical quantity, $\Delta\phi$, by the distance, L, over which the flow takes place to define the "gradient" of ϕ to be $\Delta\phi / L$. For very small distances we write the gradient as $d\phi / dx$.

2) For each of the four physical problems in this part, find the SI units of this gradient term. In the third row of your chart describe what is the gradient of $\Delta\phi/L$ in each column and write its SI units.

C) **FNT 1, part d (15 mins)**

1) Come to a consensus on your answers to the questions in this part and put your group's responses for the various resistances as the fourth row of the chart. Then continue with 2) and 3) follow-up parts below.

2) We will use the generic variable, k, to relate the gradient *to* the flux. In other words, we write the equation for flux as $j = -k\,\Delta\phi/L$. (You can refer to pp. 79-80 of course notes).

For the electrical transport model, show that $k = L / RA = 1/\rho_r$ where R, is the electrical resistance of a wire of length L and area A. and ρ_r is the resistivity defined on page 69 of the course notes.
To get started: remember what is changing for the charge carrier in electrical transport when it encounters resistance, and then find an expression for I in terms of that change and use the definition for flux: $j = I/A$. Now find a relationship for k in terms of the other variables.

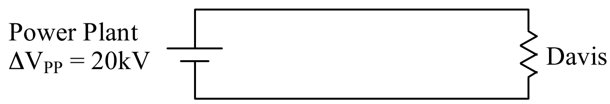
Explain in words why this relationship between k and R makes sense. Put your work and responses on the board.

3) In diffusion problems, people usually use D instead of k and call D "the diffusion constant". See the Table on page 82 of course notes to compare the values of the diffusion constants for O_2 and H_2 molecules in air (some of the exponents in the powers of 10 in this table are not formatted correctly). Why would you expect these two values to differ in this way? Also compare the values for O_2 in air and water. Why would you expect this difference to be so much greater than between O_2 and H_2 molecules in air?

Whole Class Discussion

Voltage Drops and Heat Transfer

A) Voltage Drops - A simple picture of the transmission of electrical power is shown below (the resistor represents all the power uses of the city of Davis). Use the linear transport model to **find the voltage drop per meter** (this is the voltage gradient) along a 20 kV electrical transmission line carrying 800 A if the wire is aluminum with a radius of 5.0 mm. See page 68 of the course notes for the value of the resisitivity of aluminum (how is the resistivity related to the conductivity?). Explain why the fact that there is 20 kV between the aluminum wire and the ground has no effect on your result.



In your small group

a) Find a numerical answer for the voltage drop per meter (ΔV per meter) **along** one wire of the transmission line and put it on the board. Don't put your work on the board. Also, put your explanation for why the 20 kV doesn't enter into your calculation.

Work out responses to the following two additional questions and **put them on the board.**

b) How many watts per meter does this ΔV per meter represent? How many watts per kilometer?

c) What power is transmitted down this transmission line? That is, how much electrical energy per second is converted to some other form of energy in Davis? How does this transmitted power compare to the amount of power that "is lost" in heating the transmission wires?

Whole class discussion

B) Thermal Conductivity - Explain how wetsuits keep you warm in cold water, even though they don't keep you dry.

A web page advertising a particular kind of wetsuit had the following statement regarding how a wetsuit "works":
"Wetsuits are made from neoprene, a stretchy synthetic rubber material. The Wettie (like that - cool surfer speak!) is made out of several of these pieces of neoprene stitched together to cover the desired body parts. The neoprene comes in different thickness', from 2 to 6 mm. (1) The thicker the neoprene the warmer the suit. (2) A Wetsuit works by trapping a thin layer of water between the Wetsuit and the skin. (3) The body temperature of the surfer heats this water giving a nice warm water blanket. (4) This is why getting a Wetsuit that fits well is a must. (5) The Wetsuit should be a nice tight fit (not too tight that you can not move freely) and there should be no baggy areas where the suit comes away from your body."

In your small group

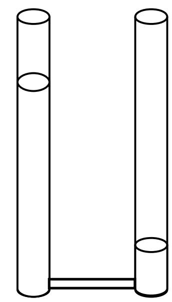
a) Develop a consensus statement in your group (containing as few words as possible) that provides an explanation for how a wetsuit "works". **Put your statement on the board.**

b) What crucial information is missing from the statement from the webpage? Is there anything special about neoprene? Are any of the sentences in the statement incorrect, misleading, or inconsistent with one another?

Whole class discussion

Water Flowing out of a Standpipe

The phenomenon



Water flows out of a vertical cylinder (initially filled with water) into another vertical cylinder (initially mostly empty) through a small-diameter tube near the bottom.

a) Taking care not to spill water, fill one cylinder with water up to the top graduation mark and put water in the other cylinder up to the point where the tube comes in. Open the clamp very slowly until you can barely see that the water level in the full cylinder is going down, then open the clamp about ¼ to ½ turn more. Observe how the current (how fast the water level drops) changes in time as the water level decreases. Without using a mathematical term or expression, describe how this flow changes in time.

b) Making certain the tube will take at least a minute to drain, set up the cylinders again as in part a) and **measure** the time dependence of the volume, Vol(t), of the water in the cylinder when it is allowed to flow through the tube. Make a table on the board showing the volume, Vol, of water and the corresponding time taken to reach the hole, with $t = 0$ at the largest volume just as you open the clamp. You can use the second hand on the wall clock or on a watch to record times when the volume is at one of the major divisions on the graduated cylinder.

c) Plot your data on a sheet of graph paper. Fit (eyeball) a smooth curve through your data points. Remember, you want a best fit curve; the curve doesn't actually have to go through each point. Then sketch this graph on the board.

d) Describe in words how the **rate of change of volume** appears to depend on the volume.

e) What fluid quantity is the **rate of change of volume**?

f) From your graph, determine the time taken for the extra volume (the amount above the steady state value) to decrease to one-half of its initial value. Then determine the time interval required for the extra volume to decrease by half again. Write these time **intervals** above the curve on your graph on the board.

g) Look around the room at the results of the other groups. Notice the relation of the two values from each group to each other as well as the relation of the values between different groups. What is the same and what is different about these values?
Whole Class Discussion

FNTs

1) 3 kg of ice and a 12-pack of ice-cold soda are placed in a 25" × 25" × 40" (outside dimensions) Styrofoam™ cooler with 1" thick sides. How long will its contents remain at 0° C if the outside is a sweltering 35° C? Assume no condensation forms on the outside of the cooler. Ignore the effects of convection and conduction of the air inside.
2) Use your smoothed curve of Vol(t) on the graph you made in part (c) of Activity 7.1.1 to calculate the derivative of the curve (actually measure the slope) at intervals 5 seconds. Plot the derivative of Vol(t), dVol/dt, you experimentally determined from the slopes on the same time scale as your graph of Vol(t). Does your curve of dV/dt have approximately the same half life as Vol(t)?

Some Background (also see Course Notes)

In FNT 2 you should have found that the derivative of Vol(t), dVol/dt is also an exponential function with the same half life as Vol(t). Name all of the mathematical functions you can find that have this "magical" property: namely that the derivative of the function is proportional to the original function. Are there any besides the exponential function? Ask your friends, math professors, whoever, if you are not sure. So, for the exponential function, we have the following relationship:

$y(t) = y_o e^{-\lambda t}$ and differentiating we get $dy(t)/dt = -\lambda y_o e^{-\lambda t}$ But since $y_o e^{-\lambda t} = y(t)$, we have

$dy(t)/dt = -\lambda\, y(t)$	In words again, when the rate of change of the quantity y is proportional to the value of y itself, the function, y(t), that satisfies this relationship is an exponential function

This (rate of change is proportional to the amount of the quantity) is exactly what we found for the case of the water emptying out of the cylinder. The quantity we measured must have a time dependence given by the exponential function.

$Vol(t) = Vol_o\, e^{-\lambda t}$ where the subscript "o" signifies the initial value and

$dVol/dt = I = -\lambda\, Vol$

3) Imagine two rectangular conducting plates that are oppositely charged in equal abundance and are held a fixed distance apart. A wire is then connected between them.
   a) Draw a schematic of this scenario. Pick two points on the wire and describe what energy systems, if any, change between these two points.
   b) Will there be a current in the wire? Will the current be constant over time? Explain.
   c) If a light bulb is connected between points A and B how will the current passing through A, before the light bulb, compare the current that passes through point B? Explain
   d) Will the brightness of the light bulb be constant over time? Explain
   e) Describe a simple way to recharge these plates with devices we have discussed.