In Search of Newton
Projects
for Studio Calculus/Physics
University of New Hampshire

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and all the students who took this course!

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Part I

Introduction
Project 1

Overview of Course and Materials

This is a collection of activities designed over three years for a combined freshman level calculus/physics course at the University of New Hampshire. The development of this course was funded by the National Science Foundation Division of Undergraduate Education (NSF-DUE-9752485).

What does this course look like? This is really two courses (eight credits) that meets for 10 hours a week (two 2-hour sessions of physics, two 2-hour sessions of calculus, one combined 2-hour session). The topics covered are essentially the same found in a standard physics or calculus course (though in the physics we have cut back a bit on breadth in favor of depth); we use standard textbooks in each course. However, the calculus topics have been reordered so that students have the mathematics they need to do the physics. For example, students can take antiderivatives of polynomials by the end of the first month of class so that in physics students can work with the idea that velocity is the antiderivative of acceleration instead of focusing only on constant acceleration equations. Also, during class time students are working in groups a good deal of the time; class is not all lecture. The two-hour class session allows us to intermingle lab activities as appropriate (there is no separate lab time). This is based on the model of studio physics pioneered at Rensselaer Polytechnic Institute.

What is in this booklet? This booklet includes the projects that we have written. These are meant to be done in groups outside of class, and should take 10-20 hours, and require and understanding of physics and calculus. There are many other sources of non-trivial problems in physics (although they may not all have significant calculus components). Physics Education Research groups at University of Minnesota (http://www.physics.umn.edu/groups/physed/), University of Massachusetts (http://umperg.physics.umass.edu/), and Carnegie Mellon University (http://cil.andrew.cmu.edu/) all may have problem-solving resources on their web pages.

Other booklets from this same course include the instructor manual, the calculus activities, the calculus lectures, the physics activities, suggestions for physics lectures, and the combined activities.
Part II
Projects
Project 2

Water Slide of Doom

It is your first day at JoyRide, Inc., and you are asked to work on one small part of a flume ride (*The Titanic Water Slide of Doom*). Near the end of the ride, the cars are on the same track as a large object made up to resemble an iceberg (see Figure 2.1). The cars, which are full of people, are initially moving down from the top of a ramp with velocity 1.4 metres per second, and the distance from the top of the ramp to the bottom is 20 metres. The mass of the styrofoam iceberg is 40 kilograms, and the car has a mass of 400 to 700 kilograms depending on how many people are in it.

The iceberg starts halfway down the ramp and is at rest when the car is at the top of the ramp. The track is designed so that the iceberg moves out of the way of the car as soon as it reaches the bottom of the ramp. Both objects ride on a thin film of water, and the friction between the track and the objects can be ignored. The car is very sleek and it can be assumed that its air resistance is negligible. The air resistance for the iceberg is proportional to the square of its velocity, and you are able to design to the car to give you whatever constant of proportionality that you want (by changing its frontal area).

Your boss wants you to design the ride so that the iceberg moves out of the way of the car full of frightened people at the very last moment.

![Figure 2.1: Both objects are on an inclined place at an angle of 30 degrees](image)

Hint:
The solution to $\dot{v} = -av^2 + b$ for both $a$ and $b$ constant is

$$v(t) = \frac{\sqrt{b} \left(-1 + e^{(2\sqrt{ba})(t+C_1)}\right)}{\sqrt{a} \left(1 + e^{(2\sqrt{ba})(t+C_1)}\right)}$$

The anti-derivative of the velocity is

$$x(t) = \ln\left(\frac{1 + e^{(2\sqrt{ba})(t+C_1)}}{a} - \sqrt{ba} (t + C_1) + C_2\right)$$

To find the values of $C_1$ and $C_2$ you have to use the initial conditions.

You should verify that these equations do solve the differential equation.
Project 3

Crash Test Dummies

You work for Consumers Group in their automotive testing division. As part of your job, you are asked to decide where to place sensors in the crash test dummies so that you can calculate the location of the center of mass of the dummy as a function of time. Once the sensors are in place, a detector will record the $x, y,$ and $z$ location of each sensor (with respect to a fixed coordinate system in the crash facility) every hundredth of a second during the crash. This information is recorded and available for later use, and will allow you to find the total external force on the dummy during the crash. In order to do this, you also need to tell the programmers how to take the data from the sensors and calculate the location of the total center of mass of the dummy every hundredth of a second.

The dummy is made of uniform density, 1.2 g/cm$^3$, with dimensions listed below. The dummy is roughly shaped to match the human form and must have the same joints in order to correctly mimic the reaction of a human in a crash. The dimensions of the dummy are given below in inches.

<table>
<thead>
<tr>
<th>body part</th>
<th>length</th>
<th>circumference at top</th>
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<tr>
<td>upper arm</td>
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<td>lower arm</td>
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</tr>
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<td>20</td>
<td>15</td>
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<tr>
<td>neck</td>
<td>6</td>
<td>circumference=14 inches</td>
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<tr>
<td>hand</td>
<td>4</td>
<td>width = 4 inches</td>
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<tr>
<td>foot</td>
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<td>width = 5 inches</td>
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<tr>
<td>head</td>
<td>circumference=23 inches</td>
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Project 4

Car barrier

Plastic barrels can be used to protect cars from striking fixed installations along roadways. A car will slow down as the barrels deform, and the car’s velocity can be greatly reduced before striking an existing object along a roadway. After a terrible accident along Rt. 4 it is decided that a large rock is too close to the road, but it cannot be removed. Since you have taken a physics course, the town administrator decides that you must design a set of barrels so that a vehicle of mass 800 kg travelling at 100 KPH will be slowed to a speed of 20 KPH before striking the rock.

After asking a renowned tranportation professor in the Civil Engineering Department you are told that if you arrange the barrels in the configuration in the figure above, the force on the car as the sets of two barrels collapse is

\[ F(x) = \begin{cases} 
4x \text{ kN} & 0 \leq x < x_1, \\
6(x - x_1) \text{ kN} & x_1 \leq x < x_1 + x_2,
\end{cases} \]

where \( x \) is the amount that the barrier is deformed.
Project 5

Comparing Bicycle Wheels

Professional cyclists usually look at a race course and make an educated guess as to what kind of wheels should be used for a given course. The decision is based on the number and steepness of the hills, weather, wind speed, the other riders, and other considerations. The director sportif, Mark Gorski, of your favorite team would like to have a better system in place. He has asked your team to determine what kind of wheel should be used for a given sprint as a function of wind speed. He will then use this information to help determine what kind of wheel to use for a whole course.

Cyclists have different types of wheels that they can use on their bicycles. The two most basic types of wheels are those that are constructed using wire spokes and those that are constructed of a solid disk (see Figure 5.1). The choice of wheel that is used depends (among other things) on how the current wind speed. The spoked wheels are lighter, but the solid wheels are more aerodynamic.

A spoked wheel is constructed by taking a hub, 420 g, and 28 spokes, 7 g each, and a rim, 480 g. A solid wheel is constructed of a hub, 420 g, a solid core fixed between the hub and rim, 300 g, and a rim, 480 g. The diameter of the rim is 700 mm and the diameter of the hub is 30mm. A solid wheel has roughly half the air-drag of a spoked wheel, and the spoked wheel has a drag coefficient $\beta = \frac{1}{2} C \rho A = .02$ kg/m. (The drag is different, not because the frontal area is different, but because the spoked wheel tends to churn up the air, while the air flows more smoothly past the aerodynamic wheel.)

Figure 5.1: A solid wheel is shown on the left and a spoked wheel is on the right.
Today, Gorski is only concerned about the effects of wind speed. He asks you to consider a cyclist accelerating from rest to 15 m/s in 4 s. At what wind speed do you switch from a spoked to a solid wheel if you want to minimize the power required for this sprint.

Hints:

1. Typically 70% of the weight of the whole bike and rider rests on the back wheel, and therefore 70% of the friction is on the back wheel.

2. Draw the free body diagram for the whole bike (leave out internal forces!) in order to get some information about the forces.

3. Consider the torques on the back wheel about the axis through the rear hub (i.e. the center of the wheel).

4. The drag force with wind = \( \frac{1}{2} C \rho A (v_{\text{bike}} + v_{\text{wind}})^2 \). Consider the wind speed to be constant throughout the sprint. Consider the drag force to be acting at the center of the wheel.

5. Consider the power due to tension in the chain. (Can you see why this is directly proportional to the power due to the biker’s muscles?)
You are in the market for a grandfather clock for your grandparents. A friend takes you to an antique store where you have find a grandfather clock with beautiful woodwork, but the pendulum and hanging weight are missing, oddly enough. Because it is not in working condition, the clock is a bargain. You have a friend who can fashion the pendulum and weights, but you have to give her the design information.

You can tell by looking at the inside gears, that they are designed for a pendulum with a 2 second period. The toothed wheel inside your clock has a radius of 5 cm and has 30 teeth of depth 1 cm. Your clock has the measurements shown in the figure below:

After doing some reading on how such clocks work you set to work to find out the following:

1. What shape and material should the pendulum be in order to have a period of
2. How much energy is lost each cycle to drag? What should be the size of the weights to give the correct energy back to the clock?

3. How anharmonic is the motion?

You write up the results neatly for yourself so that you’ve got accurate and clear results to help you complete your designs for the clock. (A complete design would require detailed knowledge of all the gears...)

Hint: you should begin by finding more information on how a grandfather clock works. But don’t get too caught up in the details of the mechanism.
As part of the NASA flight management team, you are quite dismayed to hear that an anti-terrestrial party has formed a new coalition within the Martian parliament. This is especially bad news since the Martian Lander, a manned spacecraft and the focus of your current project, is on its way to Mars now. Unfortunately, the new Prime Minister of Mars, ✧◆✦◆✦, has asked the Martian Defense Force (MDF) to erect a force field to stop the Mars Lander from reaching Mars. (See Figure below.) General ✧◆✦◆✦ promptly complied with this request.

Your flight manager is furious and demands that you prepare a briefing. The force field can only exert a force normal to its surface, and the lander cannot move past the force field. Once the lander settles on the force field, though, the force field acts like a frictionless plane. Parts of the team say that the lander will keep sliding away in one direction, and other parts of the team say that the lander will just sit on the shield without moving.
The flight manager would like to put the mars lander as far as possible away from Mars hoping that the force field does not extend too far from the planet. The problem is that if this is not the case, the lander might land on the force field a long distance away from the planet and nobody knows what will happen. In particular, if the lander is on the force field the flight manager needs to know the following:

- Will the lander move away from the planet and be lost?
- What will the maximum velocity be and when will it occur?
- What will the maximum acceleration be and when will it occur?
- Is there anything that is being overlooked? What are the potential dangers to the flight crew?
- What should the flight crew expect? (Give a qualitative description of the motion.)
- How do your answers depend on the velocity and location at impact with the force field?

The lander will be arriving in the area of the force field in about two weeks. You need to be able to answer the questions and make a recommendation about what will happen with respect to the lateral distance away from the red planet.
You are part of a team to design the inner workings of a television set. The basic layout has already been done, you are in charge of calculating the necessary voltages and the last distance $d$.

The big picture is that electrons are accelerated by an initial voltage difference, then steered by a set of horizontal parallel plates (which sweeps the beam up and down) and a set of vertical plates (which sweeps the beam back and forth). Given the complexity of the problem, at this stage you will only worry about the first vertical set of plates.

The details of the design are as follows. Electrons are "boiled off" of a hot filament; they essentially have zero velocity at this point. Some of the electrons "wander" into a region between two charged plates which are mounted vertically. Once inside this region they are accelerated; The voltage difference between the two plates is is $V_1$. The electrons pass through a small hole in this plate, travel another 5 cm before they go between two parallel plates with a variable voltage difference of $V_3$ between the two plates. These plates can deflect the beam up or down. After leaving the region with the plates, the electrons travel another 12 cm before they hit the screen. The place they hit the screen we label by $\Delta y$.

Both $V_1$ and $V_3$ can change so that the beam of electrons sweeps over the whole height of the screen (19.5 cm).
You need to make choices for $V_1$ and $V_3$ as a function of $\Delta y$ so that the individual electrons hit the phosphor screen with 10,000 eV of kinetic energy. This is enough energy to make the phosphor glow with the appropriate brightness.

You also need to find the smallest value of $d$ that will allow the electrons to be accelerated and hit the screen. You want to minimize $d$, because this minimizes $V_3$ which in turn minimizes the power needed.
Project 9

Gas Gauge

As part of your job with Really Big Motor Company, you have been assigned the task of completing the design of the gas gauge circuitry. You know that the gas level in a car’s gas tank is measured by placing a float in the tank and attaching the float to a variable resistor. The level of gas in the tank can be measured by the voltage drop across the variable resistor. However, the sloshing of the gas in the tank creates unacceptable wiggles in the gas gauge. This is corrected by attaching an RC circuit (which damps oscillations) to the circuit and measuring the voltage across the capacitor in the circuit:

The previous designer (who is on leave to travel to Mars) had just begun to consider how to take care of the sloshing of the gas in the tank. She had begun to model the actual circuit by making a huge simplification to replace the variable resistance by an oscillating voltage $V_0 \cos(\omega t)$. (Why is this useful and reasonable?) The circuit is modeled as follows:
Using the general equation for $q(t)$ for this RC circuit with a variable voltage source, find values of $R, C$ and $R_1$ that will reduce the magnitude of oscillations whose frequency is greater than 20 Hertz to 5% of their original level ($0.05 \times V_0$).

Use your values for $R, C$ and $R_1$ and $q(t)$ to create a mathematical RC circuit to approximate the fuel level readings for the data set found at the anonymous ftp site www.math.unh.edu. The file is in the pub/black/calcPhys directory and is called sig.dat.
Part III

Supplementary Materials
Project 10

Technical Writing for Projects

You have done a lot of writing. You have probably done many kinds of writing: letters, email, term papers, essays for college applications, job applications, notes to yourself, poetry, stories, or answers on essay exams. Each type of writing has a different purpose and a different audience. Each has its own guidelines. In this short note we will introduce you to writing a technical paper which may be quite different than any other kind of writing that you have previously done. However, as a CEPS major with a technical career in your future, it is likely that one quarter to one third of your work week will be spent on technical writing. It is worth learning to do well!

Technical writing can take many forms: letters, job applications, evaluation and feasibility reports, assessment studies, proposals, progress reports, trip reports, instruction manuals (the kind everyone hates to read!), and scientific reports. Oral presentations, while not writing, follow many of the same rules. The written reports for the projects have been mostly evaluation and feasibility reports. In the project on bicycles, for example, you evaluated the aerodynamic and spoked wheels for varying wind conditions. In what follows we will focus exclusively on what you will need in this class to write a good report.

We begin this report with a discussion of the general purpose of technical writing and follow with suggestions for how to achieve that purpose through organization, grammar, word choice and careful presentation of the mathematics. We will also discuss guidelines that are specific to technical oral presentations.

10.1 Purpose of Technical Writing

The purpose of technical writing is to inform, instruct and persuade the reader. For example, your supervisors may ask you to evaluate laser printers and recommend one for purchase by the company. Your job is to collect relevant data, present the data clearly, and draw conclusions based on that data. You need to give enough evidence in your report to persuade your supervisors that your conclusions are reasonable. (We will return to this same example throughout the text.)

Because the purpose of writing is to help the reader, technical writing is reader-oriented. You want to help the reader easily digest new information. You should focus your efforts on writing clearly and logically, and on presenting all of the relevant information. Analogies, examples, graphics, definitions are all appropriate if they make the
main argument clearer.

Your reader’s goal in reading your report is to learn something quickly and efficiently. For example, your supervisors need to decide within a few minutes if your conclusions about the printer are sound and whether or not to buy 1000 units of the brand that you recommend. Help your readers achieve their goal by keeping to the point. For example, do not distract them with details about your process to create the report (*It took many hours to compile this information*), with interesting but irrelevant facts (e.g. details of how a laser printer works), or efforts to entertain. (Although this rule can be relaxed if you know your readers well!)

You might come to the conclusion that technical writing is dull and lifeless. From one point of view, that is true. Certainly, very little of the personality of the writer or the beauty and richness of the English language is obvious in technical writing. However, because the information that you are sharing is of interest to the reader (otherwise why would they be reading?) then a clear and persuasive presentation can be a delight.

10.2 Audience With any kind of writing, the first thing the writer must know is the audience, that is, who is likely to read this report. If you do not write with your audience in mind, your writing will not be useful or powerful. For example, if you mention the acronym “dpi” (dots per inch) in your printer report and your supervisors are unfamiliar with the term, you will irritate and frustrate them. They do not understand what you are writing. On the other hand, you do not want to describe in detail the advantages of laser printers over dot matrix printers if they are already aware of these differences. You do not want to waste their time.

Because your audience for the reports is fictitious, we have to tell you explicitly what to assume. In these assignments, assume your reader has a knowledge of physics and calculus equivalent to any student in our class. You need not explain, for example, Newton’s method of root finding or kinetic energy. On the other hand, you do need to explain in detail the assumptions and calculations used in your arguments, since these are not well established facts.

10.3 Organization There are many ways to organize a piece of technical writing. The one that is most useful in the context of our projects is the problem-solution scheme. The main parts of a paper written in this scheme are introduction, justification and conclusion. The introduction is a concise description of the problem and a statement of the solution *without* justification. The introduction should also include a short outline of the justification that is to follow. The bulk of the paper is the justification for your conclusion which includes all of the technical details. Finally the conclusion restates the solution of the problem and summarizes the justification for the proposed solution.

This organization is an essential part of writing clearly. The information you are presenting is difficult and you must help the reader in every way possible. Readers need to know up front where you are headed and what your conclusion is; this allows them to follow and evaluate your argument more efficiently. Otherwise they will need to read the report several times to understand your point. By providing an outline up front you are giving them a way to immediately recognize how you will share your information.

For oral presentations, this initial organization is even more essential because the
audience does not have the option of listening to your talk several times. In addition, because we have limited short term memory the organization of the talk must be written as well as spoken. You need to provide a written outline at the beginning of the talk, either on the board or in your handouts, so that your audience can anticipate what will be presented.

For the same reasons, you also need to be aware of the places in your talk in which you move from one topic to another. When this occurs, give a brief, one or two sentence review of what you just covered, explicitly tell them that you will be moving to the next topic and give them a short summary of what you are about to discuss, and remind them how the new subject fits into the whole argument.

### 10.4 Stylistic hints and grammar

The problem-solution scheme helps you make decisions about the overall flow of the paper. There are also many ways to make your writing clearer at the sentence and paragraph level. Below is a discussion of some key points.

#### 10.4.1 Transitions

Readers need to follow your argument. As you begin a new paragraph or section, they need to know at the beginning how the new idea fits into the whole. For example, a beginning line of a paragraph in the printer report might read *The next characteristic that we consider is print speed*, letting the reader know that you are in the middle of presenting data on essential printer characteristics. If the paragraph does not fit into the whole argument, either rework the paragraph or omit it.

Each sentence must also play a clear role in the line of argument. Some ways of making transitions between sentences are using phrases as *for example* or *on the other hand*. Such phrases indicate to the reader how the next idea connects to the last.

#### 10.4.2 Word Choice

Difficult words make for difficult reading. Here are some general rules for choosing words.

1. Use prosaic words when possible. (For example, use *know* instead of *cognizant.*)

2. Don’t use contractions. (Use *do not* instead of *don’t.*)

3. Avoid double negatives. (For example, in writing *It is important that you do not fail to miss this seminar,* did the writer mean *It is important that you attend this seminar.* or *It is important that you miss this seminar?*)

4. If a term is likely to be unfamiliar to your audience, define it before you use it. An example might also help if the concept is new as well.

5. Be direct. Even though adverb phrases are a nice way to begin sentences, avoid using them. (:-)

#### 10.4.3 Excessive Nominalization

Nominalization is the act of changing verbs into nouns. Compare the nominalized version (*an analysis was conducted of the situation*) to the active version of the same idea (*we analyzed the problem*). The first version is less
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clear and less powerful than the second. As an extreme example (due to John C. Bean) compare the following: Effective writers express actions with verbs and for the production of a prose regarded as effective, the expression of an action through the use of a verb is the most highly preferred. One way to recognize nominalization is the presence of the tion ending - where did the tion ending show up in the preceding sentence?

10.4.4 Active vs. passive voice Consider this sentence in the passive voice: Dot matrix printers are preferred by purchasers with small budgets. The passive voice occurs when the primary focus of the sentence (the dot matrix printer) is acted on rather than initiating the action. The active version of this sentence is Purchasers with small budgets favor dot matrix printers. The active voice is more precise and less wordy and is therefore much better in technical writing.

10.4.5 Avoid the expletive pattern Some sentences are much longer and muddier than they need to be because the contain the expletives there is, there are, there were, there will be, it is, it was. For example, compare It has been decided that the company must spend less than $300 for each printer. to The company must spend less than $300 for each printer.

10.5 Mathematics Presenting mathematics to a group of people is a perilous game. Some people do not want to know details, some people do, some people just do not care, some people care passionately, and some people are afraid. You will always have to make decisions on how to balance your presentation.

For the written reports in this class, we do not want to see all of the steps presented. We would like to see important or subtle details though. For example, we do not need to see the details of integrating ∫cos²θdθ (since that is something we covered in class), but we do need to see a discussion of any assumptions that you made or why you chose a particular approach to a problem (e.g. why you chose to use conservation of energy instead of Newton’s second law). See Appendix 1 for a specific example of the level of detail that we expect.

The goal for an oral presentation, on the other hand, is to give people a more general understanding and provide them with an outline and the details of the more interesting parts of a problem. It is okay to skip steps, just let people know what you did. For example, it may take five or six algebra steps to simplify an equation down into a usable form. During a talk, do not go through every step in excruciating detail. Just write down one or two of the steps and simply state why you end up with the final equations. If someone does not understand a step, they will ask!

Keep a list of all of the steps with you. Someone might ask you a pointed question or disagree with one of your results. Be prepared to justify everything that you say!

There are times when you cannot avoid working with very complicated equations. For the really nasty stuff, do not write them down on the board. You can make up a transparency with very complicated formulas - this saves time and places less demands on the patience of your audience.

In addition to transparencies, handouts are also helpful because they give your audience a visual and permanent record of what you said. These handouts can include the
10.6. ORAL PRESENTATIONS

outline and the key mathematics and graphs. In general, the more that you hand out to the audience the better, but you should be very careful. It can be difficult to refer to certain things on a page that you hand out. Make sure that everything is clearly labeled. Also, do not put items from more than one topic on a single page. This will allow you audience to keep things organized.

10.6 Oral Presentations All of the above remarks on purpose, audience, organization, transitions and word choice apply to oral as well as written technical presentations. In this section we will discuss a few guidelines that apply to oral presentations in particular.

10.6.1 Where is your audience? Face the audience when you are talking and do not block the board. It is easy to get wrapped up with the equations on the board, but do not forget that you are trying to share your information with the rest of the class. Face the class and speak in a loud clear voice. The people in the back of the room would like to hear you.

(Tip from Kelly: when I am in front of a class I find it hard to keep the equations straight, avoid blocking what I am writing, make eye contact with people, and project my voice all at the same time. Sometimes, with complicated derivations, I just look at the back of the room and try to focus my voice on the back wall.)

10.6.2 Practice, Practice, Practice Practice your presentation. Practice by yourself and pay careful attention to the timing. You should also practice with the rest of the group. It is quite difficult to get a smooth transition when you are passing off the speaking position to another person. Practice this!

You will find as you practice that you may stumble over your wording in several places. It is best to clear up these difficult spots before you are in front of an audience.

Remember the old baseball saying: Practice does not make perfect. Perfect practice makes perfect.

When you practice, always keep a clock in clear view.

10.7 Conclusion and Summary The hallmark of good technical writing is clarity and conciseness. This document in itself is a short piece of technical writing. Did we follow our own suggestions?

The key points to keep in mind for both oral and written presentations are as follows:

- Begin your discussion with a summary of the problem and your solution.
- Provide your audience with an outline to help them follow your presentation.
- Make clear how each new idea fits in the whole; make the transitions smooth.
- Give details of important or difficult parts of your justification; give summaries of more mundane parts of your justification.
- Present your information clearly and concisely.
• End with a restatement of your solution and a summary of the justifications for that solution.

10.8 Appendix 1 Below is an example of the level of justification that we would like to see. The example is calculating the electric field due to a bar of uniform charge at a point $P$ along the perpendicular bisector of that bar. This level of detail would be appropriate if we pretend that this example was never done in class.

Notice how much information is also conveyed in the sketch.
We can find \( \vec{E} \) due to the whole bar by adding up \( \vec{E} \) due to each point of charge in the bar; this is the principle of superposition. We also use the known formula for \( \vec{E} \) due to a point charge.

This is due to symmetry. \( E_x \) due to a chunk of charge at location \(-x\) is equal and opposite to \( E_x \) due to the chunk of charge at location \( x \), where the origin is at the middle of the bar. Due to symmetry \( E_y \) for the whole bar is equal to \( 2 \times E_y \) for half the bar, since the \( y \)-components on each side are equal and they add.

To obtain the \( y \)-component we multiply the magnitude of the \( \vec{E} \) field by the sin of the appropriate angle.

When we do Riemann sums, we need to know what is varying; in this case it is \( x \), the location along the bar. In the following steps we write everything in the sum in terms of \( x \) and parameters. Also, we need to find a \( \Delta x \) in the sum.

Because the charge is uniformly distributed in the bar, the relationship between charge and bar length is linear. The slope \( Q/L \) is obtained from looking at the charge in the whole bar.

Here we use the Pythagorean theorem and take the origin to be in the middle of the bar.

\[ \Delta q = \frac{Q}{L} \Delta x \]

\[ r_i = \sqrt{x_i^2 + h^2} \]

\[ \sin \theta = \frac{h}{\sqrt{x^2 + h^2}} \]

\[ E_y = \frac{2kQ}{L} \int_0^{L/2} \frac{h \, dx}{(x^2 + h^2)^{3/2}} \]

Take the limit as \( \Delta x \to 0 \) so that the sum becomes and integral. Substitute in values given above, take constants out of the integral. Use symmetry to integrate over half of the bar and multiply by 2 to get the full \( E_y \).

\[ E_y = \frac{2kQ}{h(L^2 + 4h^2)^{1/2}} \]

Use u-substitution with \( x = h \tan \theta \). Pull a factor of 2 out of the square root in the denominator.