A Chemistry and Society Book with Experiments and Discussion of Climate Change

Michael E. Green

University of New York, USA, https://orcid.org/0000-0001-9008-9085

Abstract: In a chemistry course for students not majoring in science, there is more to learn than some memorized facts: the student can find, in most non-major chemistry texts, the definition of atomic number, something about chemical bonding, and names of some classes of chemical compounds. Where facts come from and how accurately they are known are often missing. A book is now available in which a number of experiments are included. The first two "experiments" can be done in class; they help the student to understand what is meant by experimental error, accuracy, and precision. The remaining experiments are real, and require a laboratory. In courses lacking labs, students can be given the results, as done by technicians. This was done when the course was most recently taught. Three repeats of measurements allowed an error estimate, to be included in a student's pseudo-lab report. Most lab reports indicated the students understood the material. The text included a qualitative introduction to thermodynamics and black-body radiation, to present some of the science behind climate change. pH is introduced with application to ocean acidification. A Chemistry and Society book should apply the science to the most pressing societal problem with a scientific basis. Also, the book starts with a much more considered introduction to what is usually passed over as "scientific method". There is a fairly extended discussion of the distinction between hypothesis and well-established theory. There is a chapter on the history and philosophy of science, not going deeply into either, but setting out much more than is found in many books. The book is Chemistry and Society (M. E Green, 2018, Linus Publishers). Based on the final exam over 2/3 of the students understood the material. Overall, this did as well as standard texts, when used for the same course.

Keywords: Public implications of science, Scientific proof, Climate change, Student experiments, Error analysis

Introduction

A science and society book for non-science majors has more than one purpose. It must introduce the student to some of the facts of one science or another, or sometimes some combination. Most textbooks for such courses do this, often quite well. There is a variety of books for such a course in chemistry; here we cite a couple of examples, but this list is not at all comprehensive(Cooper, 2020; Jordan, 2017). On-line separate topics that

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allow a faculty member to prepare an individual curriculum also exist, e.g., this site from Lumen Learning("Chemistry for non-Majors," 2021). Timberlake and Timberlake have a book that is in its sixth edition (Timberlake & Timberlake, 2016) Each book has its own emphasis. For example, the book by Jordan just cited emphasizes biochemistry. There is a successful multi-author series with the American Chemical Society listed as author, now in its tenth edition; this is accompanied by an optional lab manual, one of very few that has that even as an option. That book includes chapters on climate change and other public policy issues.

It is worth considering why we require non-science major students to take such a course. It has been suggested by Baum (Baum, 2004) that it is because the non-majors will play a key role in setting public policy, and therefore need to know enough science to apply it to public policy. In essence, this is the same point of view we take here. The specific facts (atomic weights, ionic vs covalent bonding…) will do little to affect the future course of the students understanding of life. If taught merely as specific facts, they will be learned for the final exam, and forgotten. The fact that such facts exist is itself useful, and will be retained; the existence of such facts, possibly together with understanding that these facts have been established by rigorous methods, and can be accepted as true, is important. This is not trivial, given the attacks on science we are experiencing. However, if we give the students no reason to understand how the facts are established, then the student leaves by the same door wherein they came. Furthermore, the use of science in understanding certain problems in society is, to scientists, obviously essential, but to much of the population, not appropriate at all. Students, at least, should understand the fundamental reasons that science is a reliable guide to policy, as well as the limits of science, because of error limits on measurements, and the necessity of building upon what has gone before. The course must enable the student to understand why the facts obtained by the use of scientific methods and measurements are reliable, and the conclusions that can be drawn from them can be relied upon. If, in addition, the course applies to the leading problem of the day for which technical content is central, in this case climate change, it has further salience, and for many students would be reason in itself to pay serious attention to the course. If students take in the material with some degree of seriousness, they will be able to participate that much more knowledgeably in the public discourse on the subject.

This Book (Green, 2019)

We take a viewpoint that non-major students need to know enough science to be able to appreciate scientific arguments. This includes understanding where scientific knowledge comes from, what the limits on this knowledge are, and why we can be confident that when properly acquired, this knowledge is reliable. If the student gets the sense of how data are acquired, and what is meant by accuracy, this makes it possible to not only understand but see the reason for accepting scientific results. Error limits mean the results are not exact, but they also mean that the results are reliable with these limits. The student will not come away as a scientist, but should come away with an appreciation of the reasons for doing science, and the importance of using the results of scientific work in setting public policy. Therefore, we will here go through parts of the book, sufficient to gain an appreciation of what the book does, and what the student should come away with. For this reason, we integrate experiments with text, so that the student gets the sense of how at least a little of the information being discussed in the chapter can be acquired. Some specific topics are covered that are necessary for the overall understanding of the discussion of climate change, but might not otherwise be covered in a book at this level. We include thermodynamics. Other books discuss heat, sometimes entropy, but it is relatively unusual for such a course to discuss the laws of thermodynamics; it is necessary here for understanding much of the science behind energy generation, with application to energy storage. In general, the book was written with a more physical point of view than most chemistry books for non-majors. It covers the material needed to understand the main points that it is intended for the student to understand; the student, by the end of the course, should be able to contribute to the public discussion of science, and of its application to climate change. The price for this is that the student will have seen less of the standard material than is found in most texts. The book is designed for a one semester course and is set up to be covered in the order presented; the later chapters depend on material covered in the earlier chapters.

The book begins with a discussion of “scientific method” that is more extensive, and less simple, than that usually given. The difference between hypothesis, a guess, and theory, generally well established, with much evidence, is considered. There is a limited discussion of the philosophy of science. Topics discussed include Popper’s ideas on approaching a proof by failure to disconfirm a hypothesis by experimental tests: testing a hypothesis by experiment is necessary, as well as understanding that one cannot generally prove something right, but one can prove it wrong; if after enough attempts to prove it wrong have failed, one must begin to believe that it is not wrong. There is a more extended discussion of what experiments do, and how they are analyzed, and relate to a testable hypothesis. This has a further implication: one cannot take an experimental result as infinitely precise; there is always a limit to the accuracy of measurements. Until one knows how accurate a measurement is, one cannot know whether the result can be trusted to drive a policy.

The experiments have two roles: they show the students how it is possible to know something: one must measure it. There are enough experiments to make this point clear. In addition, whether the students do the experiments themselves or not, they do the data analysis, including experimental error, a topic often omitted in presenting “facts” in a course for non-majors; this includes a fairly formal error analysis for each experiment. A couple of the experiments may be too difficult for the students, or they may require more time than is available in the typical student lab period; in these cases, the students must be given data. However, there are enough real experiments that students could actually do their own measurements, if the course schedule includes labs; if not, they can be given the results of the experiment, as done by technicians; the students must still do an error analysis based on the scatter of these measurements. The last experiment, involving black-body radiation, is also somewhat difficult without equipment not always found in a first-year lab, and simulated data can be used. However, this topic cannot be avoided in a discussion of the science behind climate change. On the other hand, experiments involving pH are entirely feasible, and could be done by the students themselves. In the text, the topic is applied to the falling pH of the oceans, which is one of the effects of increasing atmospheric CO_2 concentration. The discussion of acids and bases includes the $H_2O + CO_2$ equilibria, with an explanation of how this affects ocean pH. One problem that showed up with some students was that they had lost even their junior high school arithmetic, so there is a brief (re)introduction to logarithms and exponents. Hopefully most students could skip this, but either way it was possible to discuss pH after this.

The experiments were mostly fairly simple; the students would be in the lab for probably the only time in their lives, and there is no way they could be expected to be highly precise. Neither were the measurements always very interesting scientifically. One simply required the students to prepare a solution of known concentration. That experiment is inserted here as a sample:

Sample Experiment

Experiment 4A: Preparing Solutions of Known Molarity

Instruments and Materials

One 250 ml plastic graduated cylinder, one stirrer and one stir bar, one stemless funnel, one deionized water bottle, one 9 cm glass pipet, one pipet bulb, one spatula, an electronic balance, deionized water, paper towels, and several packs of sugar. Refer to Figure E4A-1 for details.

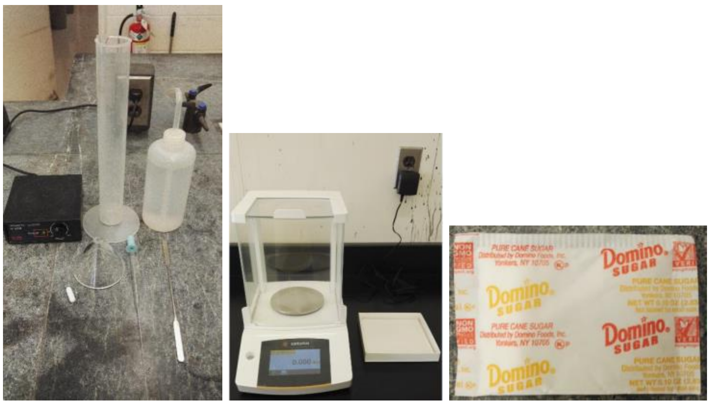

Figure 1. Instrument and Materials used

Experimental Procedure

1. *Equipment Setup*

Place the 250 ml cylinder on top of the stirrer, put a stirring bar inside the cylinder, add deionized water to the cylinder, and use the 9 cm glass pipet to break the air bubbles inside the cylinder; then continue to add water up to the 230 ml mark of the cylinder; record this under the "cylinder mark before sugar added" column in Table E4A-1. Wipe the water on the cylinder wall above the 230 ml mark with a paper towel. Place a stemless funnel on top of the cylinder.

2. *Measuring the volume expansion of sugar*

a. Weigh one sugar bag to the nearest milligram (0.001 g); record the mass in the "mass of sugar packet" column in Table E4A-1.

b. Turn on the stirrer, carefully open the sugar packet (keep the torn paper bag), and slowly transfer the sugar into the cylinder via the stemless funnel. Lightly tap the funnel and the cylinder wall to let the sugar all transfer inside the water. Stir for several minutes to let the sugar dissolve. Turn off the stirrer. Read the water level in the cylinder when the water has stopped moving, and record it under the column of "cylinder mark after sugar added" in Table E4A-1. Weigh the torn paper bag, record its mass in the "mass of paper bag of the sugar packet". ***Show your data to your instructor before you proceed to the next step.***

c. Weigh another sugar bag to the nearest milligram, repeat **step 1) and 2)**. Continue to add two more sugar bags following the same procedure into the cylinder to finish **Trial One** test.

d. Dump the sugar solution into the sink, **keep the stirring bar**, and rinse the cylinder several times to clean it. Repeat **step 1) to step 3)** to run another two tests: Trial Two and Trial Three. Record the results in Table E4-2 and Table E4-3 respectively. Note on Tables: Add lines for trials as needed—the number of blank lines here is not sufficient.

3. *Cleanup*

Dump the sugar solution to the sink, rinse the cylinder, clean your bench, and put everything back as it was when you entered the lab.

Data Entry: Sample Tables for three repetitions of the measurement

Table 1. Trial One Experimental Result

Trial One	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (mL)	Cylinder mark after sugar added (mL)	Volume increase (mL)
1						
2						

Table 2. Trial Two Experimental Result

Trial Two	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (mL)	Cylinder mark after sugar added (mL)	Volume increase (mL)
1						
2						

Table 3. Trial Three Experimental Result

Trial Three	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (mL)	Cylinder mark after sugar added (mL)	Volume increase (mL)
1						
2						

This is the form given to the students, if the students are to do the experiments themselves. If the students do not have a lab period, they are given the results, which are in the instructor's manual; here are the results for this experiment, as given in the instructor's manual; the instructor in this case will give the results to the student. With these results, the students are expected to write a lab report. When the course was taught at City College of New York, this was done.

Table 4. Trial One Experimental Result

Trial One	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (ml)	Cylinder mark after sugar added (ml)	Volume increase (ml)
1	2.970	0.173	2.757	230.0	232.0	2
2	2.958	0.172	2.786	232.0	234.0	2
3	2.983	0.176	2.807	234.0	236.0	2
4	2.987	0.173	2.814	236.0	238.0	2

Table 5. Trial Two Experimental Result

Trial Two	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (ml)	Cylinder mark after sugar added (ml)	Volume increase (ml)
1	3.051	0.168	2.883	230.0	232.0	2
2	3.027	0.172	2.855	232.0	234.0	2
3	2.954	0.174	2.780	234.0	236.0	2
4	3.005	0.170	2.835	236.0	238.0	2

Table 6. Trial Two Experimental Result

Trial Three	Mass of sugar packet (g)	Mass of the paper bag of the sugar packet (g)	Sugar Added (g)	Cylinder mark before sugar added (ml)	Cylinder mark after sugar added (ml)	Volume increase (ml)
1	3.040	0.167	2.873	230.0	232.0	2
2	3.042	0.176	2.866	232.0	234.0	2
3	2.954	0.173	2.781	234.0	236.0	2
4	2.926	0.171	2.755	236.0	238.0	2

There is enough scatter in the data as given (this is real data: the experiment was actually done by lab technicians) for the students to do an error analysis. They are also expected to answer questions at the end of the lab report.

Error analysis: from the scatter in the repeat measurements, estimate how accurately the solutions have been prepared.

Answer the following questions:

1. What is the Molar mass of table sugar? ___________________________
2. How many moles of sugar are in one packet of sugar, assuming the weight on the label is correct? How many moles, based on your weighing of the contents of the packet? ___________
3. How many moles per liter are in each sugar solution? _______________
4. How large is the scatter in the repeat measurements? Can you estimate the precision of the volume measurement? The accuracy (here, beware of bubbles)? _______________________

This experiment was accompanied by text introducing molarity, and then pH. There was an experiment on pH as Thwell, in which $CaCO_3$ is dissolved. Originally it was intended to use CO_2 in water to dissolve calcium carbonate. The experimental procedure is provided in detail to show what the student is expected to do, and the questions show what the student is expected to understand.

Note: Dropping the pH with CO_2 in water produced a pH drop insufficient to dissolve $CaCO_3$ during class time, so a strong acid had to be used to do that experiment in the time available.

Discussion to This Point

The introductory material is suitable for the first week of the course, concerning definitions of theory and hypothesis, references to Karl Popper and Thomas Kuhn, and other material devoted to discussion of what science is about, and how it proceeds. We then proceed go on to the basics of chemistry, which are must be in any book on the subject. These include atomic weights, the nucleus and electrons, elementary stoichiometry, solution concentrations, and chemical bonding. What is not always present is a fairly extended discussion of equilibrium and rates, leading to a need for a basic understanding of thermodynamics. The main section of the book, through experiment 9, and the Summary on Chemistry, has relatively little direct relation to climate change, although the lowering of pH of the ocean is discussed with pH. The inclusion of experiments illustrates several of the main concepts e.g., error analysis). Texts that have no experiments, hence no error analysis or discussion of how we know what we know, and to what accuracy, fail to teach a central aspect of what science means. By including experiments, we allow consideration of the kind of work needed to establish scientific facts. Thus, by about 2/3 of the way through the book, the student should have learned the kind of effort required to obtain facts, and have come to understand the necessity of having a good estimate of how well the fact is known. In addition, the student should have learned fundamental chemical concepts, including bonding, chemical reactions, both as to equilibrium and kinetics, and the other topics listed earlier. This accomplished, it is possible, and necessary, to apply what has been learned to climate change.

Rates of Reaction and Chemical Equilibrium Followed by Thermodynamics

Rates and chemical equilibrium are presented before the introduction to the Laws of Thermodynamics. We start with the idea that a reaction must overcome a barrier, and use the standard simple diagram:

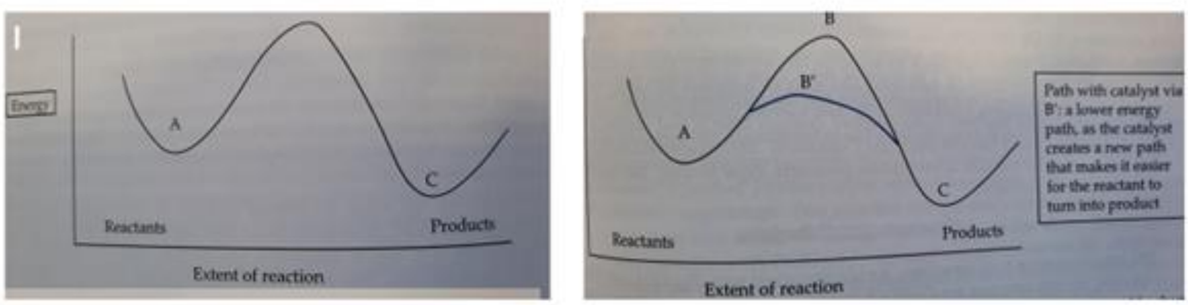

Figure 2. These figures show the energy barrier for a reaction without (left) and with (right) a catalyst, shown to lower the barrier to reaction, speeding it up. In the book, these figures are only 3 pages apart. The idea of an energy barrier is introduced early in the chapter on rates and equilibrium.

Once the idea of rates is understood, equilibrium follows, and the relation of equilibrium to the ratio of rates is next. Again, simple figures illustrate the point. There is no math used.

To illustrate the idea of equilibrium, and the ratio of the rate of a forward reaction to the reverse reaction, Figure 3 was used:

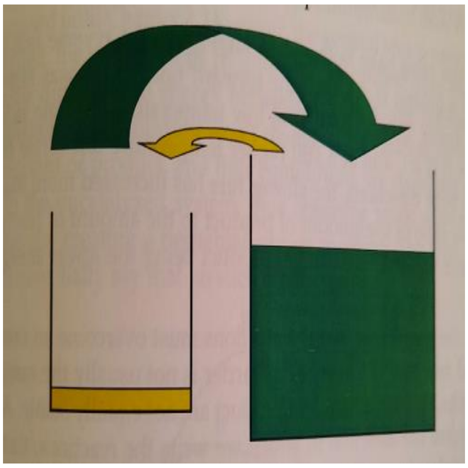

Figure 3. (This caption is copied directly from the book, and illustrates what the student was given, so as to be able to understand the relation between the ratio of rates and chemical equilibrium)

Forward and reverse reactions at equilibrium. In this example the reaction from left to right is fast (the big arrow), from right to left slow (small arrow) As a consequence, the amount on the right (the product, shown in green) is large compared to the amount left (reactant, shown in yellow) One can think of the arrows as a sort of pipe, with the amount that can go through determined by the size of the pipe. On the other hand, the amount of material in the product bin is larger in exactly the same ratio as the amount the pipes carry in the two directions. As a consequence of the ratio of amount equaling the inverse ratio of the rates, the amount passing through the pipes, forward and reverse, is the same per unit time, and amounts of the substances, yellow and green, do not change with time. The system remains at equilibrium.

With a little further explanation, the students understand that the ratio of the rates is the inverse of the ratio of the amount of each substance at equilibrium; it has to be made clear that the rates apply to the entire amount, so that the "pipe:" analogy does require a little modification. However, the point does become clear.

After the diagram in Figure 2, this understanding can be extended to the effect of temperature; higher temperature makes both rates larger, as the barrier in the figure remains the same, but the energy available to climb the barrier becomes larger, so both "pipes" (rates) become larger, but the smaller one increases more, relative to the larger one, so that the equilibrium shifts in favor of the higher energy substance, in this example the reactant. A figure similar to Figure 3 makes the point graphically.

Two experiments (but counted as only one of the eleven; only one can actually be done in lab) go with this chapter. The first experiment (in principle only—not to be done in lab), is the reduction of $Cu(H_2O)_4^{2+}$ by metallic tin. This takes too long to actually do, but by including the description not only of a rate measurement, but temperature as well, helps the student to understand the chapter. The questions that the student must answer (with help from the instructor, since the data are not actually available) are as follows:

1) What equilibrium was studied in this experiment?

2) Why does temperature change affect equilibrium in a chemical reaction? (Remember Fig. 7-1) (*this is Fig. 2 in this paper)*
3) How can you tell when chemical equilibrium has been reached in a reaction? Caution: Your answer will be valid for this reaction. In some cases, there are more complications.
4) Why do we expect the initial rate to have a regular pattern, but expect the equilibrium and also the later parts of the rate curve to be more complicated? *(Note: This is a tricky question, and probably should have been omitted)*
5) Is there an upper limit on the concentration that it is prauch a limit?ctical to use in this experiment. What determines such a limit? Is there a way to work around the limit? (Hint: the answer to this last question is not so obvious.)

This gives a sense of what the student is expected to understand; the questions are to some extent open ended, and allow the student to show his or her level of understanding of the principals involved.

This done, a more practical experiment, which the student can actually do in lab, is provided. The dye FD&C Red #3 is oxidized with 6% NaOCl (household bleach, essentially). The loss of color as a function of time is measured with a spectrophotometer. Two concentrations of dye are used, and the rates compared; a log(absorption) vs time curve gives the rates (by this time, those students who needed a review of logs have had the review). The questions that go with this experiment are more directly related to the experiment itself, and include questions as to the reason the late readings are less likely to be accurate.

Taken together, this chapter illustrates the approach to getting the students to understand both the principles underlying chemical processes (Figure 2 is valuable here), some of the consequences of these principles, and then, with the aid of an experiment, helps the student to see how they apply to a real system. It is expected that the student will be able to see how the same ideas apply in other cases.

Thermodynamics: In the next chapter, we go through the Laws of Thermodynamics. The fundamental principle of the First Law and the Second Law is not hard to illustrate. For the Second Law, for instance, we use the classic example of the ship that cannot move by using the energy of the sea water, spitting out ice cubes at lower energy. This does not violate the First Law, and is a clear example of the limitations set by the Second Law. We also note that these two Laws are stability conditions for any well-run universe. It would be inconvenient to have things pop in or out of existence, forbidden by the First Law, or to have all the air in a room go to one side, forbidden by the Second Law. It is not difficult for students to get the point.

Once we have this much, we introduce heat, work ΔH, ΔS, and then ΔG; we can then reinterpret Fig 2 in terms of ΔG. There are two experiments, one illustrating exothermic and endothermic reactions (dissolving KNO_3 in water, endothermic, and one dissolving $CaCl_2$, exothermic). There is a second experiment using osmotic pressure to illustrate ΔG as the driving force. While osmotic pressure is an odd topic in this level course, it is a clean illustration of how ΔG determines the result of a chemical (sort of) process. The fact that no chemical reaction is involved simplifies the interpretation for the students.

Of course, an experiment must go with this, and we use two: one is freezing point depression, which is simple and practical. The salt used for the solution is NaCl, although others would do; NaCl is easily available and cheap. The other experiment is less practical, and may not be done in class; however, it does allow the student, by considering what drives osmosis, to understand how ΔG drives the process. Students can be given data, or pseudo data, to analyze.

For the freezing point experiment, the questions the students must answer at the end of the lab report include:

1) Can you see a way to make the freezing point determination more accurate with the same thermometer? If not, why not? [Note: the thermometer, according to the instructions, should be accurate to 0.1°C.]
2) Can you think of a physical reason for the existence of a latent heat of fusion? Would you expect that there would be a latent heat of vaporization when water boils? Would this be larger or smaller than the latent heat of fusion? (Hint: think about the differences in the molecular arrangement between the solid (all molecules in contact, and well ordered, liquid, all molecules in contact, not well ordered, and vapor, molecules far apart, no order)
3) Would a solution of sugar in water have a lower or higher *boiling point* than pure water Explain. (Hint: Go back to the explanation of freezing point depression. Then consider that the vapor phase with which the water must be in equilibrium in order to boil has a *higher* free energy than that of the liquid water, while ice has a *lower* free energy. We had to withdraw extra free energy from the liquid to get it to freeze; we have to add free energy to make the liquid be in equilibrium with vapor. What is the consequence?
4) Which of these would have the lowest freezing point: a) 1 M sugar solution; b) 0.7 M NaCl solution c) 0.5 M $CaCl_2$, which should produce 3 ions per $CaCl_2$ d) a solution of 400g of a non-ionizing substance, with a molecular weight of 1000 g/mole, in one liter of water.
5) Of the solutions in question 4, which would have the largest, and which smallest, osmotic pressure? Why? Is the question really redundant after question 4?
6) We said that the freezing point depression should be 3.72°C/M. (that is, 3.72°C per molar concentration) Can you detect the difference between your measurement and 3.72°C/M, when you take into account the experimental error?

These questions suggest at what level the students were expected to understand the driving force for physical processes and the role of free energy. It was still necessary to use "Hints" to pull them across some barriers that they would not otherwise have been able to cross in answering these questions. However, in a qualitative way, they are expected to have a reasonably sophisticated understanding of what drives physical processes. They should also be able to put the previous, rates and equilibrium, chapter together with this newer set of ideas. The instructor may have to help the student realize the connection, although the book does try to do this. Since this was preceded by a chapter on how free energy drives chemical reactions, and the freezing point depression/osmotic pressure physical processes are presented as directly analogous to chemical reactions, the students are expected to come away with a physical understanding of how thermodynamics controls processes in the real world. Along the way, they must acquire some basic physical understanding, for example, of why the free energy of water in pure water is higher than it is in a solution, or why water in the vapor phase has higher free energy than in the liquid.

If there were only text, and no experiment, it would be much more difficult to make the connection between free energy, the First and Second Laws, and real processes like chemical reactions or freezing point depression. Along the way, we introduce the standard thermodynamic quantities of heat, work, energy, enthalpy, and entropy. All this is done using no math beyond elementary arithmetic, and as little of that as possible.

With the concept of free energy, and equilibrium and rates, the students can understand how black body radiation from the sun and from the earth leads to something like a steady state and fairly constant energy balance. We proceed to that topic.

Summary of The Remainder of The Book, With the Applications to Climate Change

1: There is one other topic that must be covered before enough of the background can be understood by the student to proceed to climate change: light and radiation. This is rarely taught in a chemistry course at this level, not because it is not an appropriate topic in chemistry, but because it is not all that easy to explain, and partly because it seems to be a specialized topic. It is often enough left to advanced courses, omitted even in science major chemistry courses. In reality, it is not less relevant than teaching more reactions, or more examples of plastics, which is a specialized topic itself. In fact, light plays a critical role not only in providing energy for some chemical reactions (including some polymerization reactions that lead to plastics), but also in the energy balance of the earth. It is in the latter context that we discuss light, and black body radiation in particular. For this we have to start with introducing electromagnetic waves, but even before that, the idea of waves. It is then possible to introduce wavelength and frequency, and the idea of a spectrum. With this, it becomes possible to introduce black body radiation; thermodynamic equilibrium having already been discussed, the idea that this radiation is in thermal equilibrium is natural.

Ocean acidification has been discussed with the introduction to pH. Other examples of the role of lower pH on $CaCO_3$ include the erosion of monuments, including the Taj Mahal, which is largely made of marble. However, the main discussion concerns the effect on sea creatures that form $CaCO_3$ shells. This begins to suggest how the human production of CO_2 affects the environment, even before we come to the effects on climate.

The emphasis on climate change requires introducing discussion of alternate energy sources. The earlier introduction of thermodynamics, in addition to rates and equilibrium of chemical reactions, makes this somewhat easier. The discussion of spectra is somewhat detailed, as it is necessary for the student to understand how there is a difference between what the earth absorbs and what it reradiates, which in turn requires the extended discussion of black body radiation. In addition, the added contribution of CH_4 to light absorption in the atmosphere and thus atmospheric heating can only be understood with a discussion of absorption spectra. Overall, therefore, there is an appreciable section devoted to light, black body radiation, light absorption, and their measurement. Thus, the students are introduced to spectrometers. This being a course with experiments, there are two out of eleven experiments devoted to light absorption and spectroscopy. The eleventh experiment is difficult, and may be omitted when the course is taught, but is well worth discussing. The problem is that there no good way of producing black body radiation in a manner that fits an ordinary lab spectrometer, unless a high temperature source is available, and some sort of light pipe (optical fiber) can be obtained. However, the experiment may be modified or adapted, and in any case, it is not critical that it is actually done. The book has the standard graphs illustrating the "hockey stick" increase in global temperature, as well as the Keeling curve showing the rise in CO_2 with time. In essence it is a standard discussion, but this time the students have the background to understand where the data is coming from, and enough experience to understand how the data must be taken seriously. No extended discussion of the effects of climate change is included, as this is beyond the scope of the chemistry text. It would be good to add a second semester to this course, devoted to earth science, which could include all the effects to be expected from climate change. However, this seemed too great a diversion for a book that needed the entire semester to teach the rudiments of chemistry.

2. Finally there is a chapter on nuclear energy. An earlier version of the book was used in 2011 when the Fukushima meltdown was occurring, so it became necessary to include that material in that class, and the notes for that class have been expanded into a chapter here. No experiment goes with this chapter, but the basic ideas of radioactivity, half-life, chain reaction, and the structure and function of a boiling water reactor, are covered. The discussion is agnostic as to whether the use of nuclear power is a good thing; the reactor does not produce CO_2, but disposal of nuclear waste is still an unsolved problem. It was not originally intended to include this chapter, but it is actually useful; students know at least a little about another public problem with a major technical component, and they have the background at this point to understand it.

Experiments

The book has 11 experiments, some with alternates, some with subsections, that are designed to illustrate many of the main concepts that constitute the text.

The first two experiments can be done in class. These are intended for teaching the ideas of estimating errors and of testing a hypothesis. The first experiment consists of comparing two lines (they have to be shown as perpendicular to prevent judging by eye); the lines are measured with a coin (not so accurate) and then a ruler with a mm scale (smaller error). The error estimate as done is augmented by illustrating the effect of using the more accurate test instrument, the ruler.

The largest number of experiments covers the chemical concepts that make up the central portion of the book. While the book is intended to have the students understand how science is done, and the relation to a critical societal problem, nevertheless it would not be a course in chemistry without covering fundamental chemical ideas. These topics are reinforced by the experiments. Often when the topics are first covered in class, they seem opaque to many students. The experiments both serve as review and reinforcement, and make the concepts concrete with specific examples that make the student work out the calculations for a real example. The concepts are not only the usual (pH, for example) but also the relatively unusual topic of osmotic pressure; this is not a normal topic in such a course, but it does illustrate the concepts covered in the sections on thermodynamics. Once the student has the idea that a process, in this case, water transfer across a membrane, is driven by a free energy gradient, much of the rest of chemistry makes sense. In this course, in which the student is expected to understand what drives chemical change, such an experiment is necessary. Osmotic pressure, in which there is a simple physical application of the change in free energy, without chemical complications, serves this purpose.

The final two experiments are directly concerned with light absorption and black body radiation. These topics are necessary for the discussion of climate change. The last experiment is difficult, in that it requires measuring a black body source. It is difficult to get the light from such a source at a relevant temperature into a spectrophotometer of the sort found in most first-year classes. This experiment may be only discussed in class.

Overall, the experiments, as noted earlier, also introduce students to the use of a limited set of chemical instrumentation. This is missing from a course in which experiments are not included. Even if the students do not get to do the experiments in a real lab, they can still be shown the apparatus and understand how the measurement is made, as well as the accuracy of the instrument. Optionally the lecture can cover the range of available accuracy in instruments; for example, there could be a discussion of the accuracy of spectrophotometers. However, this is not essential, and is not explicitly supported by the text. There is some discussion of the accuracy of balances, however. The initial in class experiment also covers the topic of accuracy of “instrumentation” (there, pennies and rulers, not real instruments, but the same idea).

If the students get to do the experiments, they come away with a valuable sense of what chemistry is about, and in particular the way in which chemical knowledge is obtained. Even if the students only see a demonstration, and then do a lab report with data obtained by technicians, they have learned more than they would by memorizing facts that are presented as true because the book says so and the teacher says so. They will not discover new facts, but they will discover what it means to discover new facts.

Summary

The book is intended to teach the students (not exactly in the following order):

1) the rudiments of chemistry
2) the nature of measurement, with the meaning of error analysis; to the extent possible, some experience with chemical experiments
3) what it means to say that something is proven, or disproven, in science
4) certain topics not always found in textbooks of this type, especially in thermodynamics, and blackbody radiation
5) the application of these concepts to ocean acidification and to climate change; this is a major point and is required for the students to know how what they have learned applies to the present major public issue with technical content. This is where the students will have to use judgment as political actors, and the book is intended to provide a basis for students to make the necessary judgments.
6) finally, the rudiments of nuclear energy, as it is used now for commercial power generation

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Appendix

TABLE OF CONTENTS:

FORWARD: TO THE INSTRUCTOR AND THE STUDENT: **4**
1: INTRODUCTION **10**
2: THE LABORATORY, THE TEXT, AND THE CONTEXT **19**
WHAT IS A LAB REPORT AND WHY DO WE BOTHER? **24**
EXPERIMENT 1: THE FIRST MEASUREMENT: HOW LONG IS A LINE? *33*
ORDERS OF MAGNITUDE AND THE MEANING OF NUMBERS **40**
EXPERIMENT TWO: FORMING AND TESTING A HYPOTHESIS *44*
SAFETY **50**
UNITS **52**
EXPERIMENT THREE: CONSERVATION OF MASS *58*
3: ATOMS, AND HOW MOLECULES PUT THEM TOGETHER **70**
4: THE PERIODIC TABLE, AND MORE CHEMICAL PROPERTIES **81**
5: MOLECULES, AND THEIR STRUCTURE **89**
6: CONCENTRATION, WITH EXAMPLES FROM ACIDS AND BASES **103**
EXPERIMENT FOUR A: PREPARING SOLUTIONS OF KNOWN MOLARITY **108**
REFRESHER ON LOGARITHMS 114
EXPERIMENT FOUR B: ACIDS AND BASES: Part 1 *118*
Part 2 *123*
EXPERIMENT FIVE: MORE ON THE EFFECT OF ACID ON $CaCO_3$ *128*
EXPERIMENT SIX: ANALYSIS OF A SOLUTION; WHAT DO WE HAVE, AND HOW MUCH?
EXPERIMENT SIX A *136*
EXPERIMENT SIX B *141*
7: CHEMICAL EQUILIBRIUM AND RATES **145**
EXPERIMENT SEVEN: RATES AND EQUILIBRIUM *154*
8: THE LAWS OF THERMODYNAMICS **164**
THE APPLICATION TO CHEMISTRY **180**
ENERGY STORAGE **186**
EXPERIMENT EIGHT: HEAT OF REACTION/HEAT OF SOLUTION *190*
EXPERIMENT NINE A: OSMOTIC PRESSURE
EXPERIMENT NINE B FREEZING POINT DEPRESSION *212*
SUMMARY ON CHEMISTRY **216**
9: LIGHT ABSORPTION AND SPECTRA **220**
THE ABSORPTION OF LIGHT WARMS THE PLANET **229**
EXPERIMENT TEN: LIGHT ABSORPTION AND SPECTRA *233*
10: CLIMATE CHANGE **238**
EXPERIMENT ELEVEN: RADIATION, THE VISIBLE REGION *255*
11: NUCLEAR REACTORS, NUCLEAR POWER **271**
12. *SUMMARY:* **PUTTING IT ALL TOGETHER** **290**
EPILOGUE **300**