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COMMUNITY EDUCATION THROUGH TEACHING CONCEPTUAL PHYSICS

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Abstract

Community Education through Teaching Conceptual Physics

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This paper discusses a conceptual physics course I taught in the local community. The entry-level class covered many topics, including several found in upper division physics. I planned the course, including implementing teaching methods and making lesson plans. It was well received and enjoyed a relatively large attendance. It also helped encourage other academic classes to be subsequently offered. This paper covers the details of the class, including its inception, execution, and local impact.

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Acknowledgements

A heap of gratitude goes to Mr. Joel Martinez for his willingness, patience, and assistance in handling the mighty task that was this class. Thanks also go to Professor Jason Nielsen for volunteering his time for lecturing, advising, and moral support throughout this endeavor. My great appreciation goes to Professor Fred Kuttner, who has helped me both academically and with this class. I would like to thank Professor George Brown for explaining concepts to me so I could pass them to others and for entrusting to me many lab materials. Lastly, great thanks go to the SubRosa collective for allowing me to use the building so often.

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Introduction

In the Spring of 2009 I learned of Free Skool Santa Cruz, a decentralized school of sorts. It is composed solely of individuals interested in promoting autonomous living, anticapitalist learning, and community education and involvement. People both experienced and inexperienced volunteer to teach self-initiated classes, lead discussion groups, or plan nature-based field trips. These classes are typically based on the leaders' interests or expertise and tend to be rooted in sharing practical skills such as bread making or mushroom foraging. With only a few years of continuous activity, Free Skool teachers now collectively submit dozens of classes each trimester, summing to over 200 class meetings. It was through this venue that I began to consider becoming more involved and teaching a physics class. I had a few reservations which had to be placated before I was willing to jump into a teaching commitment, though. These objections were eventually outweighed by the overwhelming number of reasons in support of offering the class. These reasons, while numerous, can be divided into four main categories: Physics Education, General Welfare, Summer Activity, and Personal Interest. In no way can I say that any one of these reasons was more convincing than another, for each was respectable and convincing in its own right. Therefore, the order of the explanations that follow is not representative of their importance.

The first group of reasons, Physics Education, was the first impetus in considering offering a course. It has oft been relayed by those in physics the expressions of awe, bewilderment, and lack of comprehension of non-scientists upon learning that one studies physics. Fear of complicated mathematics and ignorance of what exactly physics *is* seem to be common sources of the public's general lack of physics understanding. This ignorance and this fear (among other things) I wished to challenge and dispel. The question might be asked why (or whether) it is important or meaningful to study physics and its principles. To these I would answer yes, it is important; the reasons why constitute my second group of reasons: General Welfare.

It is disheartening that there is no great and widespread emphasis within our society in defense and support of education. In offering an entry-level academic class to the public I hoped to stress and demonstrate the applicability and benefits of being educated. (In this I also desired to support the idea of decentralized learning, including homeschooling and individualized education within the parent-child relationship.) One of these benefits of learning (especially physics) includes an increased capacity to think critically and consider more holistically a problem to solve it more effectively. Critical thinking and problem solving are vital to the health and wellness of our society and help us improve the ways in which we observe and make connections. They have applications not only in physics, but in more quotidian endeavors like navigating through traffic, avoiding or solving disputes, and understanding current events. From this, one can easily develop a more complete understanding of the natural world and the world fashioned by man.

I wanted also to offer an open venue in which people of all ages and levels could become involved, thereby strengthening the community and engaging and stimulating minds. I wanted people who had long since experienced mental engagement outside of standard daily life to rediscover the excitement of learning: those who had not been challenged or who did not mentally challenge themselves but who had instead become akin to stagnant mental activity. I wanted to encourage seeking, exploring, questioning. I wanted to offer something new.

Not only did I want to see community engagement through *learning*, but I wanted to re-introduce *academic* learning. It's less easy to learn physics on one's own than, say, gardening. Also, without a sum of money, the freedom to make a many-month commitment, and even the smallest amount of direction, academia is closed off to any interested party. Since these requirements by no means constitute legitimate barriers to keeping someone from entering into an academic setting, I wanted to alleviate these obstructions. I wanted people to be given a chance to bypass the bureaucracies and pursue their goals.

Thirdly, with summer imminent and my plans consisting only of working, I found that I was going to be left with much free time. Having no task before me left open the possibility of teaching this class, thereby redeeming otherwise wasted time for a beneficial purpose. This free time allowed me the chance to commit to preparing for, teaching, and recovering from each class meeting.

Lastly, the appeal for adventure enticed me. Though I had previously tutored academically and taught tangibly, a scholastic course I had never taught. This seemed to be an open invitation to try my hand at teaching: planning, executing, and modifying the course and its material as needed. Furthermore, I wanted my involvement in Free Skool to be a way to become more involved and meet more people, both in the community in general and in the freethinking radical community.

After several weeks of debate, I submitted my class proposal the day of the deadline. I titled it "Physics for Everyone!" and had decided to teach the class once a week in two-hour sessions for the entire 13-week summer schedule. These choices must have been unusual because I was gently encouraged to ease my way into teaching (and this, an academic class) by slimming down the frequency and length of each class. I declined. The class was held in downtown Santa Cruz at SubRosa, an anarchist library and infoshop.

The remainder of this paper will focus on the details of the class, including its reception and local impact. I will begin by describing the equipment used to supplement the endeavor in the Instrumentation section. Following this is the Methodology section, in which I will describe the methods employed in promoting, preparing, and teaching. A discussion of the class meetings and attendees, including responses and notes on learning styles and difficulties follows in the Results section. An analysis of the course proceedings is in the Analysis section. Lastly, the Conclusion section will summarize the project.

3

Instrumentation

To prepare for the class, I used the following texts: Conceptual Physics by Paul Hewitt; Introduction to Electromagnetism by Griffiths; Modern Physics by Tipler and Llewellyn; Introductory Quantum Mechanics by Liboff; and The Feynman Lectures on Physics, Vol.1 by Feynman.

To teach the class, I used the following equipment: a 4'x6' dry erase board, colored dry erase markers, eraser, and demonstration equipment. The equipment included the following: prisms; diffraction gratings; helium-neon laser; helium, hydrogen, and neon gas tubes and voltage source; polarizing lenses; Karo syrup; inclined tracks with various weighted balls; pendulum and timer; rotating stool, hand weights, and wheel; compasses and magnets; and cup, paper, and coin.

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Methodology

4.1 Promotion

Though the class was included in the summer Free Skool calendar, which is widely distributed and available online (See Appendix A.1), I wanted to reach a broader audience and do so quickly. I therefore employed several methods of promotion.

I began by constructing a flier using both hard copy elements and computer images and text. These were printed on to 8.5" x 8.5"-sized posters (See Appendix A.2). These large fliers were distributed liberally by bicycle within a three mile radius. They were placed in libraries and cafés and stapled on countless community events boards and telephone poles. Smaller handbills of the same flier, measuring 4.5" x 5", were generally distributed by hand at one of the local farmers' markets, though were once placed on car windshields.

As for electronic promotion, I listed the class on a small number of websites and sent out informational e-mails to a few e-mail lists.

Lastly, I wrote a Public Service Announcement (PSA) which I delivered to two local radio stations, one of which I am certain obliged. I spent about 20 hours promoting the class during the week prior to its commencement and an average of three hours per week following.The first and most basic method of promotion, the Free Skool calendar itself, introduced me to my first interested party: Joel Martinez, a physics graduate student at U.C.S.C. After his initial contact, we decided to collaborate and with him I began preparing to teach.

4.2 Preparation

Because I was initially unsure of what material I ought to cover and wanted to maintain flexibility to accommodate the students, I did not outline the fullness of the course material before the course started. I instead began by choosing each week's material the week prior to each class. It was not until the seventh or eighth week did I decide the remainder of the course content and even then it was not concrete.

The course's weekly topics were generally chosen by a combination of inputs. I knew which topics I could reasonably handle teaching based on what I already knew. I heard the topics suggested by the students and I was encouraged by Joel to cover topics that he considered important or interesting. The outcome of the inputs and the final topics of the course offerings will be discussed in the proceeding section and are listed in Figure 5.1.

To prepare for teaching each class, I spent at least ten solid hours in the following way. I began each preparation period by brainstorming topics, ideas, and facts that related to the weekly subject matter. I then shortened this list by eliminating topics which required excessive background information or complicated math or were too irrelevant, off-topic, or obscure. For example, though I discussed Maxwell's equations, I refrained from showing mathematically what a cross product is and how to find it, for this would require familiarity with systems of equations, determinants, and aspects of advanced calculus. With several of the students unfamiliar with math and confounded by simple algebraic equations, I decided to omit great detail. With the remaining list I then estimated whether or not I could discuss the points within the two hour class. If I thought not, I again lessened the list.

After these parings, I ordered the topics such that they followed an easy progression. I then began reading texts on each topic. These texts were chosen based on their readability, thoroughness, applicability, and my familiarity with them. I read and studied until I felt confident (or at least somewhat capable) to teach others. Some of the material was a review; other portions were wholly new to me. In studying, I consulted many books (See Instrumentation) and asked Joel for explanations. It was quite a thing when textbooks, Joel, and the internet could not give sufficient explanations to phenomena; and, when asked, sometimes professors could not, either! (Why, exactly, *do* polarizers block the $\vec{E}$ part of the electromagnetic wave?)

Having completed my studying, I wrote my lesson plan. The lesson plans consisted of diagrams, expository paragraphs, examples, and clarifying pictures (See Appendix B.1). These lesson plans progressed as the summer continued; this transition will be discussed in the analysis. It was during this time that Joel and I also ended up making weekly homework packets and the occasional answer key. The packets included both basic questions and those that required an understanding of more depth (See Appendix B.2).

4.3 Set-up

The classroom, a library café, was set up 15 minutes prior to each class. On the short stage in one corner, I placed a white board vertically. A short table next to it held the writing implements and demonstration equipment as needed. About a dozen chairs surrounded the stage in semi-circles.

Figure 4.1: The classroom setup.

4.4 Teaching

Before beginning the course, I knew that I wanted to implement as many learning tools as possible to keep the class interactive, accessible, and complementary to learning styles. I sought to employ the use of demonstrations, experiments, open questioning, lectures, and guest speakers. Though all of these tools were used, the majority of most class periods consisted of lecture and open questioning. While I taught the lecture portion and answered many of the questions, Joel remained active by fielding questions that were outside of my expertise, allowing for more full and comprehensive class discussions.

In lecturing, I extensively used the white board to draw pictures and diagrams, write definitions and short examples, and play gently with the occasional equation. I incorporated demonstrations into the lecture as I spoke about each respective phenomenon. When discussing light emission and the photoelectric effect I took gas tubes of hydrogen, helium, and neon with a voltage source across them to show the various colors given off by different atoms.

In general, the class sessions were littered with stray questions and discussions; some were on-topic while others were merely tangential. Two weeks were graced with guest speakers; I will discuss these more in the following section.

5

Results

The class began on July 2, 2009. 14 people were in attendance. According to the staff members on shift at SubRosa and from others involved in Free Skool, it was one of the largest Free Skool class turnouts they had ever seen. Most of these students attended a large portion of the subsequent classes until their summer travels, work commitments, or other plans drew them away. Some students took textbooks to class in weeks following and wrote out notes during the classes while others just watched and listened. There was little to no association between the students' verbal participation and their note-taking preference. This was true through the duration of the course.

During the first meeting I asked the class then present if they would be interested in homework sets and homework help sessions, which were both affirmed. I also inquired as to the topics in which people would be most interested in learning. I hoped that their responses would be able to guide the direction of the class content. However, they gave only a few suggestions, most of which were topics about which I had little knowledge, including quantum computing, astronomy, and dark matter.

Week	Topics
1	Science, History of Physics, Introduction to Energy
2	Units, Vectors, Rates, Laws of Motion
3	Speed of Light c, Special Relativity, Transforms, γ
4	Conservation of Momentum and Energy, Relativity
5	Atomic Structure, Uncertainty, Particles, Forces
6	Electromagnetism, Maxwell's Equations
7	Guest Speaker: Jason Nielsen
8	Light pt. 1: Waves, Double Slit, Photoelectric Effect, Color
9	Light pt. 2: Polarization, Emission, Energy Levels
10	Blackbodies, Planck's Constant h, Particle-Wave Duality, Exclusion
11	Guest Speaker: Fred Kuttner
12	Fun with Physics
13	Assessments and Evaluations

Table 5.1: List of weekly topics.

I wanted to begin the course without assumptions of the class's experience or knowledge of physics, so the first class included an introduction to science and the scientific method, an explanation of the field of physics, the history of the natural philosophy, and some concepts about energy.

Since these concepts were mostly academic, the only demonstration I used consisted of dropping various objects from equal heights. I did this because, according to Aristotle and based on his observations, objects moved according to where they ought to be: their natural place. For example, feathers were believed to move more slowly to the earth than a stone because there was more "air-element" and less "earth-element" in the feather, so the draw toward the earth was less strong than that on the stone. Though this may seem consistent with what our observation may tell us, it fails to mention other, real forces acting on falling objects, like gravity with its continuity and indiscretion.

The people in attendance seemed to follow the material and were attentive. Most of the questions centered on the topic of energy toward the end of the class. These were mostly concerned with distinguishing between kinetic and potential energy. To encourage further participation I posed questions to the class. Among these were "Which of the following is a scientific claim?" and "Do cars cause energy loss?"

After putting the class into context with the discussion of physics and its history a physicist highly recommended that the next week include an introduction to those things which are considered elementary physics; namely, laws of motion, inertia, and the concepts of units, vectors, and rates of change. While I dreaded teaching these topics because of my own personal lack of interest, I obliged and proceeded thus.

The more than 10-member class seemed disinterested with the material and some seemed confused. This was probably because I also found the material dull and therefore moved through it too quickly. I enlisted audience participation, however, when making the rates of change graphs, though their enthusiasm was less than encouraging.

Week three had fewer students, dropping attendance to around eight students. I chose to cover reference frames, Galilean and Lorentz transforms, and special relativity. I carefully made my way deriving γ, the unitless factor found in special relativity. Intrigued, the students were able to follow my explanations as I derived this factor and many also understood the mathematics I used in the classic train example.

In this example, we make use of two different reference frames: one is that of a person within a train, the other of a person on the platform of a train station. Within the train is a mirror attached to the ceiling. The person within the train, who has a light source, turns on the source and measures how long it took the light to travel to the ceiling and return. In his reference frame, the time interval was simply $\Delta t' = \frac{\Delta \text{distance}}{\text{speed}} = \frac{2L}{c}$, where L is the height of the train and c is the speed of the light. If the train is moving at a constant speed greater than zero, however, the observer on the train platform will observe the light traveling a distance different than that observed by the person within the train.

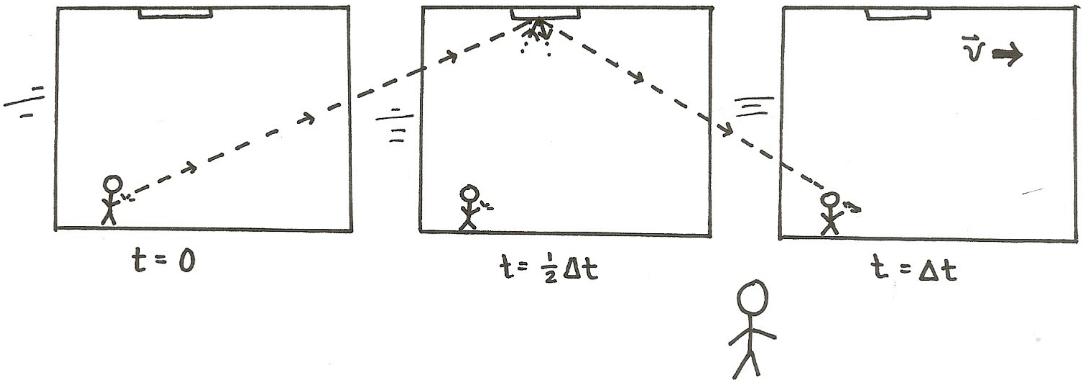


Figure 5.1: The path of light as seen by an outside observer.

As illustrated in Figure 5.1 above, the person on the platform sees the light leave the light source at one place as the train is passing by, but by the time the light has traveled to the ceiling and back, the train itself has moved some distance. By using the Pythagorean Theorem, we can figure out the distance the outside observer measures and, thus, the time interval:

$$\Delta t = \frac{\Delta \text{distance}}{\text{speed}} = \frac{2\sqrt{L^2 + (\frac{1}{2}v\Delta t)^2}}{c} \tag{5.1}$$

which becomes, after algebraic manipulation,

$$\Delta t = \frac{2L}{c} \times \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \Delta t'\gamma \tag{5.2}$$

where γ is the unitless, velocity-dependent number, called the Lorentz factor, which gives the relative discrepancies between the two observers' measurements. This tells us that the time interval between two events measured by the person on the platform is less than the time interval of the same events measured by the person inside the train! The students were very interested in this so-called time dilation. We then continued by finding specific values for γ for audience-suggested velocities and making a graph of γ versus v.

The fourth class (which had around 8 students) continued with the conservations of energy and momentum and these in the context of relativity.

The idea of conservation of energy went over well enough since I had mentioned the concept on several prior occasions. The class took a short aside to talk about conservation of energy in the face of matter and antimatter creation and annihilation. The concept of conservation of momentum was also accepted, but with a bit more reserve. I used what some might consider a substantial amount of math when discussing momentum, a topic less familiar than energy to the layperson.

I decided to talk about matter and elementary particle physics in the fifth class because of its novelty and intrigue. As expected, the class enjoyed this material. The magnitudes (both large and small) of numbers associated with the specs of matter are astounding, and even more so to those unfamiliar with physics. (Question: How many atoms are in an apple? Answer: As many apples as would fit in the Earth. Question: How many molecules are in one gram of water? Answer: About 10^{23}; more than the number of drops of water in all of Earth's lakes and rivers.) While the students understood that the orders of magnitude were great, they required a few minutes of pause to try to fathom these numbers, continuing to repeat the figures and analogies I had mentioned.

When discussing the duality of the electron, there was only the expected confusion amongst the students, some of whom imagined the dual-natured electron as a particle that moves up-and-down or side-to-side in wave-like motion until I insisted that that was an incorrect interpretation.

In the face of such complicated matters as the particle-wave duality, electron orbital shapes, and probability clouds, the students often simply accepted what they were told, some with adequate understanding and others with blind faith. (I later learned, though, that at least one of the students confused the electron's *location* probability with thinking that the electron is *itself* a probability.)

Though I talked and drew charts categorizing elementary particle physics, discussing each category (i.e. leptons), constituent particles (i.e. top quark), and the four forces (i.e. strong force), the aptly named particle zoo with its trove of information was somewhat bewildering to a few of the students. A few of them took notes to help themselves connect my many words to their physical interpretation. Others followed the quick progression well. Overall, I reiterated and cast in different ways the information a few times at various students' requests, affirming their correct understanding and amending their misinterpretations.

For the sixth class I taught about electromagnetism at the request of Professor Jason Nielsen, the scheduled guest speaker for the following week. At three students, this was the smallest class of the entire summer; I had neglected to continue promotion of the class for the two weeks prior.

Despite its small size, the class went so well that we stayed a little while after the scheduled end time discussing electricity and Maxwell's Equations. As noted earlier, I did not give any type of fullness to explaining Maxwell's equations, though I did give a quick overview of their meaning. I explained what a cross product was, mentioning what curl is and what the curl of a field indicates. $\vec{\nabla} \times \vec{E} = 0$ means that there is no curling motion of the electric field; the electric field lines are straight, as Figure 5.2 shows:

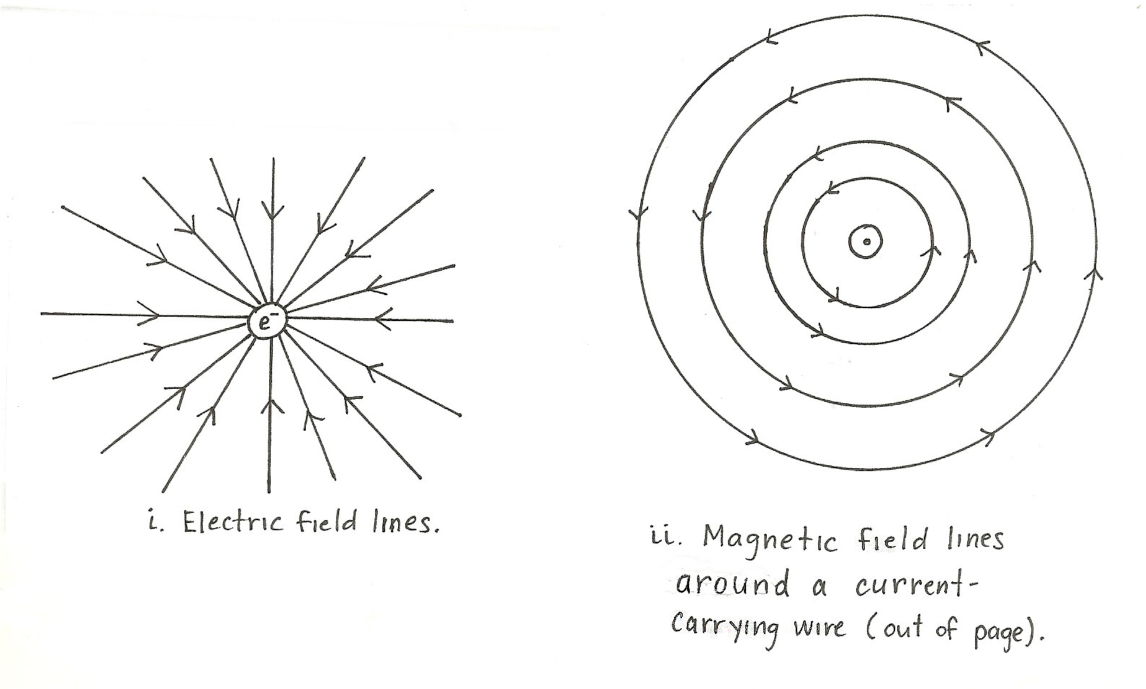


Figure 5.2: Electric and magnetic field lines.

$\vec{\nabla} \times \vec{B}$, on the other hand, is generally not equal to zero, so its field lines do have some curl. Magnetic field lines are shown in Figure 5.2.

To explain a dot product, or divergence, I simply explained that a divergence tells whether or not there is a net outflow (or inflow) of, in this case, field lines. Because $\vec{\nabla} \cdot \vec{E} = \mu_0 \vec{J}$, generally non-zero, there is a source (or sink) of the field lines. Protons have only field lines that go out and away from it. For electrons, whose field lines point inward, there is only an influx. Figure 5.2 also shows this sink, this influx. For magnetic field lines, however, Maxwell's equation says that $\vec{\nabla} \cdot \vec{B} = 0$, meaning that there is no source of magnetic field lines at any point. As also shown in Figure 5.2, these lines are continuous;

they neither start nor finish as electric field lines do.

In this class, the students also learned how electrically charged particles act in magnetic fields, as in accelerators. By using the equation $F = q\vec{v} \times \vec{B}$ and the right hand rule, which I had shown them, we all used our right hands to show that electrically charged particles travel in helices when given some initial velocity in a magnetic field.

The following week, as promised, Professor Jason Nielsen of S.C.I.P.P. visited the 12-member class. The students were very excited for his visit and took advantage of his expertise by posing many questions, some of which were relevant to his introduction to particle physics and accelerators. Others were directed toward personal curiosity, such as questions about quantum computing.

In the eighth week I was able to oblige one of the class's topic requests: that of light. I began this two-week series by introducing the class to types of waves: standing, traveling, transverse, and longitudinal. We discussed qualities of waves, including period and frequency, then related these to electromagnetic waves and their colors, both visible and invisible. I then talked about the particle-wave nature of photons, describing both the double slit experiment and the photoelectric effect. The students seemed to understand the double slit experiment well and we gathered around a laser incident on diffraction gratings to see the resultant interference patterns.

I then regressed to the discussion about color, trying to pick my way through one of those topics for which I hadn't been able to find concrete answers. I started with prisms and refraction, explaining that different frequencies of light travel through media at different rates because of their different interactions with the media itself. After a brief explanation about the resolution between this statement and the unchanging speed of light

c, the students asked the ill-answered question, “Why do smaller particles in the medium like to interact with light of higher frequencies?” Joel and I guessed that this was because light of lower frequencies, which are much longer in length, don’t “see” the material particles as much as those of higher frequency and thus don’t interact as much.

The last topic covered in this class was the apparent color of objects. After a short time it seemed as though the class understood that the colors we observe are due to reflections of light not absorbed, but when given the following situation (Figure 5.3), they had a difficult time figuring out how the third ball would appear.

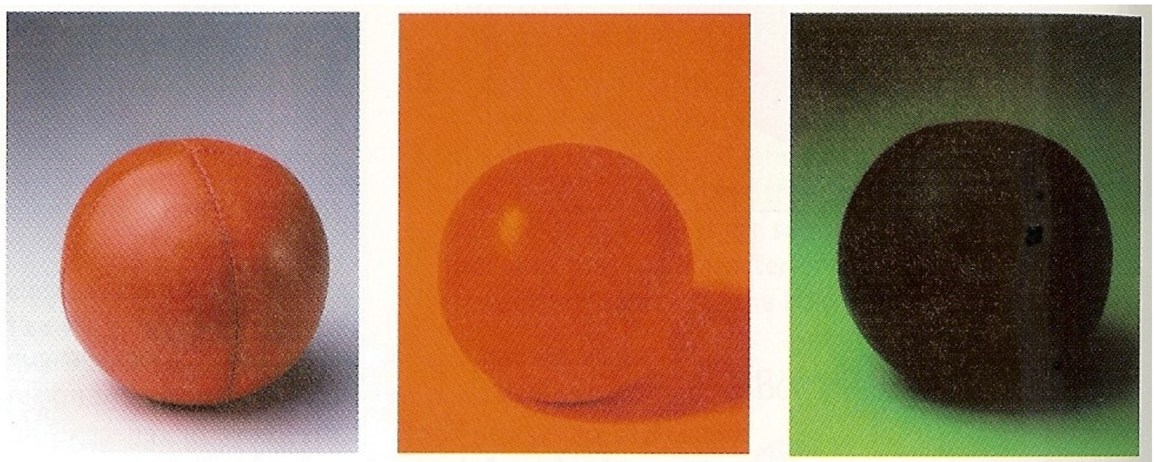


Figure 5.3: Three red balls under white, red, and green light, respectively. This figure courtesy of Cordelia Molloy/SPL/Photo Researchers.

The following week, week 9, continued with Light, Part II. I had decided to do this short series because light is such a broad topic about which there are many interesting things to say that I did not think it possible to cover most of the noteworthy material in only two hours.

I asked the seven-member class to recall the types of waves about which we had learned the week prior, and, after they had done so, continued by talking about polarization.

I explained that even though light is composed of alternating and perpendicular electric and magnetic waves, we consider only the electric part of the electromagnetic wave when discussing light polarization. I then passed out single polarizing lenses to the class and asked them to look through the single lenses as they were passed around. After this had been done, the only comments being about greater dimness, and the polarizing lenses had returned, I then passed around pairs of polarizing lenses. I asked the class to look through one lens, holding it stationary, then hold the second lens in front of the first, slowly rotating it in the same plane. Most of the students were surprised to see their surroundings go from dim to not visible at all when the lenses' polarization directions were perpendicular. They seemed to be very impressed by this phenomenon and enjoyed playing with the lenses.

We moved on to discuss light emission and electron energy levels. To show the differences in energy spacing between various atoms, I had taken three gas tubes, hydrogen, helium, and neon, along with a voltage source, to show the colors each tube emits. These colors, as we had learned, correspond to specific frequencies, which in turn correspond to different energies by the equation $E = hf$, where h is Planck's constant and f the frequency. Excited electrons have higher energies than when at rest, so when an excited electron goes back to its nesting spot, it releases its extra energy. The different allowed places for electrons are called energy levels. The energies related to the various colors show that there is a difference in electron energy level spacing amongst atoms of different atomic number.

I lastly and briefly talked about the mechanism behind helium-neon lasers; that is, stimulated emission. One girl in the audience was especially excited to learn about this because, she said, these were the things with which her father worked. All together, this was one of the most exciting, interactive, and engaging classes of the course.

In preparation of a guest speaker in the 11th week, the 10th class transitioned from talking about light in general to light in the context of quantum mechanics. Beginning with a review of what we had previously learned about blackbodies, I continued by talking about power emitted by hot bodies and showing the class the classical Rayleigh-Jeans equation, $B = \frac{2ckT}{\lambda^4}$, which I showed to be inaccurate for certain wavelengths. I then discussed the historicity and result of Planck's Law, giving the equation

$$U = \frac{8\pi hc}{\lambda^5} \times \frac{1}{e^{hc/\lambda kT} - 1} \tag{5.3}$$

and showing its graph of intensity (or power) versus λ, compared to that of Rayleigh-Jeans' UV catastrophe (See Figure 5.4, below). The number h, I told them, which was found experimentally, set the scale for the size of what would become quantum mechanics.

I then taught about the de Broglie relations and the fact that everything, even our own selves, has a wavelength. This seemed quizzical to the students because of its seeming impracticality. They, however, were intrigued and required just a few minutes to again reiterate what I had told them before we moved on to talk about Pauli's exclusion principle and fermion behavior.

The next week enjoyed a guest presentation from U.C.S.C.'s Professor Fred Kuttner. Excited by the *meaning* of quantum mechanics, Prof. Kuttner began by presenting Bell's theorem to the class using a series of simple cartoons projected on to the board from an overhead projector. After his almost-uninterrupted presentation, he was bombarded with questions from all over the room. There were simple confusions, as when one gentleman did not think that it took time for a force or event to "travel", as it were. "In my world," he said, "when I hit a ball, the whole thing moves at once. There is no time delay for one side

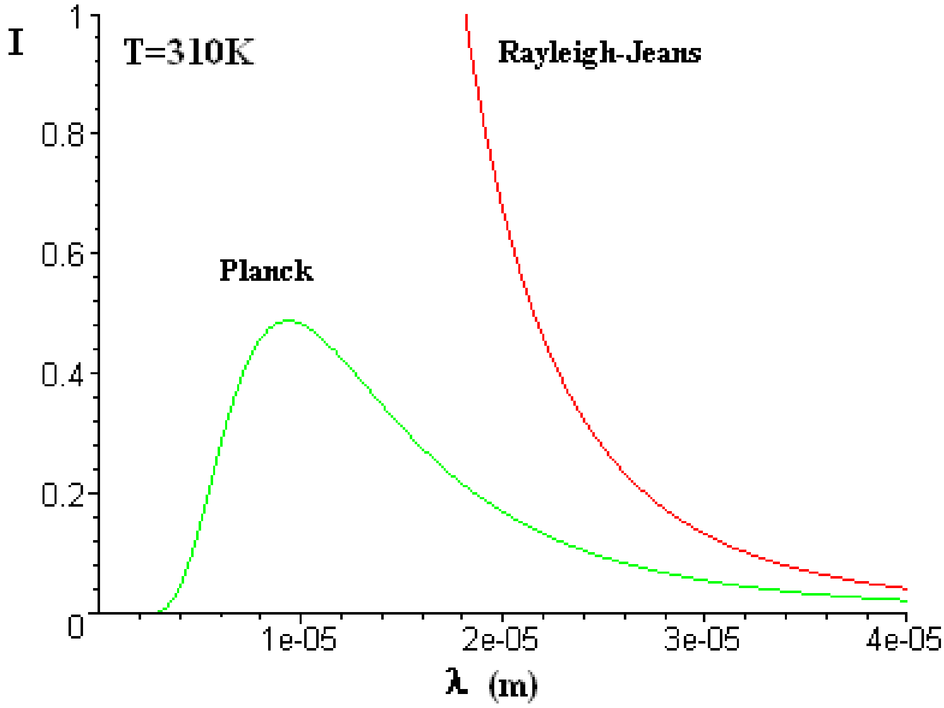


Figure 5.4: The classical Rayleigh-Jeans' UV catastrophe and Planck's Law.

to move and then the other." Others posed more abstract questions about entanglement and philosophical ideas. About 15 people were in attendance.

Week 12 lacked a formal structure, unlike the other classes. I simply gathered many materials to have a day full of demonstrations. Since it was a beautiful day we gathered outside. I took a wooden apparatus on which were several ramps, each one different. With this was accompanied several metal spheres of different metals, weights, and hollowness. These toys, though basic, were the objects of greatest interest at this class. The students really enjoyed rolling each ball down each ramp. We made marks on the ground to see whether or not each ball went the same distance, and we watched to see if they landed at the same time. One student was amazed and a bit perplexed at the fact that regardless of an object's horizontal velocity, it will land at the same time as an object dropped straight down. It was hard for him to imagine what a difference in distance two objects can cover in the same amount of time.

Using a weighted pendulum, a stopwatch, and some trigonometry, a volunteer from the class and I calculated the acceleration due to gravity. Though our result was within the expected amount of error, our answer was nearly 12 m/s^2, which was far enough away from the expected 9.81 m/s^2 to cause some class members to doubt its validity. I could only assure them that due to our inaccuracies in measuring the elapsed time and measuring the length of the pendulum, 12 m/s^2 was a perfectly reasonable estimate. I then assured them that the accepted value has been measured to great accuracy by other means.

After this I had a volunteer sit on a stool that rotated, and spun her around, asking her to move her arms out and in to demonstrate conservation of angular momentum. I then asked her to hold two weights in her hands, one in each, and repeated the process. Both this and extending her arms out made her spin much faster due to the increased mass, as in $\vec{L} = \vec{r} \times m\vec{v}$. Many other people wanted to try the experiment, too, so did.

The next experiment, similar to the first, included the rotating stool and a bicycle wheel with handles coming out from the hub on either side, perpendicular to the plane of the wheel. I had a volunteer sit on the stool, holding the wheel vertically. Keeping the stool stationary, I grabbed hold of the wheel, making it rotate. After making it rotate quickly, I let go and asked the volunteer to rotate her hands as if to try and make the wheel horizontal. She did, of course, and to conserve momentum, her chair began rotating, too. This, too, was very exciting and many people tried it.

A few other demonstrations included looking at Karo syrup through polarizing lenses and playing with magnets and compasses.

On the last day of class, Joel and I opened the floor to anyone with outstanding questions. After the small number of questions and clarifications were spoken, I gave the class an assessment to try and gauge what they had learned. The results greatly varied, but I had made the multiple-choice test challenging and had not given them any warning. After they had completed the assessment, they filled out a class evaluation form as Joel and I corrected their tests. The responses from the evaluations were almost all positive, the negative comments being related to more superficial things like the hot weather. (See Appendices B.3 and B.4 to see copies of the test and evaluation form.) Nine people filled in these two questionnaires.

Several of the following recurring students were present on the last day. Tom was an older man with some background in industry and a teacher of metal- and woodworking. He came faithfully to every class and homework session. Nina was in her 70s and, heavily accented, had emigrated from Germany. Her partner, Jim, was also in his 70s and was a musician and massage therapist. Neither had an academic background; Nina since elementary school. After several weeks, they asked permission to be excused from the class. She was having a hard time hearing and understanding and instead wanted to pursue learning the piano. They visited later in the summer. Ari, a young woman, had taken calculus and was looking to brush up on physics. She attended several classes until going on tour. David, a 12 year old homeschooler, came with his dad for a couple of weeks. Two young women who worked in town came for several weeks as a summer activity. Veloy, a middle aged woman, drove over 20 miles each week to attend class. She had no background in science or math but was simply looking for mental stimulation. Bobby, a middle aged man, diligently attended the second half of the session after learning of the class several weeks late. He had taken a conceptual physics course at a junior college 15 years prior. Katie, whose volunteer shift at SubRosa happily coincided with the class, wrote science fiction and wanted to be able to incorporate more physics and scientific concepts in her work. She also just thought that physics was cool. David and Rachel, both in their 20s, just came to learn physics.

Other, more short-term guests included university students, street kids, aspiring inventors and theorists, and wandering hippies. They came out of coincidence, excitement, a desire to learn, or to just pass the time. Some of these visitors challenged the verity of the material through their disbelief in science, but most were intrigued and interested, appreciating the existence of the class forum.

The homework sessions were sparsely attended. Between one and three people usually went for help or discussion. Joel led most of these meetings.

6

Analysis

Since this was the first time I had stepped into the role of a teacher in a more erudite class setting, I assumed that I would quickly learn from experience how to improve teaching. This turned out to be true in more than one capacity. Firstly, I began the first class meeting as nervous as I'd ever been. After the first two weeks or so, the degree of nervousness had declined by at least 70% and I was more comfortable for most of the other classes. This greatly improved the quality of the lectures. When nervous, I would refer to the lesson plans distractingly often, breaking up the progression and flow of the class material. This in turn would leave me a bit more flustered and, hence, a bit more nervous. To help avoid this, I quickly learned to cut down the amount of writing that went into the lesson plans. Less writing forced me to be more considerate, contemplative, and thorough in my introductions and explanations of the day's topics. These two things, experience in front of the class and modifying the lesson plans, were two big steps in promoting a better teaching and learning environment.

This transition into feeling more comfortable in front of the audience was not isolated to me alone. Joel, too, began to feel more comfortable speaking in front of a group of people. This mutual courage caused both of us to offer other classes in subsequent Free Skool sessions. Between the two of us, the winter session saw *Radical Math*, a weekly math class which has been offered every week up to the time of writing and has a small group of diligent students; *Physics for Everyone! Electricity and Magnetism*, a semimonthly physics class which entertained small handfuls of people; and *Crash Course in Trigonometry*, a weeklong course totaling seven hours that saw about 10 visitors.

As if these following courses weren't enough to satisfy an academically eager person, other intellectual classes were offered the next session, too! At least a few of these were directly due to my physics class over the summer. A couple of these other courses included *Evolution of Human Communication* and *Evolution*, both taught by U.C.S.C. graduate students. At the time of writing, people other than myself have plans to offer another physics class in the upcoming summer.

Regarding the ultimate selection of the course material, I am rather pleased at the outcome. Excepting the second week, I think that each class was full of topics about which the students were excited to learn. I think that shying away from those standard topics that are expected in beginning physics courses was consistent with what I had hoped to see from this class. Most introductory classes are heavy in math and analyses, which, ideally, could be included in a community physics course. However, for this first try with community physics education, I wanted the students to encounter a wide breadth of material that was far from mundane. For this reason I think that it was necessary and of great value to both my and the class's experience to have included quantum mechanics, particle physics, and electromagnetism. I think, though, that the more publicly recognized topics, such as light and energy, were also vital to the strength of the final syllabus. These topics were able to shed light on everyday phenomena, such as why we wear sunglasses and why black clothing makes us warm on a sunny day. The intersection between phenomenon observed and unobserved seemed to be in good proportion, also furthering discussions about what we *think* is happening based on observations and what we *know* happens from experiment.

As mentioned earlier, the material taught in the second week was not material about which I wanted to teach. I thought it dull and tedious. This unexcitement, doubled with my nervousness, made this class the least enjoyable of the summer for both students and teacher. My lack of luster in teaching that day was surely apparent to the students, who in turn were also not excited. This dread caused me to depend heavily on my lesson plan, which, as mentioned earlier, made things worse. From that experience I learned that a teacher ought to be both knowledgeable and interested in the subject matter. This learned advice was helpful as I chose the topics for the remainder of the class meetings.

The end-of-class assessment gave both good and poor scores, though only a small handful of folks were present to take it. However, as mentioned earlier, it was challenging and given without warning. The post-assessment discussions shed light on misconceptions and gave a thorough review of the things that people had forgotten over the course of the summer.

The evaluations were filled out by both one- or two-time visitors and diligent attendees. Most comments were positive ("thank you for creating a real learning environment" and "This class was real delicious!"). There were several suggestions about aspects that could be improved ("I spaced out when equations were balanced." and "Bit noisey + other people traffic breaks attention." and "I'd benefit from...a detailed syllabus."). Some people mentioned things they would have liked to see covered ("I'm still a bit confused Re: gravity & time & the language of physics" and "Any chance of doing the same thing with botany" and "Cosmology & how the micro & macro are the same and/or different.")

A few of the students went to the physics or math classes offered in the winter and spring sessions. Others bought books such as Physics for Dummies to continue their physics pursuits or to try to keep fresh in their minds the things they had learned.

I think that this class was entirely successful. It drew people from different parts of the county together, introducing them to the wonder and greatness of physics and their own selves. It was wholly encouraging to the students and the teachers. It sparked other academic classes, drawing education and communities nearer. It made me more confident when speaking in front of groups and taught me how to better present material and teach. It caused both myself and others to be more involved and realize how easily change can be affected. The class's mentions in the local newspaper indicate the noteworthiness and value such a class purports.

7

Conclusion

To summarize, I voluntarily taught a conceptual physics course in the community over the course of 13 weeks. It was successful in meeting its goals, including promoting education in an informal, egalitarian way and being a hands-on approach to learning how to teach. It was well received both by those who attended and those who had simply heard of it. It began a small trail of other freely offered academic classes. Though it is not a unique class, it is offered scarcely enough in communities to be a precious addition by anyone so inclined to offer it.

Appendix A

Publicity

A.1 Summer Free Skool Calendar

A.1.1 The front of the calendar

A.1.2 Inside the calendar

A.2 Original Flier

A.3 Fliers from Proceeding Classes

A.3.1 Physics for Everyone! Electricity and Magnetism

A.3.2 Crash Course in Trigonometry

A.4 Newspaper Articles

A.4.1 The first

A.4.2 The second

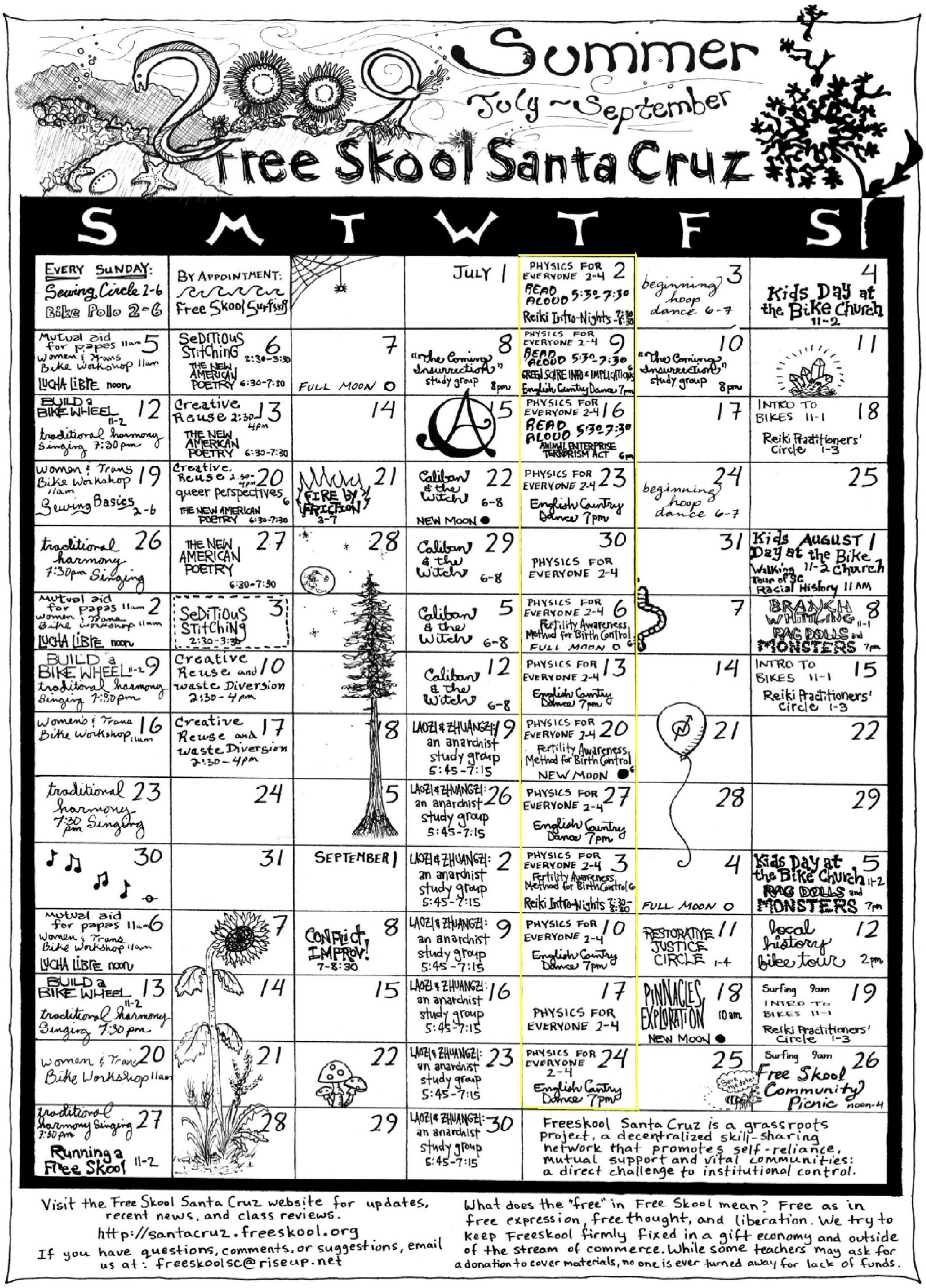
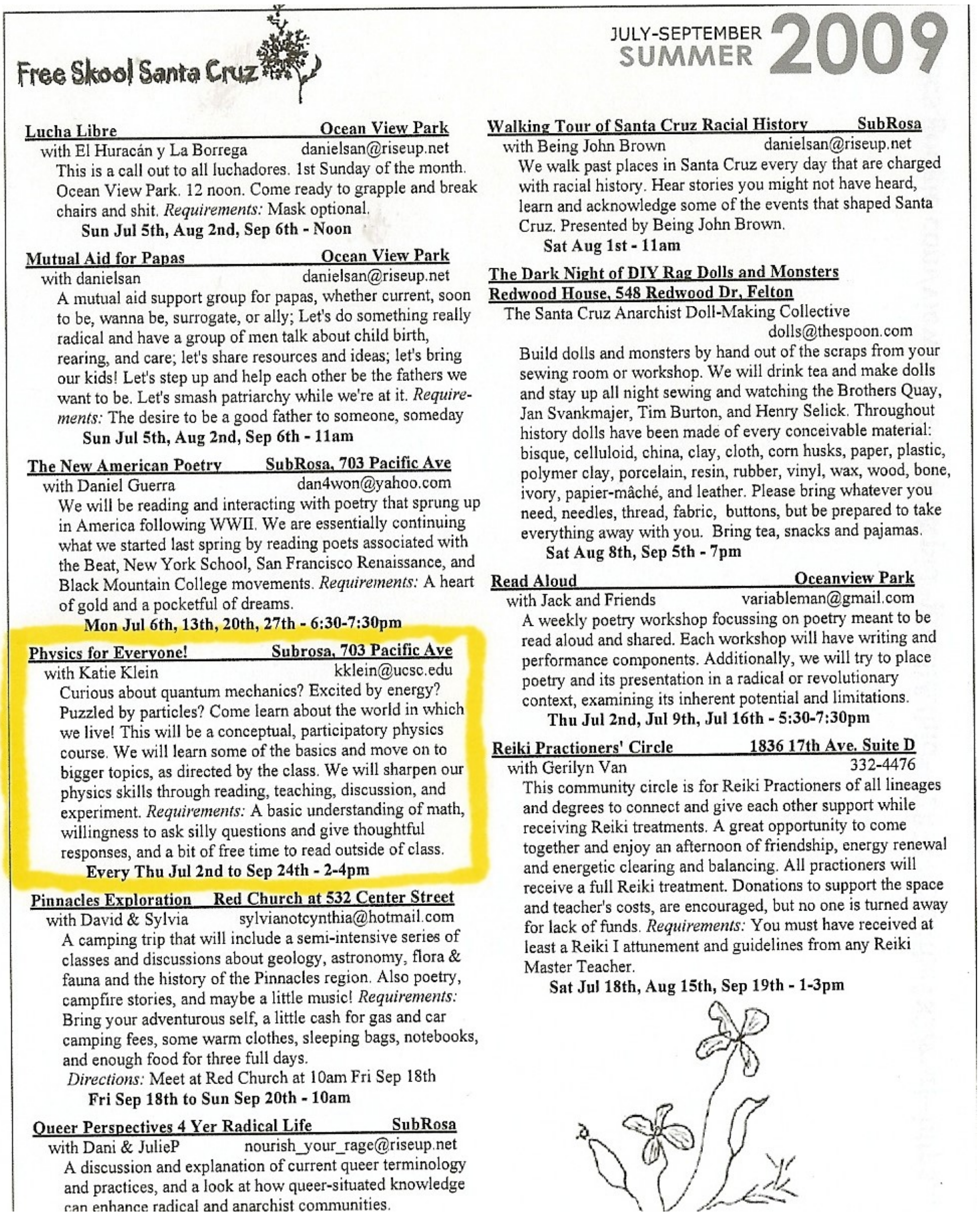


Figure A.1: The front of the calendar.



Free Skool Santa Cruz

JULY-SEPTEMBER SUMMER 2009

Lucha Libre — **Ocean View Park**
with El Huracán y La Borrega — danielsan@riseup.net
This is a call out to all luchadores. 1st Sunday of the month. Ocean View Park. 12 noon. Come ready to grapple and break chairs and shit. *Requirements:* Mask optional.
Sun Jul 5th, Aug 2nd, Sep 6th - Noon

Mutual Aid for Papas — **Ocean View Park**
with danielsan — danielsan@riseup.net
A mutual aid support group for papas, whether current, soon to be, wanna be, surrogate, or ally; Let's do something really radical and have a group of men talk about child birth, rearing, and care; let's share resources and ideas; let's bring our kids! Let's step up and help each other be the fathers we want to be. Let's smash patriarchy while we're at it. *Requirements:* The desire to be a good father to someone, someday
Sun Jul 5th, Aug 2nd, Sep 6th - 11am

The New American Poetry — **SubRosa, 703 Pacific Ave**
with Daniel Guerra — dan4won@yahoo.com
We will be reading and interacting with poetry that sprung up in America following WWII. We are essentially continuing what we started last spring by reading poets associated with the Beat, New York School, San Francisco Renaissance, and Black Mountain College movements. *Requirements:* A heart of gold and a pocketful of dreams.
Mon Jul 6th, 13th, 20th, 27th - 6:30-7:30pm

Physics for Everyone! — **Subrosa, 703 Pacific Ave**
with Katie Klein — kklein@ucsc.edu
Curious about quantum mechanics? Excited by energy? Puzzled by particles? Come learn about the world in which we live! This will be a conceptual, participatory physics course. We will learn some of the basics and move on to bigger topics, as directed by the class. We will sharpen our physics skills through reading, teaching, discussion, and experiment. *Requirements:* A basic understanding of math, willingness to ask silly questions and give thoughtful responses, and a bit of free time to read outside of class.
Every Thu Jul 2nd to Sep 24th - 2-4pm

Pinnacles Exploration — **Red Church at 532 Center Street**
with David & Sylvia — sylvianotcynthia@hotmail.com
A camping trip that will include a semi-intensive series of classes and discussions about geology, astronomy, flora & fauna and the history of the Pinnacles region. Also poetry, campfire stories, and maybe a little music! *Requirements:* Bring your adventurous self, a little cash for gas and car camping fees, some warm clothes, sleeping bags, notebooks, and enough food for three full days.
Directions: Meet at Red Church at 10am Fri Sep 18th
Fri Sep 18th to Sun Sep 20th - 10am

Queer Perspectives 4 Yer Radical Life — **SubRosa**
with Dani & JulieP — nourish_your_rage@riseup.net
A discussion and explanation of current queer terminology and practices, and a look at how queer-situated knowledge can enhance radical and anarchist communities.

Walking Tour of Santa Cruz Racial History — **SubRosa**
with Being John Brown — danielsan@riseup.net
We walk past places in Santa Cruz every day that are charged with racial history. Hear stories you might not have heard, learn and acknowledge some of the events that shaped Santa Cruz. Presented by Being John Brown.
Sat Aug 1st - 11am

The Dark Night of DIY Rag Dolls and Monsters
Redwood House, 548 Redwood Dr, Felton
The Santa Cruz Anarchist Doll-Making Collective
dolls@thespoon.com
Build dolls and monsters by hand out of the scraps from your sewing room or workshop. We will drink tea and make dolls and stay up all night sewing and watching the Brothers Quay, Jan Svankmajer, Tim Burton, and Henry Selick. Throughout history dolls have been made of every conceivable material: bisque, celluloid, china, clay, cloth, corn husks, paper, plastic, polymer clay, porcelain, resin, rubber, vinyl, wax, wood, bone, ivory, papier-mâché, and leather. Please bring whatever you need, needles, thread, fabric, buttons, but be prepared to take everything away with you. Bring tea, snacks and pajamas.
Sat Aug 8th, Sep 5th - 7pm

Read Aloud — **Oceanview Park**
with Jack and Friends — variableman@gmail.com
A weekly poetry workshop focussing on poetry meant to be read aloud and shared. Each workshop will have writing and performance components. Additionally, we will try to place poetry and its presentation in a radical or revolutionary context, examining its inherent potential and limitations.
Thu Jul 2nd, Jul 9th, Jul 16th - 5:30-7:30pm

Reiki Practioners' Circle — **1836 17th Ave, Suite D**
with Gerilyn Van — 332-4476
This community circle is for Reiki Practioners of all lineages and degrees to connect and give each other support while receiving Reiki treatments. A great opportunity to come together and enjoy an afternoon of friendship, energy renewal and energetic clearing and balancing. All practioners will receive a full Reiki treatment. Donations to support the space and teacher's costs, are encouraged, but no one is turned away for lack of funds. *Requirements:* You must have received at least a Reiki I attunement and guidelines from any Reiki Master Teacher.
Sat Jul 18th, Aug 15th, Sep 19th - 1-3pm

Figure A.2: Inside the calendar.

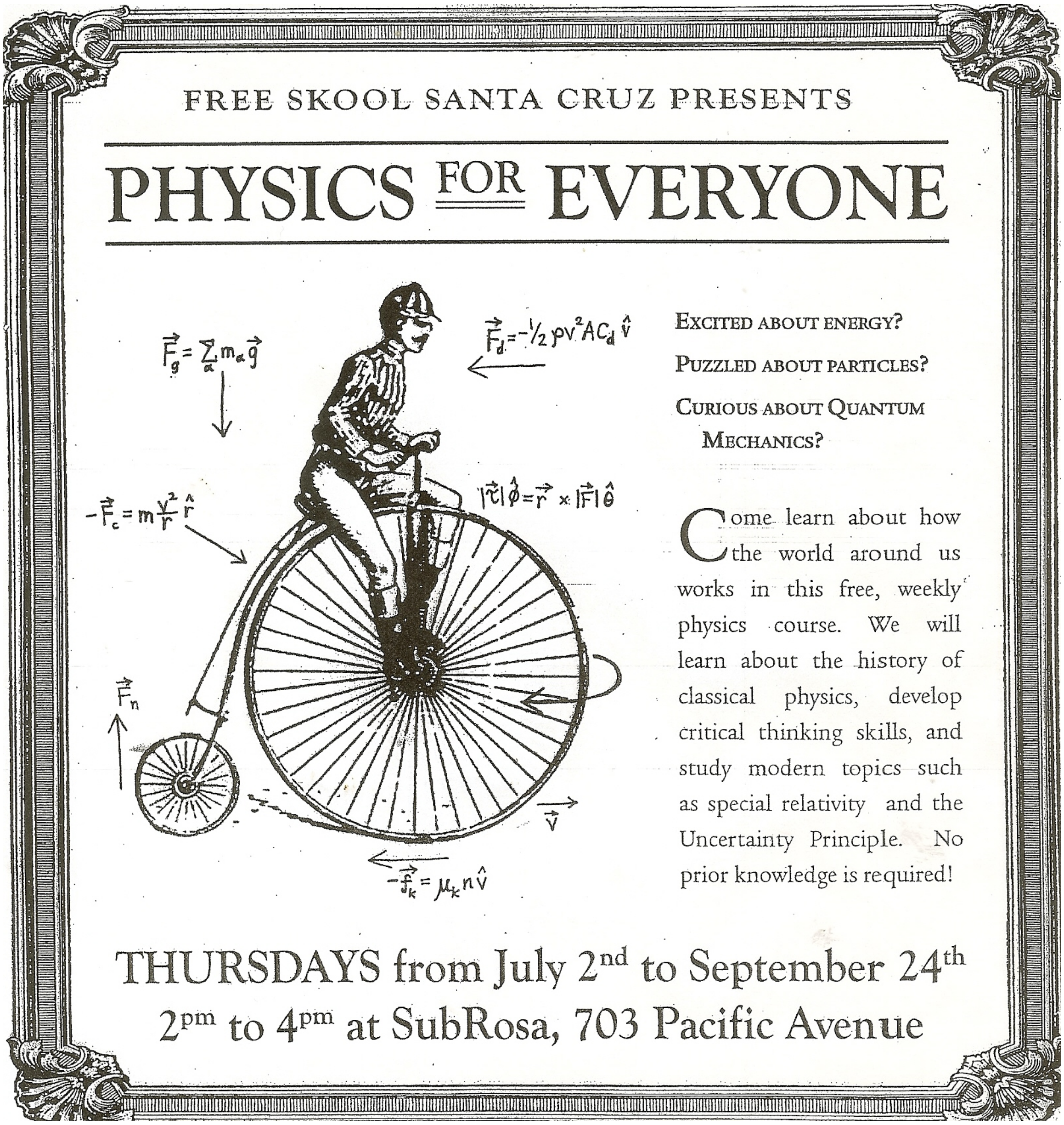


Figure A.3: The original flier.

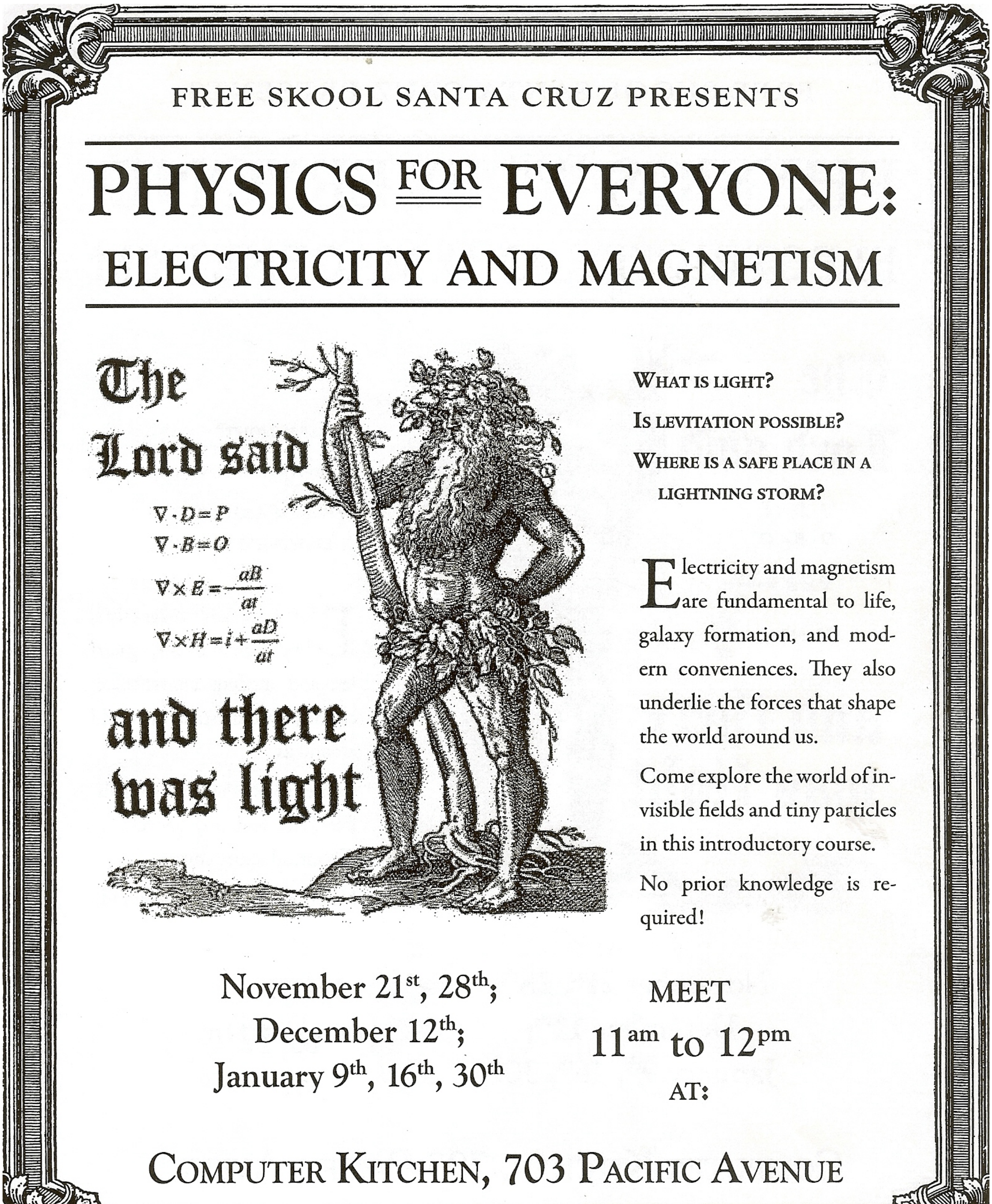


Figure A.4: The second flier.

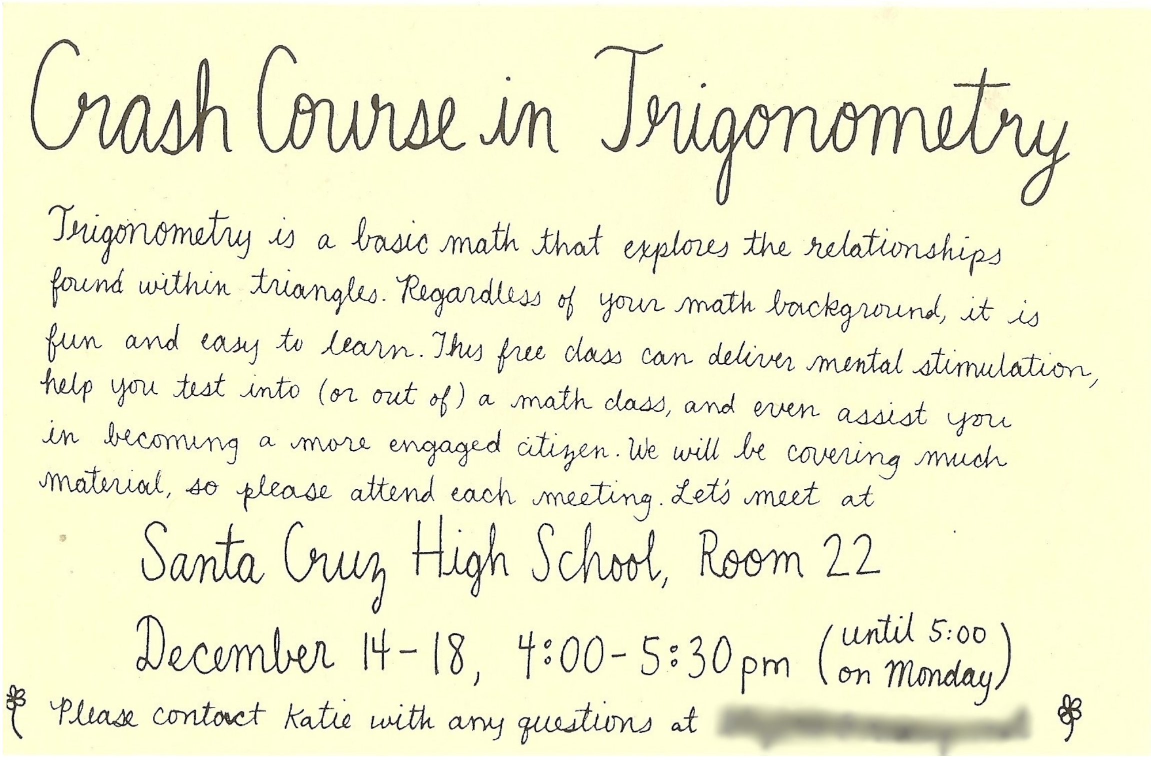


Figure A.5: The third flier.

Reward yourself: Don't forget to give a little time to yourself

By Justine DaCosta
Posted: 01/20/2010 01:30:05 AM PST

It's a new year, and for those steadfast on self-improvement, that might mean a "new me."

It's often hard to dedicate a few minutes solely to oneself, but pursuing a hobby can bring with it a sense of both relaxation and accomplishment.

[sections omitted]

Wes Modes of Santa Cruz worked with others in the community to create Free Skool Santa Cruz.

"It's a non-institutional school for adults and kids," he said. "It's sort of a "you know some things, I know some things, let's get together.'"

More than 50 free courses are held each quarter through the program. Classes are taught by community members who are passionate about a subject and want to share it with others. From "Boat Building on the Small" to "Physics for Everyone," the wide range of classes will likely pique the interest of just about anyone.

Free Skool Santa Cruz, which was formed about six years ago, allows people to pursue interests free of cost while connecting with people, Modes said. Classes are held throughout town, at people's homes, at parks and at community centers.

The program allows people to teach on the topics of their choice. Sometimes the teachers are experts in a field, and other times the teachers themselves want to learn something so they start a class as a way to form a group that can learn together.

"Whatever you want to put into it, you'll get out of it," he said. "Our desire has always been teaching people skills to help them be autonomous in the world."

Whether it's building on a current hobby or exploring something new, Free Skool can help open a door for those who'd like to become more active.

"Sometimes people are craving to connect with the community," he said. "A lot of people are hungry for something but aren't sure what that is."

Figure A.6: The class's first appearance in the Santa Cruz Sentinel.

Christopher Connery: Don't be so quick to judge Sub Rosa

Posted: 05/09/2010 01:30:20 AM PDT
Christopher Connery

I have been following with some alarm the news and especially the public comments in the Sentinel and elsewhere following the May 1 vandalism in downtown Santa Cruz. This mindless destruction is contrary to the spirit of community that many in our town value and cherish, a spirit that is at the heart of Santa Cruz's identity. I have also been very disturbed, however, by the tone of accusation and viciousness directed, without a scrap of credible evidence, at the SubRosa collective and others in the Santa Cruz anarchist community.

While it is possible that some of those involved in the violence may have identified themselves as "anarchists," this self-identification would say nothing about the majority of those so identified, who have very different values, and who embrace a very different agenda for social change.

I am not an anarchist, and have significant political differences with most of those in the anarchist community. But I have also been a supporter, financially and otherwise, of the SubRosa collective. They are a thoughtful, idealistic group of people committed to creativity, community, self-help, and a mode of life not dominated by consumption, tedium and waste. They provide resources for those in our community who, while not property owners or business people, are deeply and genuinely committed to social and environmental justice, community solidarity, and the joy of life.

They nurture many of our community's artists and musicians, and support activities such as the Free Skool, giving classes in areas such as physics, plant identification and local history. Our community would be much poorer without the collective's efforts, and we should be grateful for their presence among us.

SubRosa has condemned the May 1 violence, as most in our community have. As we begin to move beyond these very unfortunate events, it is most important that our city maintain its values of community, tolerance and good will.

These are difficult times for many, particularly for those among the less fortunate, and we need the creativity and resources of all. We should recognize that there are many kinds of commitment to community, and should value a diversity of approaches.

Christopher Connery is a professor of world literature and cultural studies at UC Santa Cruz.

Figure A.7: The class's second appearance in the Santa Cruz Sentinel.

Appendix B

Teaching Materials

B.1 Lesson Plans

B.2 Homework Set Example

B.3 Assessment

B.4 Evaluation Form

Figure B.1: Lesson Plan from Week 5.

Lesson 5

Introduction and Feynman quote

What is matter? Particles with a non-zero rest mass. Anything made of atoms or subatomic particles. Everything we see (except light) is made of matter. Observed galaxies, trees, water, vitamin C, etc. Even things that we can't see are made of matter.

Types of matter: There are three categories of matter that we think exist.

First, everyday observed matter. This is believed to make up about 4% of the total mass-energy.

Second, dark matter. This is believed to be matter that does not emit light or any radiation we can detect. This is not like the ether, which was indetectable, because we can see and measure the effects of this stuff. We have noticed gravitational lensing… We are not sure if this dark matter is made from particles that we know or not, but we think it makes up about 22% of the mass-energy in the universe.

Third, dark energy. We have no idea what this stuff is, but it makes up about 74% of the universe's mass-energy. The expansion of the universe (at an expanding rate) leads us to think it exists.

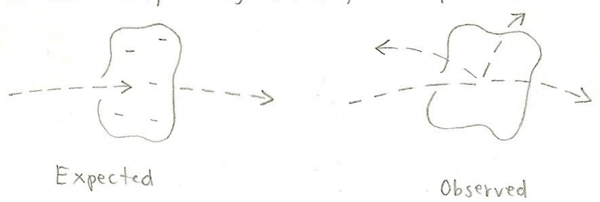
These latter two are named dark not because they are necessarily black in color (maybe they don't even have a color), but because we don't understand them.

Observed matter: The Greeks (and probably other people before them) had the idea of atoms. They imagined a boulder → rock → pebbles → gravel → sand → dust. Aristotle believed in four elements: earth, air, water, and fire, and this belief lasted until the 1800s. Robert Brown noticed what is now called Brownian Motion and atoms were again considered.

The electric force and Maxwell's equations, the laws that say how electricity and magnetism work, had already been established, so we knew that there were these positively and negatively charged particles, but that's about all we knew. Atoms are electrically neutral.

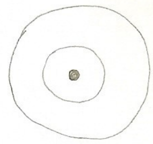
Models: J. J. Thomson and his plum pudding. He sure loved plum pudding.

Ernest Rutherford performed an experiment. He shot particles at a thin sheet of zinc sulfide and watched how these particles reacted. He was basing his experiment on this plum pudding model, so was expecting these particles to mostly go through the foil fairly easily. However, some particles didn't act this way.



He deduced from this that there was some point inside the atoms that deflected these particles through electric repulsion. This was evidence for the nucleus, the atom's central part. This experiment showed that it had a lot of mass and was positively charged.

Niels Bohr later proposed how the electrons (negatively charged particles) in atoms behaved. He said that electrons moved around the nucleus in certain orbits.



These scientists developed the background for what we now know of atomic structure.

We now know that atoms are, in fact, made of electrons, protons, and neutrons. Electrons have a negative electric charge, protons have a positive electric charge, and neutrons do not have an electric charge.

Atoms are really small! The diameter of an atom is to the diameter of an apple as the diameter of an apple is to the diameter of the Earth. So to imagine an apple full of atoms, think of the Earth, solid-packed with apples. Both have the same number. They are smaller than λ of light. Ex. shooting things

There are a lot of atoms! There are 10^{23} molecules of water in 1 cm^3. This is more than there are drops of water in all of Earth's lakes and rivers. There are as many atoms in a breath of air as there are breaths in the atmosphere.

Atoms are always moving! The movement of atoms is what we feel as heat. Every breath → diffuses → On average, after several years, anyone who inhales a breath will have one of the atoms from mine.

The atom is mostly empty space! If the nucleus, the center of the atom was the size of a marble, the electrons closest to it would be at Natural Bridges or Twin Lakes. Since you and I are made of atoms, it is completely correct to say that we are mostly empty space.

What are the components of atoms?

Protons: massive. Positively charged. $\sim 10^{-15}$ m

Neutrons: massive. No charge.

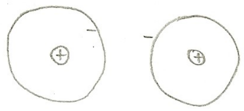
A pea-sized lump of protons and neutrons would weigh 133 million tons!

Electrons: small. Negatively charged.

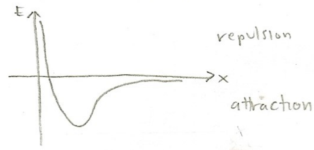
The mass of an e^- is 2,000 times smaller than a proton or neutron.

How does an atom keep its shape?

Electric forces between positive and negative charges cause the electrons and protons to be attracted to each other. They don't collide with each other because of quantum effects. The electric effects not only cause this attraction, but do not allow atoms to crash into each other.



Electrons repel.



Atoms are electrically neutral. For every proton, there is an electron.

In the hydrogen atom, there is one p, n, and e^-.

In the helium atom, there are two of each.

There are over a hundred different elements, each with a different number.

They were given names before this was known, or else they could have been called 1, 2, 3, ...

How are elements made?.

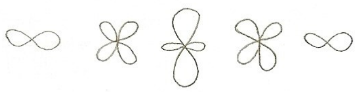
Elements heavier than hydrogen are made inside stars

Atoms have different energy levels. These depend on which state the electron is in. There is a lowest energy state for each atom and for each electron in the atom. Exclusion Principle!

The orbital which is the lowest energy can hold two electrons and looks like a fuzzy ball:

The next three orbitals also hold two electrons each:

The next five do the same.

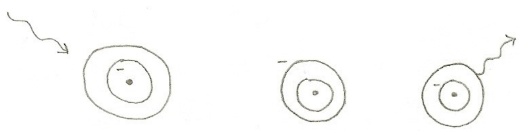


There are more after these...

Each of these orbits is the shape of where the electron "is" at different energies. An electron in a hydrogen atom can be in any of these states if enough energy is given it. The same for helium. For larger elements, like Li (3)
C (6)
O (8)

the minimum orbital won't be the first one (fuzzy ball).

Electrons can only be in these orbits and no others. There is no intermediate orbit between the first and second, etc. $E = hf$.



A curious thing about the electron is that it isn't exactly at any one place. These shapes above mostly just tell about the probability that the electron will "be" in some place described by the shape. The electron is best described by a probability cloud since the electron isn't so easily defined to be a thing as it is a wave-natured particle. Heisenberg's Uncertainty Principle tells us that we actually can NOT know both its exact location and momentum at the same time, contrary to everyday experience. Fermions and Bosons: Fermions can't be in same state.

It turns out that protons and neutrons, unlike electrons, are not fundamental particles. There are smaller things that make up these things. These are called quarks. Protons and neutrons are made of two specific types of quarks: up and down.

Proton: uud   Neutron: udd

Electrons, which we have already discussed, fall into a class of particles called leptons.

The last class of particles are called bosons. These are force carriers.

Leptons (less mass ↓ more mass)

Leptons		MeV/c^2	
e^-	ν_e	0.511	2.8
μ^-	ν_μ	105	3.5
τ^-	ν_τ	1784	8.4

Quarks

u	d	336	338
c	s	1500	540
t	b	174,000	5,000

Bosons	Force	Acts upon
graviton (th.)	gravity	mass
photon γ^0	electromagnetic	charge
weak $W^\pm, Z^0$	weak	weak/flavor charge
gluon g	strong	color

Spin ½ħ (leptons and quarks)

Spin 0 or 1 ħ (bosons)

All of these particles also have antiparticles.
Annihilation

Forces

There are four known forces. Total. These forces cause things to attract or repel and are responsible for the way things interact.

Gravity: self-explanitory. Acts to infinity.

Electromagnetic: +/- charge attraction, friction, the normal force, electricity and magnetism. EM waves are light, the photon. Acts to ∞.

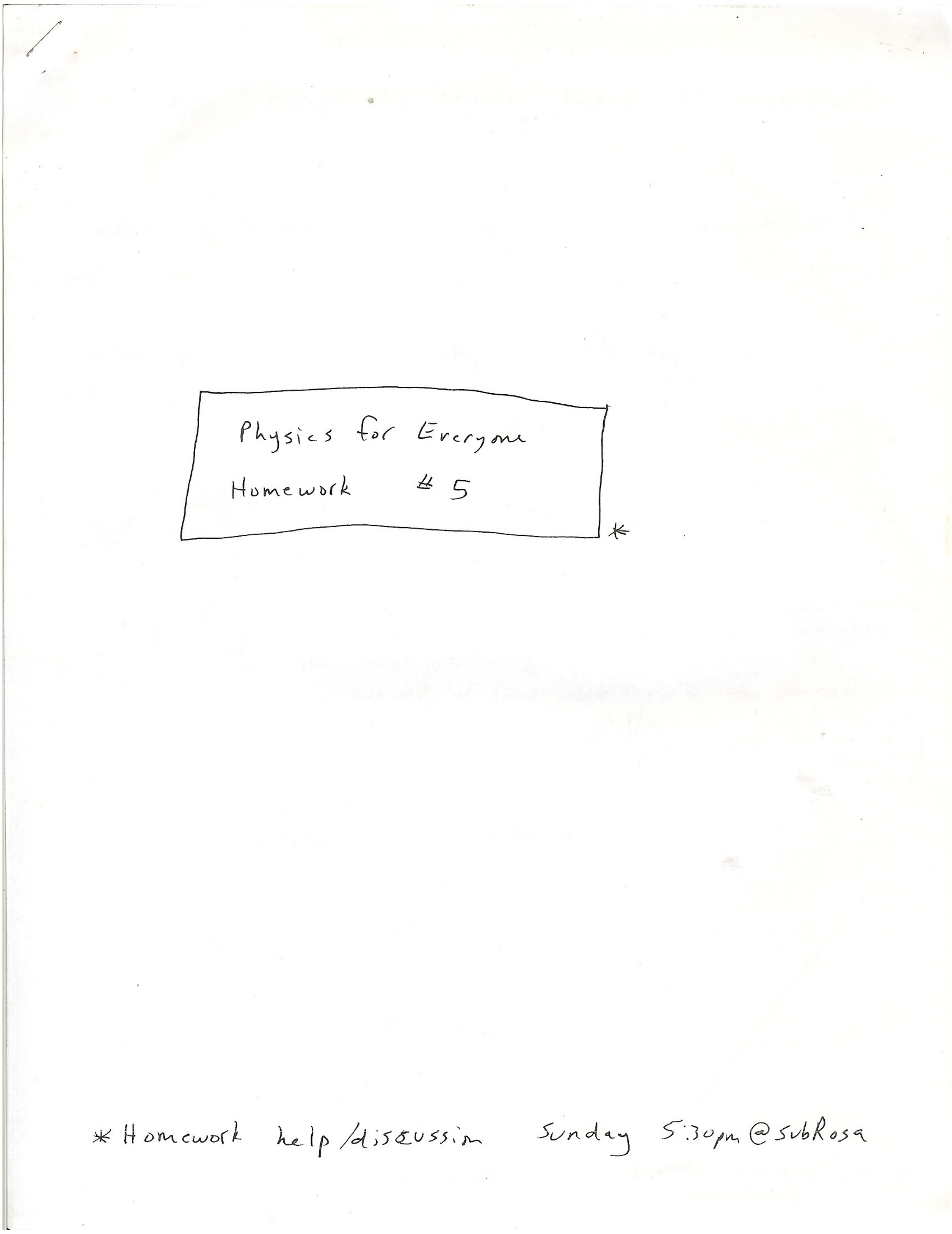
Weak Force: Acts on 10^{-18} m.

Strong Force: holds quarks together. Acts on 10^{-15} m. As its name suggests, this force is incredibly strong.

$$\frac{\text{Grav}}{\text{Strong}} = 10^{-38} \qquad \frac{\text{Weak}}{\text{Strong}} = 10^{-5} \qquad \frac{\text{EM}}{\text{Strong}} = \frac{1}{137}$$

Molecules: Atoms put together; strong force interactions; bonding (?)

Figure B.2: Homework 5 from Week 6.


Physics for Everyone
Homework # 5 *

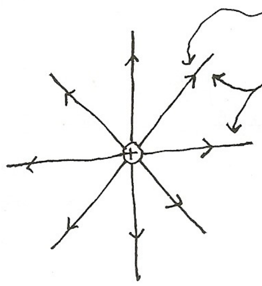
* Homework help/discussion Sunday 5:30pm @ SubRosa

What is meant by saying charge is conserved?

What is meant by saying charge is quantized?

What particle(s) has(have) exactly one quantum unit of charge?

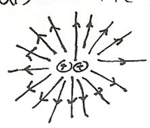
<u>Field Lines</u>



<u>positive</u> test charges follow the direction of the arrows.

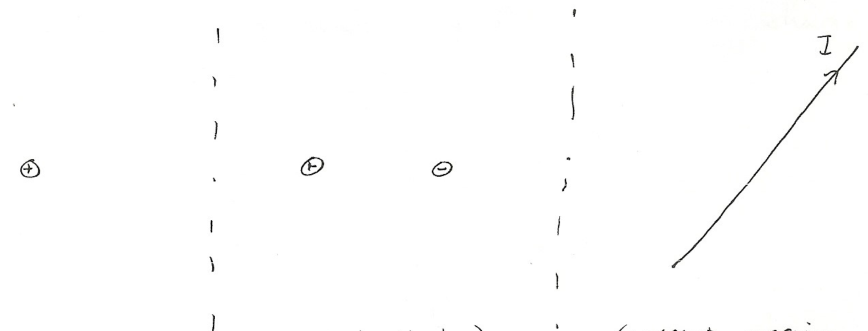
The distance between lines reflect the magnitude of the field (near the charge stronger, far from the charge weaker).

The number of lines also reflect the overall field strength. (e.g.



twice the charge, twice the lines)

Fill in the field lines for the following:



(electric monopole) (electrical dipole) (current carrying wire w/ no net charge)

What produces a magnetic field?

What is the cause of the aurora borealis (northern lights)?

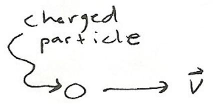
How is Coulomb's law similar to Newton's law of gravitation? How is it different?

Both gravitational and electrical forces act along the direction of the force fields. How does the direction of the magnetic force on a moving charged particle differ?

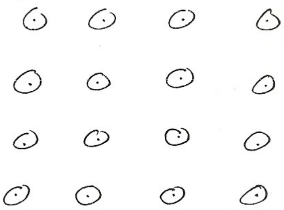
What condition is necessary for the flow of heat? What analogous condition is necessary for the flow of charge?

Motion in a magnetic field:

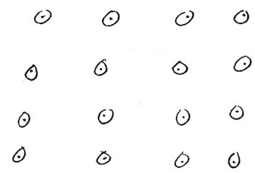
region with magnetic field $\vec{B}$ pointing out of the page.



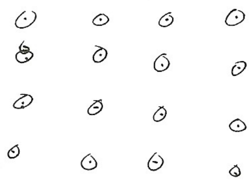
moving with velocity $\vec{v}$



Sketch the path of the motion if the particle is positively charged.



Now negatively charged.



Now imagine that the particle has some component of velocity out of the page. Sketch the motion of the particle now.

Figure B.3: The end-of-class assessment.

Physics Assessment
September 24, 2009

1. What does special relativity tell us?
   a. Light moves slower relative to a moving object.
   b. There is no absolute speed of moving objects.
   c. The laws of physics are the same in all reference frames.
   d. All of the above

2. What experiment showed that light moves at a constant speed?
   a. Young's double-slit experiment
   b. The Stern-Gerlach experiment
   c. The Michelson-Morley experiment
   d. Karo syrup and polarizers

3. Which of the following are conserved quantities?
   a. Angular momentum
   b. Kinetic energy
   c. Electric charge
   d. Heat

4. Ernest Rutherford shot particles at a thin sheet of gold foil and saw some of the particles deflect back. What had he discovered?
   a. Electrons
   b. The atomic nucleus
   c. Energy levels
   d. Quarks

5. Which of the following are components of atoms?
   a. Protons
   b. α particles
   c. Neutrons
   d. Gluons

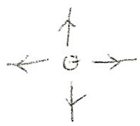
6. Which of these describe(s) an electron?
   a. A boson
   b. A wave
   c. An electrically charged particle
   d. A probability

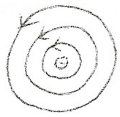
7. What is the difference between matter and antimatter?
   a. They have opposite spin.
   b. They have either mass or antimass.
   c. They have opposite electric charge.
   d. One absorbs, the other reflects.

8. There are four forces. Which of these is not one of them? (con't on next page)
   a. Gravity

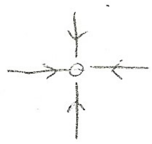
b. Electromagnetic
c. Centrifugal
d. Strong

9. Which of the following correctly shows the electric field lines of an electron at rest?

a. 

b. 

c. 

d. 

10. Which cause(s) a magnetic field?
    a. A steady electric field
    b. A moving electron
    c. An accelerating electron
    d. Magnets

11. What is a vector? Something with
    a. magnitude (size).
    b. direction.
    c. magnitude and direction.
    d. either magnitude or direction.

12. Which of the following is a/are vector(s)?
    a. Charge
    b. Velocity
    c. Electric field
    d. Force

13. What do we call electromagnetic waves?
    a. Polarizers
    b. Light
    c. Diffraction operators
    d. Blackbodies

14. How are energy and frequency related?
    a. Exponentially, as in $E = h \times 10^f$
    b. Linearly, as in $E = h \times f$
    c. Quadratically, as in $E = h \times f^2$
    d. They are not related.

15. Which of the following cause(s) rainbows?
    a. Diffraction (bending around an obstacle or as in a diffraction pattern)
    b. Reflection (like a mirror)
    c. Refraction (change of direction)
    d. Dispersion (like a prism)

16. Which of the following is/are necessary for interference patterns?
    a. The wavelength has to be near the width of the slit.
    b. The light intensity must be high.
    c. The waves have to be in phase.
    d. The wavelength has to be much less than the width of the slit.

17. What would happen if a green ball was placed under a red light?
    a. The ball would look red.
    b. The ball would look reddish-green or brown.
    c. The ball would look green.
    d. The ball would look black.

18. Classically, the emittance (output) of a balckbody gets infinitely powerful for small wavelengths. What was the name that scientists gave this malfunction in their theory?
    a. Radiation
    b. The Rayleigh-Jeans dilemma
    c. UV catastrophe
    d. Heisenberg's uncertainty principle

19. Why do different elements (like hydrogen, helium, and neon) give off different colors when excited?
    a. They have different numbers of protons.
    b. Some elements are gases and others are metals.
    c. They have different quarks.
    d. They have different electron energy levels.

20. Why haven't we measured the Earth's wavelength?
    a. It's only a mathmatical tool.
    b. It's too small to measure.
    c. It's too big to measure.
    d. The Earth is made of particles.

21. What do Maxwell's equations describe?
    a. Waves traveling through a medium
    b. Electromagnetism
    c. Angular momentum
    d. Electron orbits

22. Which quantity(ies) is/are quantized in the Bohr atom?
    a. Electron orbits
    b. Electron energies
    c. Electron angular momentum
    d. Electron refraction

23. How many class meetings did you attend? Which ones?

Figure B.4: The end-of-class evaulation form.

Course Evaluation
September 24, 2009

How was your physics knowledge before taking this course?

How do you think your physics knowledge is now, after taking this course?

Which aspects of the class did you like?

Which aspects of the class did you not like?

What topics would you have liked to cover or cover in more detail?

How convenient or inconvenient were the day, time, duration, frequency, and location of the class?

How did you hear of this class? Please be as specific as possible.

If this class was offered again, would you be interested in attending? If the class was only on one topic, what topic would you be interested in learning?

Other comments: