



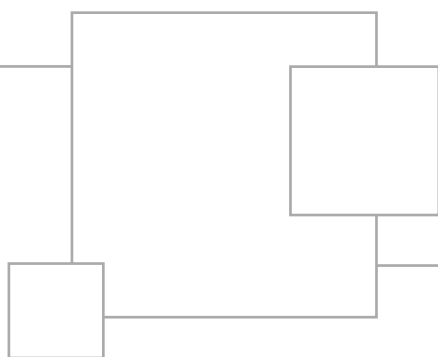
Journal of Undergraduate Research

jur

University of Rochester

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The *Journal of Undergraduate Research (jur)* is dedicated to providing the student body with intellectual perspectives from various academic disciplines. *jur* serves as a forum for the presentation of original research, thereby encouraging the pursuit of significant scholarly endeavors.



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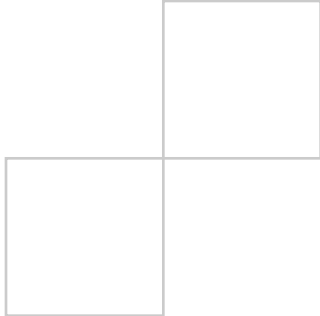
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From the Editors



The University of Rochester's *Journal of Undergraduate Research (jur)* is now in its sixth year of publication, and its central mission remains unchanged: to provide a medium through which outstanding Rochester undergraduates can have their original research recognized and made available to institutions throughout the country. Today, research is not merely useful in academia, but is also pervasive in our daily lives. The University provides a rich and nurturing environment for aspiring researchers to be exposed to their area of interest. Students in the physical and social sciences, as well as humanities, are all actively encouraged to participate in research through various opportunities including lab work, summer projects, and senior theses. Indeed, *jur* regularly receives more deserving submissions than can be possibly included in an issue, illustrating the enthusiasm of Rochester students towards research. This speaks as much to the efforts of the university to get its students involved in research as to the quality of the work of its students.

In addition to recognizing the achievements of Rochester undergraduates, *jur* also provides a medium for others to appreciate the works of their peers and encourages further involvement in active learning. While classroom training is an important aspect of an undergraduate education, there is no better way than through the pursuit of original research to foster the development of important skills relating to creativity, critical thinking, and personal growth. No classroom experience can truly serve as a substitute.

Our journal provides examples of the highest quality of research which motivated undergraduates can produce. It is our hope that our undergraduate readers gain both the new knowledge in the articles themselves and the inspiration to fulfill their similarly great potential.

Sincerely,



Andrew Niles, 2008



Harshika Satyarthi, 2009

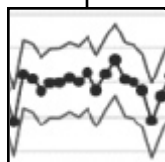
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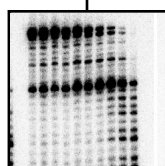
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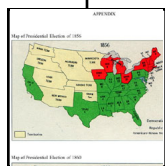
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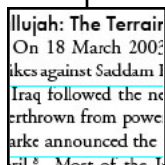
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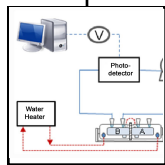
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Perspectives on Research

jur interviews Todd Krauss, Ph.D.

Todd Krauss is an Associate Professor of Chemistry at the University of Rochester.

jur: So first could you tell us a little about your educational and professional background?

Krauss: I've been a New Yorker all my life; I grew up on Long Island and studied at Cornell University, where I majored in applied and engineering physics (AEP), which is not a common program. Basically it's an engineering degree but with significant physics training. So my first few years consisted of core engineering courses: mechanical, civil, electrical, materials, etc. Towards junior year in the program you begin to specialize in AEP, in this case by taking mostly physics courses but with an added emphasis on applications. Topics like fluid dynamics and condensed matter physics were the more popular courses, more so than courses like string theory or astrophysics (which aren't necessarily going to lead to practical applications here on Earth). The nice thing about the program was its size: there were only fourteen faculty members or so, so it had a "small" feel like here at UR but with this huge university to draw from. For various reasons I ended up staying at Cornell for graduate school, so I received my masters and my Ph.D. there as well. These were in the same department, but for graduate students it is just referred to as applied physics. After receiving my Ph.D. in 1998, I went to Columbia University for two years to study chemistry with Louis Brus, a well-known figure in nanotechnology. I was there until 2000, which was when I came here. I was an Assistant Professor until 2006 when I was promoted to Associate Professor.

jur: When did you first participate in scientific research, and what kind of research were you involved in as an undergraduate and as a graduate student?

Krauss: As an undergraduate I didn't do much research because I was in the Army ROTC program, which took a lot of my time, particularly during the summer; it was nearly impossible to get involved in research. As a senior I started to work in the lab of John Silcox, who is very well-respected and one of the most senior members of the faculty down there. He works in the field of scanning transmission electron microscopy. I was

building the vacuum apparatus for a new electron microscope instrument. I soon decided that I wanted to go to graduate school and eventually get a job like the one I have now. For graduate school I didn't necessarily want to work in pure material physics; I wanted to somehow work with photons, with light. Lasers fascinated me. However, I didn't want to just build lasers as a Ph.D. student, but I certainly wanted to do something with light, to use optical phenomena for something. So when I was looking for research advisers as a senior, I came across Frank Wise, who was teaching the junior level quantum mechanics course. I always liked quantum mechanics and I did well in it, and I thought it was interesting how at certain length scales, when you look closer and closer, strange phenomena start to happen. Wise had just started to study these nanoparticles, which are minuscule chunks of semiconductor made of lead and sulfide. Large pieces of lead sulfide are used in infrared detectors. But when you make lead sulfide very small, strange quantum mechanical things begin to happen. I thought it would be great if we could work on these particles; since Frank Wise was a laser person, we could use some of the laser training I was getting and start to examine the particles with lasers - that was my very naive thinking at the time. So that's how I really started to get into research. I spent a lot of time in graduate school actually not working on my thesis. It is really common for graduate students to hunt around looking for something interesting before specializing and putting together a thesis. I had a lot of experience with some microscopy, but more with ultrafast optical spectroscopy.

jur: What are your current research interests, and how did you get interested and involved in that specific field?

Krauss: My research group is interested in a lot of diverse things, which could be considered atypical, especially for a somewhat younger person like myself. I have always had this fascination with nanoparticles and their fundamental properties. That's what excites me, the new discoveries we might come across. I suppose it's like Star Trek, the new frontier: you don't know what you're going to get in different episodes, but you know it will be something new and different. We start looking for physical phenomena, with some predictions as to where to go, and we follow that. My research interests (as for any faculty

member, especially younger ones) are really a mixture of what I did as a graduate student and as a postdoctoral fellow, and what I've come up with on my own. Some things are even vestiges of what I did as an undergraduate student; we still have an ultra-fast laser in the lab where we excite particles and look at electrons in an excited state, to see where that electron goes energetically and how it relaxes back to where it was, and how fast it does that. That tells us a lot about how these particles "tick" internally. Then as a postdoctoral fellow I really got into materials called carbon nanotubes. They are all carbon; but diamond is all carbon, and graphite is all carbon, and a lump of coal is all carbon. A carbon nanotube is a very different material, like a little cigar tube of carbon, a nanometer across, but potentially microns or millimeters long. But they are single molecules - normally chemists only work with molecules that are small on all dimensions: water, or nicotine, or whatever an organic chemist can cook up. Those are small things; even all the drugs organic chemists create for the health care industry and stuff like that are small in every dimension. Carbon nanotubes are small in two dimensions, but they can extend forever in the third dimension, so with nanotubes we can really start to connect molecules to the outside world. We are studying these nanotubes on a number of levels. One of the ways we study them is with ultra-fast laser spectroscopy, which we already talked about. Another thing we do is look at them one at a time, which is quite painful; we essentially spread them out completely far apart on a piece of glass and move a molecule to our laser beam to look, for example, at their fluorescent properties, one at a time. That's something we've sort of picked up largely from my postdoctoral studies and carried forward.

Since I've been here we've had new projects, things I never thought I would be doing. Part of my group works on biological sensing using DNA based sensors, and I have started a little company with Professor Ben Miller in Dermatology for them which will start pursuing that idea into engineering and creating a device. We also recently received a grant (with Professor Kara Bren in Chemistry) to do work with single protein folding. Folded proteins cause things like Alzheimer's, Parkinson's, mad cow disease, cancer, and other major diseases. People have looked at them for fifty years, and nobody understands why proteins just fold the way they do. Folding randomly, it would take the protein something like ten billion years to fold itself correctly; it somehow has to "know" intrinsically how to fold, and we're trying to understand that. So that's a new direction in which we've been moving. And then another new direction is energy. The more I've gotten into different areas of science, the more I've realized that we're in some serious trouble when it comes to energy and energy policy and things like that. It's not because I think the world's going to run out of oil anytime soon; it's more that we're doing a massive experiment on a global scale in terms of carbon dioxide atmospheric production. By the time today's undergraduates are fifty or sixty, at our current pace we're going to double the carbon dioxide in the atmosphere. And no one knows how that's going to affect things. One effect will be global warming, but that's not really the critical issue; the critical issue is what happens to life when we have all this carbon dioxide, and global warming could just be one side effect in the end. The last time this experiment happened was around 220 million years ago or so, and ninety percent of the

planet died, so we're really rolling the dice here. I think it's important that we find alternative energy sources sooner than later, so we're starting to do some work in that area as well. Protein folding and sustainable energy are two grand challenges for the group coming up over the next twenty years.

jur: What exactly are nanometer-scale materials and devices, and how do they contribute to the creation of photonic devices and biological sensors?

Krauss: A good fraction of our research is very fundamental. We're trying to understand the behavior of semiconductors at a nanometer scale. Cadmium selenide is an example of a material we study, though it isn't used for too much in its bulk form; lead selenide is another example; in its bulk form is used all over the place in infrared detectors. Silicon is another good example of a very useful semiconductor material, though we don't study it in our lab; for instance, there's a little piece of silicon in every iPod powering it, giving it all the instructions - on it are transistors and wires and everything that allow your iPod or my computer to work. The reason why the iPod is fairly thin is because we've taken what used to be computer technology that would fill this room and shrunk it down to the size of an iPod or smaller. What makes this whole process possible is that as you shrink the silicon, as you make it smaller and smaller, there are no differences in the properties - it behaves as a giant piece of silicon. However, when you reduce something to the size of around five nanometers, you start to see strange things happening. One example is shown on my website - a picture depicting solutions displaying a rainbow of colors. In each solution is the same material, cadmium selenide, but with the size of the particle changed by a factor of 2 from left to right - we get it to glow from blue (an energy state with 2 units of energy) to red (1 unit of energy, changing the energy substantially). If you were to do that with a piece of silicon, you would have to actually utilize other materials; and some of that is in fact done - they put in some phosphorous or some arsenic, and that would change the energy states somewhat. But by the time you got done with doping the silicon, it would not be silicon any more - you would have changed things too drastically. So the change in color (i.e. energy) with size is the basic fundamental effect.

The question is, what else is out there that we don't understand? When we make materials that have some interior atoms but some surface atoms, what are their properties? Our particular research area is looking at the fluorescence and optical properties of these nanoparticles, and I would include our work in the carbon nanotubes in that area as well. A nanotube is a rolled-up single sheet of graphene; graphene itself is a metal - conductive, though not a very good metal. But if you roll it up into a tube, you can actually get metallic or semiconductor behavior based just on how you roll it. Chemists haven't figured out how to make these yet with any sort of reliability, but if you could make a semiconductor one and connect it to a metal one on each side, you would have a transistor that is just a nanometer across. This would have significant applications (for instance, shrinking the iPod down to something much smaller, in principle). So there is a lot of potential out there, but before we can get into any of that, we've got to understand how these nanometer scale things

work. Here's a good example of fundamental work leading to getting some new technological devices. For years and years people studied the relaxation of quantum dot excited states electronically. You would excite an electron into a higher energy state to see where it would go in energy and how fast it took to get there. What was found was that if you put two electrons in higher energy states, one electron essentially killed the other one, and all of a sudden you had only one electron there. If you're trying to get these quantum dots to emit light, if you put two photons in, what you want is two photons out; that's the most efficient process, though you never quite get that. But what was found was that you would only get one out at best, which was killing the luminescence, and if you can't get a particle to luminesce, you can't get a laser, which is just an amplification of that luminescence. So before we understood how to make quantum dot lasers, we needed to understand the fundamental properties. Once we understood them, we could make a better laser and try to get around this electron-electron annihilation process. So the devices are coming, based on leveraging some of the fundamental science that we do first.

We're also doing some device work directly. In collaboration with Michal Lipson, Professor in Electrical and Computer Engineering from Cornell, we're trying to make a light move on a silicon chip. To couple light into silicon is very difficult; silicon itself isn't a very good optical material – it doesn't emit the right wavelengths. So why do this? For example, if you wanted to make faster phone calls or make the internet faster, what is limiting the potential speed is the electronics, the fact that you need electrons to move to transmit the signal. And if you could get rid of the electrons and make it transmit information using light, it would be a million times faster. However, to do that, you need light to move on silicon chips. And how do you do that? One way to do that is to put quantum dots on a piece of silicon, integrating it all together: quantum dots can be the luminescent material (to generate the light) and silicon can be the optoelectrical material that manipulates the light. So that's some of the work relating to devices that we've been doing. Also, for years and years, people at the medical school have used dye molecules for things like fluorescence-based imaging. For instance, if you want to look at for the presence of cancer cells, you can take a sample of cells and actually stain it with red fluorescent dye specific to the cancer cell to see if it glows red, and that can tell you whether the cells are cancerous or not. Quantum dots are much better than dyes in principle, because they are little but robust semiconductor materials. Organics, on the other hand, are pretty "wimpy" by comparison, just simple carbon bonds, while quantum dots are hard, inorganic "rocks," essentially; they can be brighter (than dyes), they don't bleach as quickly, you can have many colors... there are many advantages. We're just starting some of this type of research; we have several collaborations getting started with the medical school to try to use these particles in a biological environment. But the disadvantage is that they are inherently not biological, so some tricks are needed to get them into cells or attached to cells. We're trying to push them slowly in this area to see if we can get them to replace the dye molecules at some point, for then medical research overall would benefit from it. So, for example, we have projects with a group doing flow cytometry at the UR Medical Center trying to look at fluorescence based cell sorting and things like that,

trying to get these particles to be better for that application. We have a project with Günter Oberdörster in Environmental Medicine at the medical school looking at the toxicological effects of these particles on the body; you have to be careful if you want to use these particles for biological applications. Cadmium? Not good. Heavy metals? Not good. We want to know what's going to happen if we put these inside of people: Do the particles stay whole? Are they chewed up (i.e. do they disintegrate)? Does the cadmium leach out? And how do these particles in general affect the toxicological viability of cells? So that's another application of our work.

jur: Could you explain some of the techniques used in your research?

Krauss: Atomic force microscopy (AFM) is a technique that is essentially the nanometer-scale equivalent of a record player. The way a record player works is that there are bumps on the record that bounce the needle up and down, and these movements get translated into electrical signals that come out through the speakers as music. AFM works in the same way. Essentially there is a little needle on the end of a long diving board, and the needle goes up and down, as it hits a small nanoparticle or a nanotube. It actually moves only a nanometer or so high, but we take a laser beam and bounce it off the end of the "record player" needle and look at the reflection of the laser really far away; so even though the AFM tip is only moving a few nanometers up and down, far away we can get a signal. Then, if we split the detector that is measuring the laser power in half, we start to see the beam moving up and down, higher on one detector than on another, and we can use this to calibrate height. Now, in the end, the AFM tip needle does not care what is really hitting it. It experiences a force to move it, so if you can actually lift the tip off the surface and if there's charge on the needle tip, and you have a charge on your surface, they are going to interact through an electrostatic force. For instance, if you have two things that are positively charged, they will repel. So the laser in the end bends up and in the far field you see the change. So what we do is put a little charge on the needle AFM tip and then we go looking on the surface for charges on our particles. We actually have been able to modify a commercial instrument a little bit to be sensitive to a tenth of an electron's worth of charge at room temperature. So if there is an electron on the particle, it hops off, which we can see fairly easily. The big picture we are trying to understand is this: if we put electrons on these particles, what happens to their fluorescence? It's a solved problem for molecules: the molecule becomes "messed up" – in other words, the fluorescence is killed. It's a solved problem for macroscopic things like silicon: they don't care about extra charges. For nanoparticles this is a really important problem because if you want to do something like make a laser or a solar cell out of a nanoparticle, you don't want to have charges on the particles. You certainly want to know whether the fluorescence will be killed by additional charges, because that can really kill any potential application.

Another technique we use is single molecule spectroscopy. Ten years ago it was state of the art, but now we're getting it under fairly good control. Single molecule optical spectroscopy consists of a class of experiments where you look at molecules one at a time. The way we do it here is a brute force approach

where we look at single quantum dots, single nanotubes, or single proteins. You just find a way to spin them out, which is really neat. You just have a drop of liquid containing these particles and you just put it on a disk spinning at 5000 rpm or so, and the particles go everywhere. You end up with one particle per every couple of microns at best, sometimes even less than that. Then we can use the laser beam to look at fluorescence from the individual particles one at a time. So you can look at fluorescence and it turns out that your detectors, and even your eyes, are very sensitive and can see photons from single molecules as long as you excite them quickly enough; it's the background fluorescence that usually prevents this. So a lot of this type of experimental work is spent on reducing the background noise, and once you get that to below a certain level, the detectors see the single molecules easily. We can see all sorts of weird behavior when you look at one molecule. The fluorescence spectrum does many strange things, like moving around in wavelength or energy and going up and down in intensity. This is one of the reasons we look at single molecules, so we can understand what happens with this ensemble one at a time.

jur: What kind of applications could your research have?

Krauss: As I already mentioned, we've been doing some work that someday can be applied to improved solar cells. We're actually working with Kodak on a project in what is called all inorganic solid state lighting. Light bulbs, even fluorescent ones, are horribly inefficient. So much energy is wasted in heating the light bulb. It would be better if we could make light-emitting devices that are more efficient. So we are trying to make a device out of completely inorganic components, with the centerpiece being an emissive layer consisting of nanoparticles. We're working on that with Kodak's experts in emissive devices. I also mentioned protein folding and applications for that in terms of disease treatment. The "light on a chip" project is another one with technological relevance. With that project comes some laser work; what we want to do is put nanoparticles into special small optical cavities that will allow us to create really small-scale lasers for these applications involving light on a chip. A lot of our other work is more fundamental; applications would be something to look at later on down the road. We are not studying Alzheimer's disease, but understanding protein folding can solve that problem; on the other hand, we're not going to solve that problem ourselves. Our piece will contribute to solving this bigger problem. Hopefully someday we'll know how to tackle things like Alzheimer's or Parkinson's based on some offshoot of our research.

jur: In what ways do you interact with undergraduates?

Krauss: Many ways. I teach general chemistry; between myself and the other professor teaching the course, we get half the freshman class every year. I really enjoy that; it's a different interaction than what you would get dealing with a smaller class. I also teach a small laboratory class right now, and I have undergraduates working in my lab. So I have three levels of interaction. General chemistry is really fun and I really enjoy it. The students may not enjoy the material so much; chemistry is usually a required class and many people do not like to take

it, or would not take it if it was not required, but I hope by the end of the semester we at least have a good time. Of course, you can't get one-on-one attention for the most part; I try to encourage people to come to office hours, but you can't have two hundred students at office hours. On the other end of the spectrum, I have a smaller laboratory class, which is a lot more intimate, where I get to work with my students and teach them a lot about optical spectroscopy. This course is the most "uncanned" laboratory we have here at UR; half the time the equipment does not even work, and the students have to troubleshoot things. It's not actually intentional that things break down, it's that we're doing experiments that are essentially research-grade; it's not like simply putting something into a canned commercial instrument and making a measurement – everything is a homebuilt setup, and sometimes homebuilt things fail. There are three undergraduates in my laboratory with two active this semester. I interact with them several times a week on their research or even on other things; sometimes it's more along the lines of mentoring, with regards to applying to graduate school or advising where they should go. The undergraduates are certainly part of the lab and we treat them like graduate students; we understand that they have strong constraints on time, but when they are in the lab working they're simply part of the group.

jur: How can undergraduates get seriously involved in research in your field?

Krauss: My philosophy is that I don't like to give undergraduates busy work or "get the coffee" projects. I try to give them projects that give them the flavor of several things. One is what science research is like in general, so they are struggling for the most part, just like all of us, trying to get things to work, trying to understand their data, trying to push their science forward. I also try to give them a sense of what nanoparticles are like. Hopefully by attending group meetings and through their own research they get a feel not just for their own area but for the whole nanoscience field. I also give them a graduate student as a mentor/liaison, and they initially work on a subproject of one of the graduate students, generally something that the lab needs to get done or would like to get done, and on which they could use the assistance of a student, so that in the end of the day, if they are successful, they'll have some sort of publication. A good example would be James Camera, who graduated two years ago; he was working on a DNA sensing project. The larger project was taking DNA and putting it onto a piece of gold, and then coming in with complementary DNA, and it would bind to the DNA on the piece of gold, which would lead to a fluorescence response. We needed to know how much of that DNA was on the surface (how many molecules per square centimeter) and how it was arranged: was it all packed together, or spread out? So James looked into this and did some measurements, and he did a nice job with that; at the end of the day it became part of a paper, so James received an authorship out of it. That's the way undergraduates generally work in the lab. If you're creative, you can always find ways to get students involved in projects. I tend not to give them projects that are too technical or focused on building instruments, because then they would end up spending their senior years making instruments and not actually engaging in research. In my six



years here we've had several undergraduates involved in our research. One of them, Mike McCoy, is going to be a Take Five student this fall, and he is actually going to come back in the summer between his fourth year and his Take Five year to do additional research.

jur. Do you have any advice for undergraduates considering a research-oriented career, particularly in your field?

Krauss: It depends; there are many ways you can do research. When I was an undergraduate, I really thought that the faculty members were these lords of research and that they were echelons above everyone else in ability. As I developed as a graduate student I realized that while some were true titans of intellect, for the most part they were just smart people who had good common sense. To be a good researcher, of course you have to have some intellect, but a lot of it is just hard work and common sense. Quoting Einstein, genius is 99% perspiration and 1% inspiration. So if you can get the one percent out of it, the rest is just hard work.

The best advice I can give is to learn how to do things like change the brakes of your car. This may seem unrelated, but I've noticed that some of the students who are the best in research are the ones who are able to really get a feel for instrumentation and how experiments work. A lot of it is not easy to teach; it's very difficult to teach somebody how to know if the microscope is out of alignment or if the laser is out of alignment. If your brakes aren't working, you find out right away if you have technical ability when you smash into the next car. I was always interested in things like changing my brakes and changing my carburetor, getting mechanical things to work; and those are to some extent precursors to doing research. Get involved with a lot of things with your hands, other than just playing video games.

Another piece of advice that I have is not to specialize too early. As you get older you realize there is always so much you don't know, and what you don't know is always several orders of magnitude greater than what you do know. Many people take organic chemistry their sophomore year, decide they like it, and then decide to be a chemistry major and go into organic chemistry research; but they are missing this entire field, including inorganic chemistry, physical chemistry, materials chemistry, and biological chemistry. And that's just chemistry; there is also physics and engineering and all sorts of other options. So it's important to avoid tunnel vision. As an undergraduate, research is all free, at some level; but once you become a graduate student, you want to get out with a thesis in a reasonable time frame.

What helped me a lot was that I was able to do things with my hands, like soldering wires. Fixing your car if you own one or fixing your own bicycle can help. And in the process of fixing a derailleur on a bicycle and having the chain pop off every five minutes, you start to do similar processes to what you would do in an experiment. If my experiment is not working, I troubleshoot it. If my derailleur is not working, I troubleshoot that. If I move this screw or that screw, how does that affect things? So those are the kind of things that I think will enable you to be a successful researcher as you get older.

Finally, research is not always in academics. This is a great place to do research, and the wonderful thing about this job is

that within reason I can do pretty much whatever I want, as long as I can get it funded. But there is also research in companies and in government laboratories; there is research vicariously living as a program officer – through evaluating research you can be involved in it in some way. So there are many ways to be involved in research and science without teaching a general chemistry class a few days a week and having a few graduate students. I think that more top talented people need to get involved in my field and in science in general, and however people choose to do that is just fine.

Making the Most of the Lottery

Aaron Fisher, 2010

Advised by Kathryn Van Wert

Department of English

When Jefferson introduced the state lottery to the United States, he hailed it as a voluntary tax that could entertain consumers while raising money for the government. However, by the late eighteenth century, the lottery was banned partly due to its reputation as a seedy, corrupt, and immoral system.¹ Since being first reinstated by New Hampshire in 1954, the lottery has grown significantly, being run in 42 states as of 2005.² With its growth has returned its old controversy. There are arguments both in support of and against the continuation of the lottery system. Whether the lottery should be removed is still being debated; however, reconstructing the state lottery systems could increase their effectiveness and guide them away from adversely affecting those with low income.

Lottery Criticisms

There is debate over almost every aspect of how the lottery is run. Most common is the theme that lotteries overtax the poor, while not yielding significant or productively used revenue. In 1999 the National Gambling Impact Study Commission (NGISC) made a statement stressing how over 15 million Americans had lost control of their finances due to gambling and cannot afford to be gambling in general.

Thomas Donlan of Barron's National Business and Financial Weekly argues that the government should be working to help these problematic gamblers, rather than to take advantage of them.³ Also, contrary to the belief that lotteries act as a substitute for illegal gambling, the establishment of lotteries has been shown to correlate with increased illegal gambling activity, acting instead as a complementary good.¹ Regardless of how productively lottery revenue is used, many academics agree that lotteries charge too much to those who can least afford it.¹

Types of Lotteries

There is clear evidence that lotteries disproportionately cater to minorities and low income groups, those who can least afford to play. One study, funded by the NGISC in 1998 and carried out by the National Opinion Research Council (NORC), showed that although all demographics participate in the lottery, black customers spent much more on state lotteries than white or Hispanic customers.⁴ Individuals with less education were shown to spend relatively higher amounts on lottery tickets as well. Finally, the study estimated that low income individuals tended to spend more on the lottery than mid level or high income individuals, characterizing the lottery as a regressive form of taxation (see Figure 1). These

trends all demonstrate how minorities and low income groups are the primary source of sales for American state lotteries.

Minorities and low income consumers tend to purchase "instant win" lottery tickets, where the lottery system is most regressive. These tickets, which do not require the buyer to wait to see if he or she has won, were first introduced by Massachusetts in 1974.⁵ Results from the NORC study indicate 38% of low income consumers' last lottery purchase was an instant win ticket, whereas this was only 27% in mid level income consumers, and 19% in high income consumers. Low income buyers also most commonly describe the instant win tickets as their favorite form of the lottery. In contrast, the highest income buyers report on average that they favor high stakes jackpots. Among the buyers with the highest income levels, 56% said the last ticket they bought was a large jackpot ticket, while this percentage dropped to 49% in the middle-class group, and 39% among low income buyers.⁵ These results support the trend that lower jackpot lotteries specifically draw those who can least afford to be taxed and should not be throwing money into the lottery, making such lotteries more regressive than those with larger payoffs. One explanation for this could be that instant win tickets are more addicting due to their immediate results, while the large jackpots attract more wealthy customers whose lives would not significantly change from the small payouts of instant win tickets.

Similar results were found in a study conducted throughout 195 of Texas' 254 counties in the year 2000, in which instant win lottery ticket purchases were shown to be most correlated with low income groups. The study also showed a strong positive correlation between counties with large black populations and increased sales of instant win lottery tickets. Education was shown to be a factor as well. Those citizens who had received a higher level of education, such as those with college degrees, were shown to buy less instant win tickets and more jackpot tickets in which winners were revealed by a weekly lottery. The opposite effect was found in citizens with little or no formal education.¹² This evidence supports the claim that instant win lottery tickets are the most regressive, disproportionately targeting minorities and low income groups with little education.

The merit of different types of lotteries can also be analyzed by looking at the motives of their respective consumers. The speed with which the consumer learns the results of his or her bet is what may constitute its addicting nature. The odds of the buyer winning are low in instant win games, but significantly greater than those of mega-jackpots, making it more likely that buyers participate with gaining wealth as their pri-

Demographic/Socioeconomic Characteristic	Participation Rate	Average Annual Per Capita Expenditures (Participating Lottery Players Only)	Average Annual Per Capita Expenditures (Overall Group)
Demographic			
White	52.00%	\$210	\$109
Black	48.20%	\$998	\$481
Hispanic	53.60%	\$289	\$155
Other	49.80%	\$295	\$147
Education			
High School Dropout	47.70%	\$700	\$334
High School Graduate	52.40%	\$409	\$214
Some College	55.60%	\$210	\$117
College Graduate	48.00%	\$178	\$86
Income			
Under \$10,000	48.50%	\$597	\$289
\$10,000-24,999	46.70%	\$569	\$266
\$25,000-49,999	57.90%	\$382	\$221
\$50,000-99,999	61.20%	\$225	\$137
Over \$100,000	51.00%	\$289	\$147
Don't Know/Refused	43.00%	\$196	\$84

Figure 1: For different demographic or socioeconomic groups shown in the first column, the second column shows the lottery participation rate, while the column third shows the average level of expenditures for individuals who participate in the lottery, and the fourth column shows the average spending of all individuals in the socioeconomics or demographic group, including those who do not participate in the lottery. Although participation rates were fairly constant, black individuals, as well as low income and low education individuals tend to have had much higher lottery expenditures. Data Source: Clotfelter C. T., Cook P. J., Edell J. A., & Moore, M. (1999).⁴

mary goal. In the long run however, overall lottery payouts to winners are approximately 50% of what all consumers put in and are highly ineffective as a means of acquiring money.¹³ In large payout lotteries however, buyers are motivated by the joy of the gamble, and not by wealth seeking behavior.⁵ Here, the lottery has its most tangible benefit to buyers as a form of entertainment, not as a method of gaining wealth.

The common trend among all of these studies is that instant win games are the most regressive form of the lottery, while high payout games are the least regressive and give the most value as entertainment. It is clear that if the lottery is to stay in place, it should shift away from instant winnings tickets and focus more on large jackpot daily and weekly drawings to tax citizens more appropriately and equally, relative to what they can afford to pay. Unfortunately, state lotteries seem to be moving in the opposite direction, becoming more regressive. Connecticut introduced \$30 instant win lottery tickets in 2005. Other states have begun to introduce video lottery terminals, which have been described as highly addictive forms of gambling, similar to video poker terminals.⁵ If state lotteries do not begin to shift away from these types of systems, they will continue to tax citizens improperly, exploiting those at lowest income levels.

Education Uninformed and Irrational Players

For those who do not view it as an investment, but rather understand it as fun expenditure, the lottery can be a positive experience. A study of lottery games from 1981 through 1998 concluded that lottery buyers were at least partially informed, believing they were buying a thrill, not a realistic chance of winning money.⁵ Lloyd Cohen, a professor of Law at George Mason University, believes that consumers see the money they spend on the lottery as dispensable income, giving them an entertaining fantasy.¹³ However, behavior of lottery buyers can frequently become irrational, as they misunderstand their chances of winning and the methods they should or should not employ to win.

Many forms of irrational behavior have been revealed in studies of state lotteries, making it seem that buyers do not fully understand that into which they are getting themselves. One of these is known as gambler's fallacy, in which the gambler believes that if a number has not appeared for a while, it is "due" to appear, or if it has just appeared, it will not appear again for a while. Analysis of numbers chosen by participants of the Maryland and New Jersey state lotteries shows that after a certain number has been drawn, consumer choices of that number fall significantly, rising again as the time since the number has been drawn increases.⁵ In reality however, this pattern of consumer behavior has no logical backing. If a number is chosen, the likelihood that it will be chosen again soon does not change at all. This example of gambler's fallacy demonstrates one aspect of irrational and misled lottery buyers.

Another example of irrational behavior is the idea of "lucky vendors." Data from 2000 to 2002 in zip codes all across Texas indicates that the week after a vendor sold a winning ticket, its sales increased by approximately 12-38% (see Figure 2).¹⁴ Buyers believe strongly enough that stores who have sold winning tickets are more likely to again sell winning tickets, that some break their usual routines to attend these stores. Although these stores are also no less likely to sell winning tickets, this consumer behavior demonstrates superstition and uninformed logical decision making. Furthermore, this effect was more prevalent in zip codes with higher proportions of high school dropouts, elderly, or people receiving government financial assistance. For example, in a zip code with the average level of high school drop-outs, 26.2%, the rise in sales would be approximately 47%. Meanwhile in a zip code with a 90% proportion of high school drop-out, the rise in sales at winning store would be approximately 100%.¹⁴ These misinformed participants of the lottery are not only present, but also tend to be at lower education and income levels.

Not only are the odds of winning state lotteries tiny, but also some of the prizes are in reality less valuable than advertised. This comes partly from taxes withheld from winnings, and partly from diminishing real value of winnings paid out over time due to inflation. Currently for the New York State Lottery, a 25% Federal Tax as well as a 6.85% state tax is withheld from winnings over \$5,000 -- smaller regional taxes also

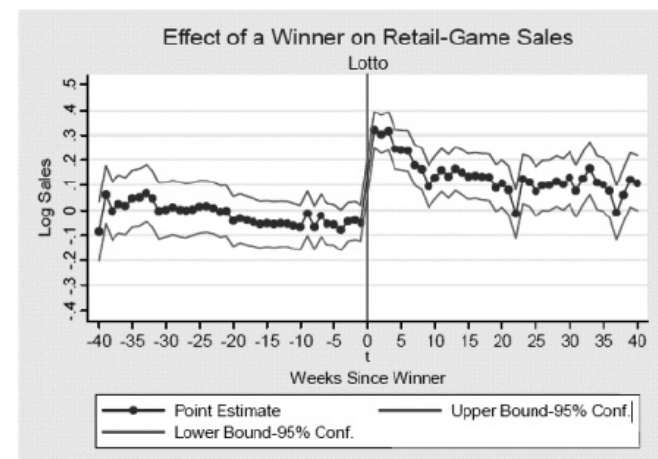


Figure 2: In the weeks leading up to a store's sale of a winning lottery ticket, the sales are fairly constant. Sales tend to rise however in the weeks following a winning ticket sale. Source: Guryan and Kearney (2005).¹⁴

apply, but only for residents of Yonkers or New York City. In addition, in order to receive the full advertised nominal value of the Lotto, Lotto Extra, and certain Mega Millions games, the winnings must be received in annual payments for up to 26 years (New York Lottery, 2003).^{15,ii} These extended payments continuously lessen in real value due to the effects of inflation (see Figure 3). Combined, the effects of taxation and inflation can make lottery jackpots approximately half of their advertised value.

Misleading consumers of any government run program is an ethical problem, but in the case of the lottery it can be avoided. In 1997, \$400 million was allocated to advertising the lottery.⁴ States should include in their ads information regarding why many common misconceptions of the lottery are incorrect. Similar information could also be present where lottery tickets are sold or on the packaging of lottery tickets. Ideally, programs such as these would inevitably reduce revenue from the lottery, but would prevent it from taking advantage of misled citizens while leaving those who understand it to enjoy the lottery for the simple thrill it is.ⁱⁱⁱ

Privatizing the Lottery

State governments now have a monopoly on legalized accessible gambling. In any case such as this, a monopoly can choose prices and products that give the most benefit to the producer, in this case the government, and the least benefit to the consumer. However, because governments see gambling as a highly negative enterprise, they provide it only when strongly taxed and regulated. The result is a contradicting “muddle” with little benefit to buyers that is not as efficient as a competitive industry could potentially be.¹⁷

Privatizing the lottery and replacing the government monopoly with competing firms could increase the benefit to consumers. Payout in the current government lotteries system is only 50% of what buyers put in, whereas in competing casinos, it is as high as 90% and often above.³ Competition has also been shown to drive higher payouts in state lotteries. Data from 1967 through 2000 shows a state’s lottery payout will rise 5% in response to a neighboring state’s lottery payout rising by 10%.⁵ These reactions to competition demonstrate that when there are multiple providers of gambling, they each must present the buyer with more benefit in order to compete with each other. Overall, breaking up lotteries into smaller more numerous firms would be beneficial to consumers and increase net social benefit.

This being said, the industry would still need to be highly regulated and taxed. Precautions would need to be taken to prevent chronic gamblers from making decisions detrimental to themselves or to loved ones. Consumers should be informed and be above a certain age to participate, in order to encourage somewhat rational gambling. If these regulations could be enforced, a competitive lottery industry would achieve a higher level of equity between the providers and users of the lottery, as no one firm or government body would have complete control over the market.

Earmarking Lottery Revenue

The lottery, like any government fundraising program, can only be as productive as the use of its revenue. In order to assure that lottery revenue helps achieve specific govern-

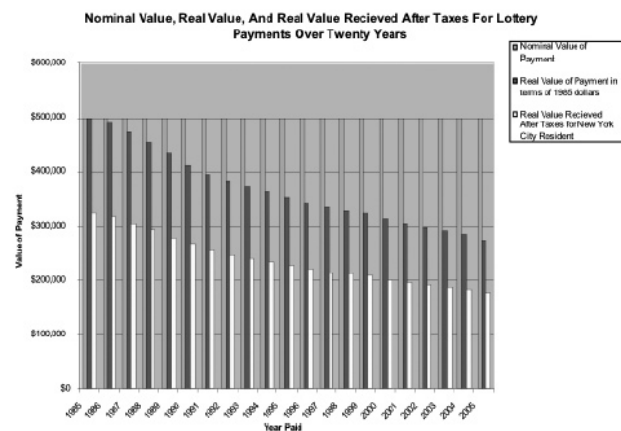


Figure 3: This figure looks at the effects of inflation and taxation, by focusing on a hypothetical 1985 lottery jackpot of \$10,000,000.00, paid in twenty annual payments of \$500,000.00. Because the average annual inflation rates from 1985 to 2005 are known¹⁶ we can see how in terms of purchasing power, the value of \$500,000.00 decreased over time. Although the nominal value remained of course the same, the real value of these payments became less and less, as the effects of inflation become more and more pronounced. A payment’s real value in year (t) was calculated by taking the real value of a payment the previous year (t-1), divided by 1 + the rate of inflation in year (t). 1 + the rate of inflation in year (t) is also known as the inflated cost. Finally, the yellow columns shows what portion of each payment’s real value a resident of New York City would keep after taxes, assuming a tax policy constant over time and equal to the current policy.

ment goals, is it often reserved for one fund, most commonly education. This restriction of spending is known as earmarking lottery revenue. A major flaw in this system is the idea of fungibility, in which money put towards a department such as education does not raise the overall budget of the department because it merely replaces money now being diverted to other areas. Despite this, the many of studies have found earmarking to be a productive way of managing lottery spending.

In a 2002 study, data from sixteen states was examined to see if switching to earmarking funds for education increased the educational budget. The study also analyzed states where earmarking was already in place, to see if increased lottery sales correlated with rising educational spending. The results showed that in earmarked states, education spending increased by 60-80% of lottery revenue, relative to only 40-50% in states not earmarking revenue, and 30% in states who earmarked lottery revenue for other causes.⁵ This study indicates how earmarking lottery funds can make significant progress towards raising the budget of a certain department.

Earmarking, however, is not perfect and has sometimes been shown to be ineffective such as in cases when politicians have high obligations to major contributors. One study in Illinois detailed how lottery funds partially earmarked for education caused no net rise in the educational budget. Instead, the 1973 initiation of the lottery corresponded with a \$171 million increase in the funding of the then struggling Regional Transport Authority (RTA), which drew \$80 million from general state revenue. Furthermore, the Chicago area, which received the benefit of this \$171 million program, was projected to have contributed only \$50-60 million of the lottery revenue. Other areas that purchased lottery tickets were neither serviced by the lottery revenue, nor did they have representation on the RTA’s executive board. Lottery revenue in this case did not significantly increase educational spending

or general state revenue, and the state of Illinois continued to fall in debt after the lottery was instated, possibly because lottery revenues released pressure on officials to run programs efficiently.^{1,iv} Although this demonstrates an ineffective example of earmarked lottery funds, the state government in this case was already weak, and the earmarking restrictions were fairly lax. Strong restrictions and a government not already weighed down with serious fiscal problems could have yielded more positive results from earmarked lottery funds.

If nothing else, earmarking funds has focused significant sums of lottery revenue towards education in numerous states. As of 2002, New York had raised \$21 billion through the lottery for education since 1967, Michigan had gathered over \$10 billion for education since 1972, and California's lottery had raised approximately \$14 billion for education since 1985.² All of these states completely earmark lottery revenue for education. It is possible that money gleaned from lottery revenue may have only replaced funds previously being put towards education.² These states however, still illustrate the strong financial influence of earmarked lottery funds.

Another 2003 study done across all fifty states illustrated that on average, lottery revenues increased per capita spending on education from 1977 through 1997. Specifically, Georgia's lottery revenue, which is earmarked towards education, provided the means for high increases in educational spending.¹⁸ From 1993 to 2005, Georgia's lottery generated \$6 billion towards college funds and other educational programs.² Furthermore, the fungibility of funds is often due to federal withdrawal of educational funding.¹⁸ This leaves little accountability at the state level.

As long as the government can enforce earmarking strategies, they can be very positive in achieving specific goals and gaining popularity with the public. At the state level, earmarking shows promise for increasing funds in a desired department, whether education, environmental conservation or any other. Earmarking can help lotteries build education programs at least more effectively than the simple deferring of revenue towards general state budget. However if being put towards education, it should be made sure that the money is being diverted to schools that need it most, as well as proportionally distributed among areas based on how much people in those areas spend on lotteries. This will help reconstruct the low income areas that tend to bet on lotteries the most.

Conclusions

It is clear that state lotteries are riddled with major flaws. However, many states have come to depend on their lotteries for revenue.³ Simply banning them in favor of general tax increases might not necessarily improve economic or social conditions in the United States. However, there are several changes that can be made which might reduce how regressive the tax is, and increase its productivity. Changing the types of tickets sold and educating buyers would go a long way to help steer the lottery away from taxing those with the least disposable income. Replacing the monopoly controlled by the government with regulated competition would yield much higher odds and more benefit for consumers. Finally, earmarking revenue would help lotteries to achieve specific goals, and would make the idea of them more marketable to the public. If state lotteries are to remain in place, reform must

be seriously considered to assure that society reaps the most benefit it can from them.

Footnotes

- i. In "The Economic Winners and Losers of Legalized Gambling," Kearney mentions several studies that come to this conclusion, including a book by Clotfelter and Cook (1989)⁶ summarizing previous studies, and more recent studies such as Scott and Garen (1993)⁷, Hansen (1995)⁸, Miyazaki, Hansen, and Spratt (1998)⁹, and Worthington (2001)¹⁰. Additionally, Price and Novak cite Stranahan and Borg (1998)¹¹ in "The Income Redistribution Effects of the Texas State Lottery Games," as well as several state specific studies done before 1990.
- ii. When someone wins a lottery prize, a sum less than the advertised amount is set aside for payment. The portion of this sum not yet issued to the winner earns interest, which eventually accounts for the remaining part of the total advertised jackpot payout. Alternatively, in the Lotto and Lotto Extra games, the winner may immediately receive this original sum as a lump sum payment, not including the value that would be gained by interest. In other words, the winner could immediately receive the estimated present cash value of the series of payments.¹⁵
- iii. This plan may not have a large effect on consumer behavior; however more extensive education plans such as a focus on statistics in schools would have high administration costs and still would not reach all consumers.
- iv. Like several other articles that argued either for or against the validity of state lotteries, Gribbin and Bean tend to use history to demonize the other side. Although never expressively stating a passionate moral opinion, they quote several politicians who do. I have tried to take from this only objective information, but the analysis of raw data not done by myself may not be completely unprejudiced especially in this case.

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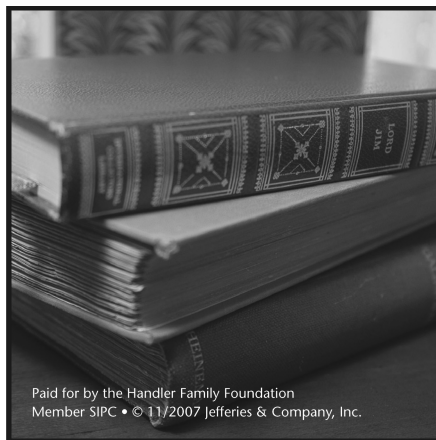
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The Tryptophan Mutant in the Human Immunodeficiency Virus Type 1 Reverse Transcriptase Active Site

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Human Immunodeficiency Virus (HIV) is a lentivirus whose infection in humans eventually leads to Acquired Immunodeficiency Syndrome, better known as AIDS. AIDS is characterized by a dysfunctional immune system, more specifically during the late stages of the HIV infection¹. When an individual contracts HIV, the virus attacks the body's immune system, which is responsible for fighting diseases and viruses. HIV is known to infect two types of cells in the body: CD4+ T cells and macrophages. When CD4+ T cells are attacked and killed, the immune system loses its ability to coordinate immune responses against pathogens. This affects both cell-mediated responses (with CD8+ T cells) and responses with antibody-producing cells (B cells/plasma cells). In other words, this causes an individual infected with HIV to become more susceptible to illnesses and diseases than an uninfected individual because his/her immune system is no longer able to mount a proper immune response to the pathogen. With a decrease in immune response, HIV continues to grow by producing "billions of new HIV viruses in the body" increasing an infected individual's susceptibility to all sorts of diseases, such as the common cold, flu, or other equally frequent virus infections².

HIV Type 1 (HIV-1) is a type of retrovirus. Retroviruses have been classified into one of three pathogenic groups: lentiviruses (of which HIV-1 is a member), cancer-causing oncoretroviruses (examples being human T-cell leukemia virus and murine leukemia virus), and non-pathogenic spumaviruses (including human and simian foamy viruses). Oncoretroviruses and spumaviruses are restricted to actively dividing cells for productive infection and replication. Lentiviruses, on the other hand, are able to replicate in both actively dividing cells (such as CD4+ T cells) and non-dividing/terminally differentiated cells (such as macrophages)⁸. An actively dividing cell refers to a cell which is actively going through the cell division process to replicate more copies of itself.

In its replication process, HIV-1 undergoes a step-by-step life cycle. First, the virus fuses into the host cell by interaction with host cell membrane CD4 receptors. CD4 receptors are present on the surface of certain T cells and macrophages, which are critical components of the body's immune system³. After HIV has entered the cell, HIV's positively oriented single stranded ribonucleic acid genome, which encodes for

the proteins necessary for HIV survival and replication, is reverse transcribed into negatively oriented single stranded deoxyribonucleic acid which is then further copied/transcribed into double stranded DNA. The enzyme Reverse Transcriptase (RT) is the critical protein which catalyzes this process. The DNA form of HIV's genetic content is necessary for further virus replication because the host cell replication process does not recognize viral RNA initially in its transcription step. The HIV proviral DNA is then integrated into the host cell's DNA and transcribed into messenger RNA (mRNA). The mRNA is translated into viral proteins which assemble at the cell membrane, along with new viral RNAs, into a new virus. The new virus then escapes or is released from the cell for infection of another host cell³. In this manner, the replication and protein expression machinery of the cell is permanently taken over by HIV since the DNA integrated into the host cell is able to remain dormant there for long periods of time. By targeting the HIV Type-1 Reverse Transcriptase (HIV-1 RT) protein for research, it is hoped that information gained could provide a better understanding of HIV viral biology.

From previous research, the structure of HIV-1 RT was determined to be a heterodimer of two subunits, p66 and p51. The p66 subunit contains all the enzymatic activity of the complex, containing a DNA polymerase domain and an RNase H domain. The p51 subunit is a proteolytic cleavage product of p66. The p51 unit has 440 amino acids and the p66 unit has 560 amino acids⁴. The DNA polymerase domain of the p66 subunit has been likened to a right hand and is divided into three subdomains: the fingers, the palm, and the thumb. Retroviruses like HIV-1 RT replicate by first 5' to 3' RNA directed DNA polymerization (DNA synthesis on an RNA template), second 5' to 3' DNA directed DNA polymerization (DNA synthesis on a DNA template), and third exonuclease (degradation of RNA in RNA:DNA hybrid) which happens at the same time as the synthesis of a negatively oriented ssDNA. The polymerase is responsible for the first two polymerization steps. RNase H also works closely with the polymerase region in these critical steps to ensure that the RNA is converted into double stranded DNA (dsDNA) by degrading RNA present in the RNA:DNA hybrid. Once the DNA (or RNA) template is in place, HIV-1 RT must now add

deoxynucleotide triphosphates (dNTPs which are the building blocks of DNA) to generate new copies of genomic material. HIV-1 RT-template interactions and the stabilizing features of polymerase site help stabilize the dNTP binding site and promote polymerization reaction⁴.

The amino acid tyrosine is located at position 115 within the palm subdomain and is frequently referred to as Y115. Tyrosine's location in the palm yields it a critical stacking interaction with incoming dNTPs allowing RT to perform its polymerase functions. Based on its extreme stability in vivo, tyrosine is believed to be a critical component to the dNTP stacking interactions within the palm subdomain of RT⁹. This then yields to the prediction made by this experiment: mutation of tyrosine to another amino acid residue should affect the stacking interactions which are quantified in terms of dNTP usage efficiency.

In previous unpublished HIV-1 RT research done in this laboratory, mutation of tyrosine to other amino acids such as alanine (Y115A), leucine (Y115L), valine (Y115V), phenylalanine (Y115F), methionine (Y115M), and serine (Y115S) led to the finding that the ability of RT to efficiently use dNTPs at low dNTP concentrations was altered. According to previously acquired data, Y115A RT followed in activity after the wild type RT. Y115S was found to be less active than Y115A. Y115V and Y115I showed similar activity to the wild type. This current study analyzes the effects of the Tryptophan mutant at position 115 in the active site of HIV-1 RT. Previous experimentation mutating tyrosine to artificial amino acids observed alterations in dNTP usage efficiency¹⁰. This observation agrees with the prediction made for this experiment: mutating tyrosine to tryptophan would alter RT's dNTP usage efficiency since tyrosine has a stacking interaction with the incoming dNTPs during transcription. A mutation to tryptophan would therefore alter the stacking interactions of incoming dNTPs since the residue structure of RT has been changed and the sugar of the incoming dNTPs have to interact with an amino acid of a different structure.

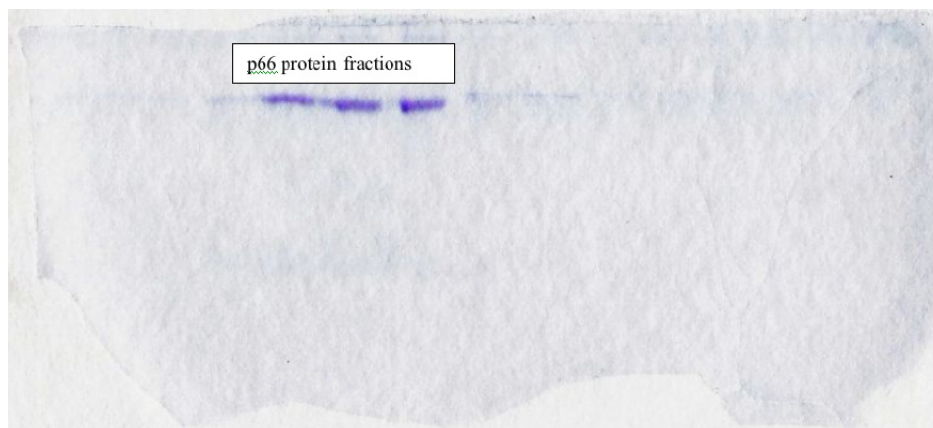
Materials and Methods

Site-directed mutagenesis involving overlapping PCR was used to generate the Y115W mutation into HIV-1 RT. A plasmid containing the sequence for HIV-1 strain NL4-3 RT was used as a template. NL4RT N-T NdeIF (5'-AAAAAAAACATATGCCCATAGTCCTATTGAGAC-3') and

NL43RT Y115 W-R (5'-CTTTATCTAAGGGAAGTGA AAACCAGGCATCGCCCACATCCAG-3') were used as primers for an initial 5' PCR fragment; Y115 overlap new F (5'-GTTCCCTTAGATAAAGACTTC-3') and NL4RT C-T HIIIR (5'-AAAAAAAAGCTTTTATAGTACTTTCCTGAT TCCAG-3') were used as primers for an initial 3' product. The process used initially yielded one 5' fragment with the Y115W mutation and a 3' (wild type) fragment. The secondary (overlapped) product was a single fragment of DNA with both *NdeI* and *HindIII* cut sites (introduced by the primers) with the Y115W mutation. The mutated RT gene was inserted into pET28a (Novagen, WI) using 5x ligase buffer and T4 DNA ligase from Invitrogen (Invitrogen, Carlsbad, CA). The DNA from the ligations was transformed to *Escherichia coli* XL-1 Blue (Stratagene, La Jolla, CA). Sequence analysis (Genewiz Inc., South Plainfield, NJ) confirmed introduction of the Y->W mutation to the RT gene.

Hexahistidine-tagged RT protein was expressed and purified using protocols, reagents, and buffers provided by the manufacturer (Novagen) as outlined previously^{5,6} with few modifications. Briefly, pET28a expression plasmids with wild type or mutant RT inserts were transformed to *E. coli* BL21 (DE3) pLysS and grown in shaking culture at 37°C to an OD₆₀₀=0.2 and then induced with isopropyl-1-thio-D-galactopyranoside (IPTG) to one-hundredth of total culture volume (5mL to 500mL culture). Cultures were allowed to shake at 37°C for an additional 3h to allow protein expression. Bacteria were then harvested and cell pellets were resuspended in 1x binding buffer and stored overnight at -80°C. Frozen pellets were thawed on ice for 2h, and then centrifuged 20min (15,000 rpm at 4 °C). Supernatants were applied to Ni²⁺ charged resin for Ni²⁺ chelation chromatography as previously described.^{5,7} Purified protein was then dialyzed against 1X dialysis buffer (50mM Tris-HCl pH7.5, 1mM EDTA, 200mM NaCl, 10% glycerol) overnight at 4°C. Purified proteins were then dialyzed for an additional 3h against 1X dialysis buffer with 1 mM dithiothreitol. Dialyzed protein was stored at -80 °C prior to usage in assays. Protein expression and purification were found to be successful based on a protein gel run of the fractions collected as demonstrated in Figure 1 of Results and Discussion section. The protocol for the preparation of DNA Polymerization were performed as previously explained⁶. The polymerization assays were performed using a 17-mer primer A (5'-TCGCCCTTAAGCCGCGC-3') annealed to a ³²P-

Figure 1: Protein gel depicting p66 protein fractions generated following protein purification.



labeled 38-mer RNA template (5'-AAGCTTGGCTGCAG AATATTGCTAGCGGGAATTCGGCGCG-3'). The assays employing wild type, Y115W, and Y115V proteins were performed at varied concentrations of dNTP (as indicated in the results and discussion section and in figure legends). The template-primer was prepared by annealing a 38mer RNA template (5'-GCUUGGCUGCAGAAUUAUGCU AGCGGGAUUCGGCGCG-3', Dharmacon Research, CO) to a 17-mer DNA (5'-CGCGCCGAATTCCTCGCT-3', A-primer) ³²P-labeled at the 5' end using [γ -³²P]ATP and T4 polynucleotide kinase (template/primer, 4 μ L of 20 μ M). Reaction mixtures (20 μ L) contained 20 μ M template/primer, RT proteins (Wild type and Y115W), dNTPs (250 μ M each dNTP), 25mM Tris-HCl (pH 8.0). Approximately 50% of the primer was fully extended by wildtype RT and Y115W RT under this reaction condition. Reactions were incubated at 37 °C for 5 min and terminated by 4 μ L of 40 mM EDTA, 99% formamide. Reaction products were immediately denatured by incubating at 95 °C for 3 min and analyzed by electrophoresis on 14% polyacrylamide-urea denaturing gels. Products were analyzed on 14% polyacrylamide-urea denaturing gel and visualized as set forth in figure 2 below.

Results and Discussion

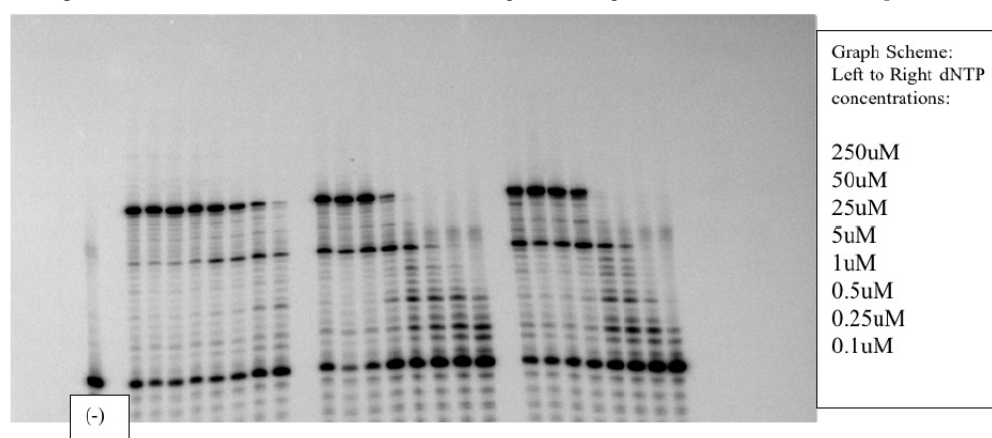
As mentioned above, the clone was determined successful based on sequencing analysis (Y->W). From the data collected in this experiment, the Y115W RT protein expression and purification was demonstrated to be successful, as illustrated in Figure 1 below. Once the mutation had been successfully cloned and transformed to appropriate cells, the protein was expressed in *E. coli* and purified by Ni²⁺ column chromatography. To determine that the protein expression and purification method had been successful, a 12% polyacrylamide gel of the protein fractions collected were run and Coomassie stained (Figure 1). Protein presence was confirmed by the visible bands on the gel. The two fractions with the higher concentration of protein were used to perform the dNTP titrations.

No significant barriers were encountered in mutating tyrosine to tryptophan or later expression of the Y115W RT protein. The overlapping PCR, transformation to XL-1 Blue (for cloning), and later BL21 (for protein expression) progressed successfully, as depicted by the Y115W protein presence on the p66 protein gel (Figure 1) and the Y115W protein activity seen in the dNTP titrations (Figure 2).

In order to find the amount of wild type or mutant enzymes showing equal extension capability, the three proteins were first used in primer extension experiments at 250 μ M dNTP (data not shown). There was approximately equal protein activities for all three proteins compared when in the presence of 250 μ M dNTP. A one-twenty fifth dilution concentration of protein was used to perform a dNTP titration of the following final concentrations: 250 μ M, 50 μ M, 25 μ M, 5 μ M, 1 μ M, 0.5 μ M, 0.25 μ M, and 0.1 μ M. The dNTP titration was performed in comparison to the wild type RT and the Y115V RT, both generous donations of other fellow lab participants. From previous unpublished data gathered in the lab, the wild type RT showed fifty percent extension at a one to one hundred and fifty dilution and the Y115V RT showed fifty percent extension at a one to one hundred dilution concentration, therefore these concentrations were used in the dNTP titration reaction. The dNTP titration reactions were refined with a more limited range of dNTP and protein concentrations varied as follows: Y115 was diluted to a factor of one to seventy-five instead of one to one hundred and fifty, Y115W was diluted to a factor of one to eight instead of one to twenty five, and Y115V was maintained at the factor of one to one hundred. The dNTP concentrations were limited to 25 μ M, 12.5 μ M, 10 μ M, 7.5 μ M, 5 μ M, 4 μ M, 3 μ M, 2 μ M, 1 μ M, and 0.5 μ M. The amount of protein then giving 50% extension capability at 250 μ M dNTP was then fixed. This amount of each protein was then used in dNTP titration experiments.

In comparing wild type, Y115V, and Y115W proteins, the mutants showed less polymerase activity than wild type at concentrations below 5 μ M dNTP. However, Y115W showed somewhat better activity than Y115V, at 3 μ M and below (Figure 3). The negative control (as shown in Figure 2) against which wild type, Y115V, and Y115W were tested contained no protein and therefore was not expected to show any extension. As stated above, the protein activity level was equalized at 250 μ M dNTP. This equivalent activity between the three proteins remained for dNTP concentrations of 50 μ M and 25 μ M. Below 25 μ M dNTP concentration however, differences in protein activity among the three proteins were observed. Wild type continued to extend equally well at 5 μ M, 1 μ M, 0.5 μ M, and 0.25 μ M. Between 0.25 μ M and 0.1 μ M, the wild type protein activity decreased significantly (see Figure 2). Y115V showed a decrease in protein activity between 25 μ M and 5 μ M dNTP. The decrease in activity continued until the last data

Figure 2: dNTP titration of WT, Y115V, and Y115W against the negative control which contains no protein.



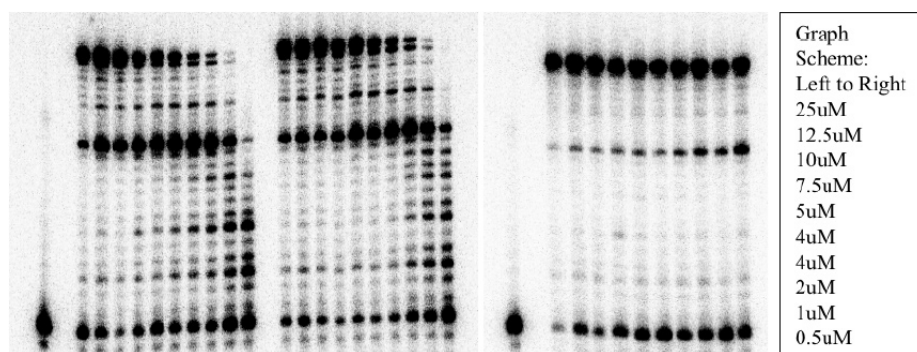


Figure 3: Limited range dNTP titration of Y115V, and Y115W against the negative control which contains no protein (left) and limited range dNTP titration of WT against the negative control which contains no protein (right)

point (0.1µM). Y115W demonstrated a significant drop in protein activity between 5µM and 1µM dNTP. The decrease in protein activity continued in similar fashion to Y115V until the last data point (0.1µM) as well. Since Y115V protein activity started to decrease at a higher dNTP concentration than Y115W, this would indicate that Y115W works slightly better than Y115V at lower dNTP concentrations. Wild type RT however still works better than Y115W at lower dNTP concentrations.

Conclusion

From the data gathered in this experiment, Y115W RT demonstrated slightly higher polymerase activity than Y115V RT but lower polymerase activity than wild type at concentrations lower than 25µM. In comparison to the other mutants generated in unpublished research done in this lab, the tryptophan mutant protein (Y115W RT) showed extension about sixty percent as good as tyrosine (Y115 RT) protein at 25µM. In the dNTP titration reactions performed, the Y115W RT activity was constant down to a dNTP concentration of 5µM. After 5µM and between 5µM and 1µM dNTP, the Y115W RT no longer showed fifty percent extension. The Y115V RT showed equal protein activity up to a dNTP concentration of 25µM. After 25µM and between 25µM and 5µM dNTP, Y115V RT polymerase activity dropped sharply. Y115 RT, on the other hand, demonstrated equal protein activity at most dNTP concentrations used in this experiment. A decrease in activity of Y115 RT was observed between 0.25µM and 0.1µM. Further refined dNTP titration reactions showed that Y115W polymerase activity dropped sharply between 2µM and 1µM but Y115V polymerase activity dropped between 3µM and 2µM. Wild type RT activity however remained constant down to 0.25µM which is a slightly higher dNTP concentration than found in in-vivo cells targeted for infection. Macrophage have a dNTP concentration of ~.050µM and activated CD4+ T cells have 2-5µM dNTP⁸. To conclude, the protein with the Y115W mutation produced in this lab was better able to use dNTP than the other mutant protein which it was compared to, Y115V, at certain dNTP concentrations. However, the Y115W mutant protein was still unable to use dNTP as effectively as the wildtype protein which is normally found in nature and biological organisms. This information showing decreased dNTP usage polymerase will help to design viral vectors that specifically infect cells containing elevated dNTP concentrations, such as cancer cells, with the hopes of

yielding more information about cancer biology for therapeutic studies.

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Frederick F. Kislingbury: Rochester's First Arctic Explorer

Stephanie Mason, 2008

Advised by Th. Emil Homerin, Ph.D.

Department of Religion and Classics

Frederick Kislingbury knelt on a rocky cliff off of the serrated coast of Disko Island, Greenland, wind cutting into his face like knives, sun hugging the horizon. Below him was an expanse of blinding masses of ice, their fractures immersed by the deep blue sea. All he could hear, feel, and taste was the blowing wind; no trees or traces of life were in sight. He was about to depart on an expedition to the High Canadian Arctic, so he wrote a letter to his son, Douglas, ending with "Do not worry the slightest about me, I know that all will go well."¹ Yet, within a week, he found himself in the middle of a predicament lasting three years, which only six of twenty-five men would survive.

In Range 3 of Mt. Hope Cemetery, underneath a nineteenth century granite stone with shallow inscriptions, lays a 700 pound iron casket (Figure 1). The ordinary look of the stone does not give justice to the extraordinary feats and heart-wrenching decisions of the man beneath it. He was Frederick Kislingbury, Rochester's first Arctic explorer. Kislingbury was born in Berkshire, England around 1846 and moved to the United States with his family when he was about ten, residing in Rochester. Next to nothing is known about his years as a child or a young adult, except that he enlisted in the Eleventh Infantry of the United States Army in the 1860's.²

In 1866, he married Agnes Bullock from Windsor, Canada, and together they had four sons. The first, Harry, was born in 1867, and Walter was born in 1869. Frederick received word in the early 1870's that he was to move to Fort Concho in western Texas to help build a telegraph network across the southern plains. He moved his family there, and

Figure 1: Kislingbury's grave stone in Range 3, Plot 177 in Mount Hope Cemetery. The front reads: "Lieut. Fred F. Kislingbury, 11th US Infantry, 2nd Officer in Command, Lady Franklin Bay, Arctic Expedition 1881, Lat 83°24' N, 40°46' W." The reverse reads: "Died June 1, 1884, Camp Clay, Near Cape Sabine, Smith Sound, Aged 38 Years."



Figure 2: The crew of the Greely Expedition. Frederick Kislingbury is in the bottom row, the third from the left. Adolphus Greely is seated to the right of Kislingbury. (L.F. Gutteridge)

worked under the command of Lieutenant Adolphus Greely. Frederick and Agnes had two sons while in Texas: Douglas in 1874 and Wheeler in 1876.³

When Agnes suddenly died in April of 1878, Frederick had her returned to her family's home in Windsor, Canada for burial.⁴ While on a two month leave from his duties in Detroit, he learned of an expedition to the Arctic, planned by the United States Army and led by his former commander Greely. Frederick wrote to Greely, stating that if he needed a man who was willing to learn and could lead through hardships, "then I [Frederick] am your man. I can say no more, I think, to convince you of my eagerness to go."⁵

Frederick married Agnes' sister, Jessie, in 1879, and he returned to his duties out west with his family, this time stationed in Colorado. While on assignment in the field a year later, Frederick received word that Jessie was dying, and he rushed back to the base to see her. Frederick lost his second wife on December 8, 1880.⁶ That winter was a particularly harsh one, and the broken family was snowed in at the base until March. About a month after Jessie's death, Kislingbury was asked by Greely to be the second lieutenant in command on the Arctic expedition. Kislingbury accepted, saying that the invitation came "as a boon...the separation from my children will be nothing as compared to the prospect of having been with those who may accomplish some great and lasting good." In March, Kislingbury left the base in Colorado to bury Jessie next to Agnes in Canada; he left his four sons with friends' families to watch over them during his sojourn.⁷

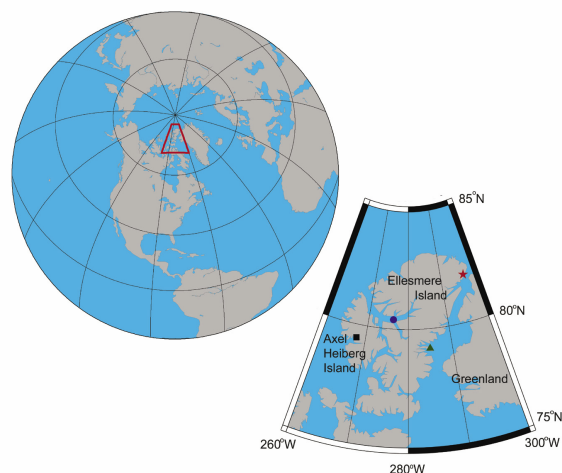


Figure 3: Map of the High Canadian Arctic. The red star is Fort Conger, the blue circle is Greely Fiord, and the green triangle is Camp Clay, all on Ellesmere Island. The black box is Expedition Fiord, Axel Heiberg Island. Nares Strait is between Ellesmere Island and Greenland.

Greely's Arctic Expedition Announced

On April 3, 1881, The Washington Post announced the details of the Arctic expedition to the public and reported that Kisingbury had been chosen to be the second officer in command.⁸ The motivation behind the expedition stemmed from the fact that, at this time, the Arctic region remained unexplored. The pole had eluded men for years, and the closest anyone had come was a British team about 10 years prior who made it to 83°20' N. Not only did the American expedition want to break this record, they hoped to reach the North Pole. The Greely expedition was one of the main components comprising the first International Polar Year from 1882 to 1883, an international collaboration on research in the Polar Regions. The team would make scientific observations during their time north, measuring air and sea temperatures, wind velocity and direction, terrestrial magnetism, and the aurora.⁹ The team would experience 24 hours of darkness during the winters and 24 hours of sunlight in the summers.

The men would be in the Arctic for three years, and re-supply ships were to drop off goods at the base camp during the summers of 1882 and 1883. The men had 2 years worth of rations to begin the expedition. If ships were unable to reach the base camp, they were to leave the supplies at Cape Sabine, 250 miles to the south; if Cape Sabine could not be reached, the ships were to return home with their full loads. If the men were not visited by re-supply ships in 1882 or 1883, they would move their camp to Cape Sabine and wait out the winter with caches of left-over supplies. A ship would pick them up in the summer of 1884 and bring them home.¹⁰ In June of 1881, a photographer in Washington D.C. took a picture of the 22 crew members before they left the United States to board their ship, the Proteus, in Newfoundland (Figure 2).

Turmoil in the Arctic

The ship left port on July 8, 1881, and two weeks later picked up the expedition's doctor and two Inuit guides on Disko Island, Greenland.¹¹ They departed Disko Island in late July to navigate between ice floes and icebergs in the Nares Strait between Ellesmere Island and Greenland. On August

10th, the Proteus reached its final destination, Lady Franklin Bay, on the eastern coast of Ellesmere Island, where unloading began (Figure 3, 4). It took a week to build the hall where the men would reside, and they named it Fort Conger after Senator Conger of Michigan, who whole-heartedly supported the expedition in its planning stages. The Proteus remained docked in Lady Franklin Bay until August 26th, unable to find a clear path through icebergs to return to Newfoundland.¹²

The first several weeks were rocky between Kisingbury and Greely. Greely thought Kisingbury was writing in his journal too much, and that he was lazy in his constant tardiness to meals. After two weeks, Greely ordered Kisingbury to resign as second in command.¹³ Kisingbury gave Greely his papers on August 26th, packed up his belongings, and walked out to board the Proteus to go home. However, Kisingbury's timing could not have been worse; he watched the ship disappear through the icebergs. He ran to the shore, fully realizing the horrible situation he was in. The next time a ship could make it to Fort Conger was next summer, so he would have to wait. Until then, he would not be part of the scientific expedition and could not interact with the crew.¹⁴

The Expedition Continues to a Tragic End

Kisingbury's hopes rose every summer, but ships could not find a clear path through icebergs in 1882 or 1883 to re-supply Fort Conger. During the summer of 1883, the Proteus hit an iceberg in the Nares Strait and sank; its crew had to be rescued by another ship.¹⁵ Kisingbury's time waiting was spent exploring the region around Fort Conger, collecting lichens and other arctic plants and trying to be a part of the expedition team.¹⁶ Since Fort Conger had not been re-supplied in two years, the crew, including Kisingbury, abandoned Fort Conger in August of 1883 and made the month-long journey south. Caches of food to last the winter were supposed to be waiting for the team at Cape Sabine, where they would create a new camp, wait out the winter, and be picked up the next summer. The new camp was named Camp Clay.¹⁷

The team found 60 days worth of rations on the coast of Cape Sabine. The rations were thrown onto the shore from the sinking Proteus during the summer.¹⁸ Greely's decision at the onset of the expedition to have the supply ship turn home if they could not drop rations at Fort Conger or Camp Clay severely hurt the team, for there was nowhere the men could go for more food. One by one, men started dying from starvation.

Figure 4: The Proteus unloading its cargo at Fort Conger during the first weeks of August, 1881. (L.F. Gutteridge)



The first death was in January of 1884. Kislingbury died on June 1, 1884. One man was executed for stealing bits of food three days after Kislingbury's death.¹⁹ The few remaining men were found on June 23rd, emaciated and barely alive. The rescuers loaded them and their dead, who had been buried in a hill near the tents, onto the rescue boats. The relief squadron with the six survivors and the bodies of their fallen comrades sailed into New York City in early August.²⁰ Kislingbury's casket arrived in Rochester on the evening of August 9th, and a military funeral was held the next day at the Monroe County Court House with more than 20,000 present to pay their last respects (Figure 5). He was interred the same day at Mount Hope Cemetery.²¹

Accusations of Cannibalism

However, suspicions had been aroused among the public and the media after the rescue party had arrived in New York City Harbor. The six survivors came back strong and fit after living the last eight months on 60 days worth of rations.²² The survivors claimed that they had chewed on their shoe leather and had eaten moss that they had gathered. Still some wondered if the men been hungry enough to eat each other. Moreover, the Army had told the grieving families of the dead, that they should inter the remains right away and, under no circumstances, should they open the caskets. The public began to ask if Frederick was even in the casket or if he had been left behind buried in the Arctic.²³ The Rochester Post pressed the issue, curious about the nature of the expedition and Kislingbury's body. They offered to pay the expenses to exhume Frederick and examine the remains to put an end to the rumors if Frederick's three brothers, John, William and Frank, would agree to this.²⁴ The relatives would also be allowed to watch the examination at the Mount Hope Cemetery Chapel. They agreed and four days after the body was buried, it was exhumed. In the morning hours of August 14th, 1884, fifty two bolts were loosened and the lid was removed.²⁵ What was found was horrific.

The Boston Globe was given the rights to publish the details of Kislingbury's autopsy in vivid detail. Fifty pounds of remains were found wrapped up in a wool blanket with the

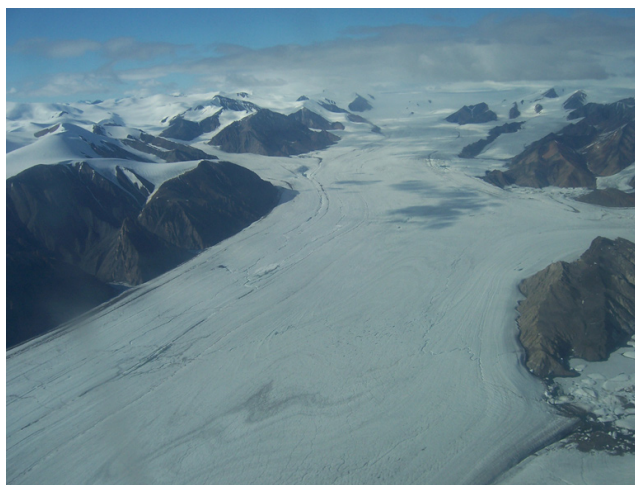


Figure 5: The military funeral of Frederick Kislingbury at the Monroe County Courthouse in Rochester, NY on August 10th, 1884. (Rochester Local History Photo Images Database, Rochester Public Library, image number rpf00548)



Figure 6: Pictures of the High Canadian Arctic taken in July, 2006. A. The University of Rochester's camp on Expedition Fiord, Axel Heiberg Island. The Dragon River is in the foreground. B. Thompson Glacier on Axel Heiberg Island near our field area. C. I am standing on Surveyor Mountain, Axel Heiberg Island while doing geological field mapping.

strong smell of alcohol. Kislingbury's body had no skin and little flesh remaining from his head downward. His arms and legs were only held on by the ligaments. After less than an hour of examination, the casket was sealed. The two doctors who examined the body concluded that he had died of starvation, and that he also had inflammation of the bowels. The only thing found in his digestive tract was a mass of indigestible hair, moss and woolen fibers.²⁶ Kislingbury's body was methodically carved, and there was no evidence of him being

purposely killed. The relatives accepted that Frederick had been consumed by others of the expedition under horrible circumstances, but they were more upset that they were not told about the nature of the last days of the expedition.²⁷

Conclusion

Frederick Kislingbury rests after a heart-wrenching turn of events in the last years of his life. The efforts of the expedition crew not only helped to map and characterize the area, but also pushed further north than anyone else ever had: to 83°24'N. They also pushed further west and discovered an unexplored fiord on the western part of Ellesmere Island, now called Greely Fiord, after the Expedition's leader.²⁸ Unfortunately, much of the area in the Arctic remains poorly mapped and exploration is still difficult and extremely dangerous. Today, all that is left on Cape Sabine are pieces of the men's tents, rims of the supply barrels and the shallow graves on the burial ridge with large rocks as headstones. These items were discovered and photographed in 1987 by researchers and historians from the Arctic Institute of North America.²⁹

I was fortunate to travel to the High Canadian Arctic as a part of a scientific expedition of the Paleomagnetism Research Group at the University of Rochester, led by John Tarduno. We were there in July of 2006, about 120 years after Kislingbury was there. I was doing field mapping as a part of a class project and assisting in fossil collecting supervised by Deborah Vandermark on Axel Heiberg Island (79° 30' N).³⁰ We were also on the western edge of Ellesmere Island at 80°N at a seasonal camp called Eureka, on the southern part of Greely Fiord, first discovered by Kislingbury's team.

My work in the Arctic has led me to a greater appreciation for nature and the elements, and for the courageous strength of past Arctic explorers including Frederick F. Kislingbury. For, unlike Greely's crew, our expedition was transported to the Arctic by helicopter and a twin engine plane. We made radio contact with a base camp twice daily to receive information about the weather and any polar bear sightings. Our food was shipped in wooden crates many months before we left Rochester and was waiting for us at our camp site. We were able to drink fresh water from the glacially fed Dragon River. We did not have the amenities of home and only our tents as shelter on the uninhabited island. Moreover, our party had to carry two shotguns in the case of a polar bear encounter. But there were 24 hours of sunlight, and in the end, we fared much better than Greely and his men.

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No relationship has ever impacted the future of race relations in the United States [more] than that of Abraham Lincoln and Frederick Douglass. As a self-taught fugitive slave, Douglass devoted his life's work to the abolition of slavery in America. Speaking at numerous events in both the United States and England and publishing his antislavery newspapers, Douglass was passionate about his cause and stopped at nothing until he lived to see the day that slavery was abolished. Abraham Lincoln's election as President sparked a chain of events that ultimately led to the Civil War, emancipation, and the Thirteenth Amendment. Throughout the years of the war, Douglass challenged the policies of Lincoln in hopes of pushing him towards a definitive and immediate emancipation policy. Although Douglass and Lincoln did not personally meet until after the Emancipation Proclamation, their relationship up to that point was defined by their correspondence through public addresses, letters, and newspapers. During the war years, Douglass and Lincoln had a tenuous relationship that fluctuated according to Lincoln's changing policies. From the antebellum period through the announcement of Emancipation Proclamation, Douglass' sentiments towards Lincoln went from cautious support in 1860, to complete outrage in 1861, and finally respectful admiration in 1863. However, evidence suggests that their relationship grew to become more profound because the realities of the war and the end of American slavery led these two men to hold a deep respect for each other.

From the moment Douglass freed himself from slavery, he began to push his policy of emancipation. He was always passionate about abolition in all parts of the United States: "I am, of course, for circumscribing and damaging slavery in every way I can. But my motto is extermination—not only in New Mexico, but in New Orleans, not only in California but in South Carolina."¹ As a Garrisonian, Douglass had been a proponent of moral suasion, that is, the preaching and practicing of evangelism as a means to abolish slavery.² Invoking the principles of moral suasion, Douglass came to see abolition directly linked to religion: "For Douglass, abolitionism quickly assumed the status of religion, drawing upon the best Christian ideals: love, morality, and justice."³ Douglass, who associated slavery with barbarity and freedom with religion, believed that it was hypocritical to be a Christian slaveholder. He tried to incorporate religious aspects into his speeches in order to show people that slavery was a moral sin. In a letter to British

radical abolitionist George Thompson, Douglass quoted a passage from the Bible that refers to the relationship between a master and a slave: "I yet take pleasure in complying with the wish of one who is a friend to me and 'how much more to thee."⁴ As tensions mounted between North and South during the antebellum period, it became evident that moral suasion alone would not lead to complete abolition, and so, split with the radical Garrisonians. After this split, Douglass used a combination of moral suasion and political action in his agenda; he was determined to work within the established political system to legally abolish slavery. He stood by the belief "that the complete abolition of slavery needed to rely on political forces within the Union, and the activities of abolishing slavery therefore should be within the Constitution."⁵ Involvement on the local level, including community and regional political activism against slavery, proved to be ineffective mechanisms to advocate change because the issue of slavery was quickly moving to the forefront of domestic politics. This meant that there needed to be a political party that included an antislavery plank in its platform in the White House. At this time, slaveholders were ardently defending their right to own slaves; compromise was slowly becoming an exhausted option, which suggests that any party that included the antislavery cause as a part of their platform had little chance of reaching the presidency. After giving his support to the Free-Soilers and the Liberty Party, Douglass realized that these third parties had little chance of winning the presidency because their platform solely rested on antislavery. Naturally, Douglass realized that he had to throw his support to another political party that had a better chance of reaching the White House. In a letter to William Seward in 1863, Douglass expressed his desire for a party that would "disentangle the Republic from Slavery."⁶

The growth of Douglass' sense of abolitionism is reflected in his pattern of political party support: "At first he would align himself primarily with the Liberty Party or Radical Abolitionists," but "come election time, he would opt for expediency and support the presidential candidate he deemed the most pragmatic compromise between his radical abolitionism and his growing political activism."⁷ The formation of the Republican Party in 1854 proved to be the best bet for the abolitionists. Within the Republican Party were elements of the Liberty Party, the Free Soil Party, and those antislavery forces from both the Democratic and Whig Parties. The Republican Party "was an alliance of antislavery forces...it was not exclusively an Abolitionist Party."⁸ This

conglomeration of several different political views appealed to Douglass because it seemed as though it was the best party with the best chance to enter the White House. Even though he was at first cautious, he decided that the Republicans offered a better chance for victory.

The Republican platform stood firmly beside non-extensionism; that is, there would be no interference with slavery where it already existed, but would also not allow it to spread any further. The goal here was to maintain the status quo in order to avoid any open conflict. As a means to execute this non-extension policy, the Fugitive Slave Law required all runaway slaves to be returned to their slaveholder.⁹

The fact that the Republicans even approached the slavery issue was a very radical move at the time. At this moment, Americans' political concerns were split right down the middle when it came to the slavery issue as indicated by the maps of the presidential elections of 1856 and 1860 (Appendix).¹⁰ While antislavery sentiments were growing in the North, slavery was still ingrained into Southern lifestyle. If the Republicans were either strongly proslavery or antislavery, they would not have reached the presidency. By sticking to the non-extension policy and broadening their platform, Republicans hoped to appeal to the majority of Americans.

Although Douglass did put his political support to the Republicans in the 1860 election, he still had lingering fears that they would do more harm to the situation of the slaves than good. Douglass was fearful that no president would realize that the only solution to preserve the Union on peaceful terms was to end slavery. While the rest of the nation saw the Republicans policy of non-extension as antislavery, Douglass and the radical abolitionists saw it as proslavery policy. In an article published in Douglass' newspaper *Douglass' Monthly* entitled "The Late Election," Douglass criticizes the position of Lincoln and the Republican Party in regards to slavery:

*Mr. Lincoln... while admitting the right to hold men as slaves in the States already existing, regards such property as peculiar, exceptional, local, generally an evil, and not to be extended beyond the limits of the States where it is established by what is called positive law. Whoever live through the next four years will see Mr. Lincoln and his Administration attacked more bitterly for their pro-slavery truckling, than for doing any anti-slavery work.*¹¹

This was only the beginning of Douglass' militant attitudes and harsh criticisms of Lincoln and his administration. Douglass was optimistic that he would be able to push Lincoln towards immediate emancipation: "Douglass believed he could turn the Republican Party into an Abolitionist party and Lincoln into an Abolitionist president."¹²

When Lincoln was elected to office, Douglass remained optimistic because he saw Lincoln's potential to eventually emancipate. In general, the Republican party "suffered from a fatally ambiguous attitude toward the Negro."¹³ But Lincoln had always been opposed to slavery because he believed that slavery was the source of all conflict tearing the Union apart. Lincoln believed that ending slavery, or at least preventing the spread of it, would end sectional conflicts and prevent open warfare: "I have said that I believe we shall not have peace upon this question until the opponents of slavery ARREST THE FURTHER SPREAD OF IT...."¹⁴ According to Lincoln's views, non-extension advocated the return to the original Constitution: "I say in the way our fathers originally

left the slavery question, the institution was in course of ultimate extinction, and the public mind rested in the belief that it was in the course of ultimate extinction."¹⁵ Lincoln also believed that slavery was not consistent with the value of human equality set forth by the Declaration of Independence. He insisted that "there is no reason in the world why the negro is not entitled to all the natural rights enumerated in the Declaration of Independence, the right to life, liberty, and the pursuit of happiness."¹⁶ However, Lincoln was unwilling to directly approach the slavery issue. In the series of the 1858 senatorial debates with Stephen Douglas, Lincoln "denounced slavery as a moral evil, and tried as much as possible to dodge the race question."¹⁷ This frustrated Douglass, which was also the source of his fear. But his criticisms of Lincoln's slowness are more harsh during his Presidency.

When Abraham Lincoln took office in the spring of 1861, he knew that his nation was in need of repair. The issue of slavery, which was increasingly becoming a major national debate, characterized the political climate of the antebellum period. The heated arguments over the future of American slavery became so great that compromise was no longer a viable solution. The nature of compromise upon the outbreak of war is best characterized by the Crittenden Compromise of 1861. As a final one-sided attempt to protect the future of slavery, the Crittenden Compromise is difficult to call a compromise because it only had the interests of slaveholders in mind. After its failure, war was inevitable and Lincoln knew it. His goal was now to keep his nation afloat.

At this moment, Lincoln and Douglass had two different agendas: "The president's mission in the war was to save the Union; Douglass' was to free the slaves and transform them into citizens."¹⁸ Because he feared that it would split the Union further, Lincoln refused to make the war a war for abolition. To Douglass, the root cause of the war was slavery. As military conflict became inevitable, Douglass was ready to let the conflict come. He viewed the secession crisis and the coming of the war as "a collision of forces that might cause this break with the past."¹⁹ Lincoln at first viewed the war as the worst case scenario: "At the outset of the war Douglass wanted precisely what Lincoln did not want: a 'remorseless revolutionary struggle' that would make black freedom indispensable to saving the Union."²⁰ Regardless of what either man wished for, the war did come and both Douglass and Lincoln each openly fought for their causes: Douglass for abolition and Lincoln for preservation of the Union at all costs.

As a means to preserve the Union and honor the Constitution simultaneously, Lincoln felt it best to suffocate any attempts at emancipation until he found a constitutional way to legally emancipate the slaves: "Cease to call slavery *wrong*, and join them in calling it *right*. And this must be done thoroughly—done in *acts* as well as *words*."²¹ At first, he stuck to his policy of war to preserve the Union and suffocated any instance where slavery was mentioned. On August 30, 1861, Lincoln immediately canceled General John C. Fremont's order to free the slaves that were in arms against the federal government in Missouri. In a letter to Fremont sent on September 2, 1861, Lincoln wrote:

Your proclamation of August 30th [gave] me some anxiety. I think there is great danger... in relation to the confiscation of property, and the liberating slaves of traitorous owners, will alarm our Southern Union

*friends, and turn them against us.... Allow me therefore to ask... modify that paragraph so as to conform to the first and fourth sections of the act of Congress, entitled, 'An act to confiscate property used for insurrectionary purposes,' approved August, 6th, 1861.... This letter is written in a spirit of caution and not of censure.*²²

Not surprisingly, this not only enraged Douglass, but also proved “to be the direct result of the Administration’s failure to come out clearly and definitively with a statement of principle opposing slavery.”²³

Later that year, when Secretary of War Simon Cameron included a section in one of his reports approving the emancipation of and the arming of slaves within the Union borders, Lincoln made him rescind his order and had the section cut from the report. Again Lincoln tried to avoid making any radical decisions regarding slavery when in May 1862, General David Hunter issued an order to emancipate all the slaves in the South Military Region, which included South Carolina, Georgia, and Florida. Lincoln again revoked the order as a means to keep the Border States loyal. On May 19, 1862 Lincoln announced a proclamation officially revoking General Hunter’s order: “I, Abraham Lincoln... proclaim and declare, that the government of the United States, had no knowledge, information, or belief, of an intention on the part of General Hunter to issue such a proclamation... and that the supposed proclamation... in question... is altogether void....”²⁴

Douglass was, naturally, outraged at Lincoln’s suppression of the slavery issue, which made him even more “determined to change his [Lincoln’s] mind”²⁵ and “in 1862, the job for [his] elegant vocal instrument was agitation.”²⁶ At that moment, he was enraged with the Lincoln administration, criticizing it whenever he had the chance: “Douglass was constantly pressing the President and everyone else in Washington to stop downplaying the slavery question and turn the war into a crusade to rid the land once and for all of the hated institution.”²⁷ Slowly but surely, the “events during the first half of 1862 pushed moderates toward the radical position.”²⁸

But as the war progressed, Lincoln started to feel pressure from the political left, including Douglass and other antislavery radicals. Regardless, Lincoln still maintained that the war was a war to preserve the Union, but never doubted that the issue of emancipation coincided with ending the war. In August 1861, the same month he revoked Fremont’s order to emancipate all slaves in arms against the federal government in Missouri, Lincoln also signed the first Confiscation Act, stipulating that all slaves who had fought for the Confederacy could be confiscated and then freed. In March 1862, Lincoln signed a bill forbidding the Union Army or Navy from returning fugitive slaves. Any officer who disobeyed would be discharged from service and not able to re-enter the service. In April 1862, Lincoln signed a bill abolishing slavery in the District of Columbia, compensating slaveholders \$300 a slave. And then in May he complied with General Benjamin Butler’s policy of “contrabands of war,” which ultimately freed all slaves who crossed over Northern lines: “When the news spread by August, thousands of slaves had run away to Butler’s position.”²⁹ Lincoln’s compliance with this policy is significant because it revoked his strict adherence to the Fugitive Slave Law, which required all runaway slaves to be returned to their masters. Although these efforts marked a significant advance in Lincoln’s growth, he still wanted to find a way to legally

emancipate the slaves: “This thing is not closed here. I am still under such pressure, and it becomes heavier and heavier.”³⁰

Early on in his term, Lincoln needed to proceed cautiously when dealing with the delicate issue of the future of slavery because he and the Republican Party had taken a non-interference stance on the issue from the beginning. If he had initially called the war a war for abolition, then he would have lost party support immediately. Therefore, his prudence was a practical move in order to gain support in the earlier stages of the war: “It was theoretically reasonable for Lincoln to... tread cautiously on the question of slavery.”³¹ He was a good leader who valued pragmatism and legality: “Lincoln was an astute politician who moved only when the time seemed right.”³² To Douglass, Lincoln’s reluctance to deal with the slavery issue was frustrating, but in reality Lincoln had some obstacles he needed to negotiate before dealing with slavery head on.

The year 1862 was significant in the policies of the Lincoln administration because Lincoln started to recognize that the issues of emancipation and preservation of the Union went hand-in-hand. That is, the military and political agendas started to merge. But even though his policies were straying a bit from his original political perspective, Lincoln still was not making powerful efforts to emancipate, which caused the abolitionists, especially Douglass, to seriously doubt Lincoln’s potential. Because of his fear of splitting the Union even further, “Lincoln made each of [his] decisions reluctantly.”³³ But to Douglass, Lincoln’s cautious approach “has often been viewed as a reluctant response to opportunity. Willing to settle for what was practicable... Lincoln was alert to the expanding potential created by war.”³⁴ But as Lincoln started acting towards abolition, Douglass grew more militant with the Lincoln administration and kept on pushing them in the direction towards immediate emancipation.

But one problem remained: Lincoln still maintained that his sole objective was to preserve the Union at any cost. Although he understood that the Union could not survive with slavery intact, Lincoln did not yet grasp that immediate emancipation was the only viable solution. Douglass pressed on with his criticism of the Lincoln administration’s inability to take powerful measures against slavery: “He told the crowd that he could no longer bite his tongue to keep from criticizing Lincoln. The government was throwing away its chance at victory by failing to attack the root cause of the war.”³⁵

As the war advanced, Lincoln’s policies were slowly radicalizing. But to Douglass, Lincoln was not radical enough; he saw Lincoln’s slowness to approach the slavery issue head on as a call to arms. Douglass was prepared to go at the Lincoln administration with full force. Douglass’ articles published right up until Lincoln’s announcement of the Preliminary Emancipation Proclamation in September 1862 are the best examples of Douglass’ militant attitudes. The article entitled “What the People Expect of Mr. Lincoln” directly addresses the impatience of the public, rather than just antislavery radicals like Douglass, at his reluctance to act on the slavery issue, especially since Congress had recently passed the Confiscation Act: “Mr. Lincoln should be informed that the people are becoming impatient for the execution of the important laws just passed by Congress... and everybody is wondering why he delays to strike.”³⁶ By pointing out that Lincoln’s slowness was a matter of public concern, not just a concern of his own,

Douglass gave Lincoln another reason to act. Even though Lincoln issued the Confiscation Act in the summer of 1862, which freed the slaves of the rebels who escaped into Northern lines, it still was not powerful enough to satisfy Douglass. Douglass believed that the Confiscation Act meant nothing unless Lincoln saw it through: “The measure is important or unimportant, significant or insignificant only as the President himself shall determine. The sole power of putting life into this law is vested in the President. He can make it effective and binding upon his generals or inoperative and void.”³⁷

Douglass was still waiting for Lincoln to step up to the plate and end the war by emancipating the slaves. The language of Douglass’ criticisms was a crucial part of his attack on Lincoln. In the September 1862 publication of *Douglass’ Monthly*, the article “The President and His Speeches” is an intense, direct attack on Lincoln’s character: “The President... seems to possess an ever increasing passion for making himself appear silly and ridiculous, if nothing worse.”³⁸ The article harshly criticizes Lincoln’s weak attempts to emancipate as unacceptable; not only are Lincoln’s statements “illogical and unfair,” but they are also telling of his racism.³⁹ Douglass’s newspaper publicly bashes Lincoln’s colonization plan: “He says to the colored people: I don’t like you, you must clear out of the country.”⁴⁰ It further claims that Lincoln is “as timid as a sheep... [he] has not been able yet to muster courage and honesty enough to obey and execute... his antislavery testimonies.”⁴¹

Over the course of the war, Lincoln slowly grew out of what Douglass considered old conservative policies and started to try new ways to bring the Union back together. Up until 1863, he had made many efforts to appease all sides of the conflict, but Lincoln was unsuccessful, leaving Douglass still frustrated: “Lincoln felt that he had played almost all his cards, unless he played his trump card—the emancipation of slaves by force—he could not save the Union.”⁴² Nothing else was working to bring the nation back together, so he had to make a bold move. During the summer of 1862, Lincoln had privately spoken to his cabinet about emancipation. Under the advisement of Secretary of State William Seward, Lincoln decided to wait until the Union had a victory under its belt before he announced his preliminary Emancipation Proclamation. Seward thought it would be best to postpone the announcement of the Emancipation Proclamation “‘until you can give it to the country supported by military success.’ Otherwise the world might view it ‘as the last measure of an exhausted government, a cry for help...our last *shriek*, on the retreat.”⁴³ But, in reality, the Emancipation Proclamation was a “last shriek” in disguise even though Lincoln waited until after the Union victory at Antietam.

However, it was still unclear as to what would happen to the ex-slaves; there were still racial sentiments against the black presence in America. At this point, Lincoln still felt that colonization was a viable option to rid the problem of slavery and the black presence forever. That is, he believed that removing the black presence in the United States by colonizing the ex-slaves in a separate location would cease national conflict; if there were no blacks, there was no problem. In addition, Lincoln also “believed that support for colonization was the best way to defuse much of the anti-emancipation sentiment that might otherwise sink the Republicans in the 1862 elections.”⁴⁴

Even though his political and military ideologies were merging through his consideration of the Emancipation Proclamation, Lincoln’s strong support for colonization shows that his moral ideology about the evils of slavery was not yet developed. On August 14, 1862, when Lincoln invited a small group of black leaders to the White House, his behavior illustrates his racism. Lincoln agreed with the black leaders that “slavery was ‘the greatest wrong inflicted on any people.’”⁴⁵ He still proceeded to blame the war on the black presence in the United States: “But for your race among us there could not be war, although many men engaged on either side do not care for you one way or the other.”⁴⁶ In this instance, Lincoln’s expression of racism dramatically outweighed his growing efforts toward emancipation. Unsurprisingly, Douglass was outraged with Lincoln’s address and pointed out that Lincoln’s affirmation of white supremacy made him representative of American prejudice: “Mr. Lincoln further knows or ought to know at least that negro hatred and prejudice of color are neither original nor invincible vices, but merely the offshoots of that root of all crimes and evils—slavery.”⁴⁷ Douglass was truly hurt by Lincoln’s efforts to colonize the slave population and this deep sense of betrayal is best illustrated in his reaction to Lincoln’s behavior towards the black delegation:

*The tone of frankness and benevolence which he assumes in his speech to the colored committee is too thin a mask not to be seen through. The genuine spark of humanity is missing in it, no sincere wish to improve the condition of the oppressed has dictated it. It expresses merely the desire to get rid of them, and reminds one of the politeness with which a man might try to bow out of his house some troublesome creditor or the witness of some old guilt.*⁴⁸

But Douglass’ outrage would soon be assuaged. After the Union victory at the Battle of Antietam in September 1862, Lincoln was ready to make public his Emancipation Proclamation. In his Emancipation Proclamation, Lincoln warned the rebels that unless they returned to the Union, by January 1 all of their slaves would be legally freed. Under the Constitution, Lincoln had no power to act against slavery in the areas still loyal to the Union. Even though slaves would be freed only in the territory rebelling against the federal government, the tone of the war had changed drastically. Lincoln said himself that on January 1, 1863, “the character of the war will be changed. It will be one of subjugation.... The [old] South is to be destroyed and replaced by new propositions and ideas.”⁴⁹ Douglass was elated and in a letter to newspaper editor and friend Theodore Tilton, he wrote that he wished “one could strike December from the calendar”⁵⁰ in order for the Proclamation to go into effect sooner.

Much changed in the way Douglass regarded Lincoln with his announcement of the Emancipation Proclamation. After the Proclamation was made public, Lincoln’s sense of the war was becoming more aligned with that of Douglass’s. As the war’s purpose expanded, Douglass and Lincoln began to share a sense of the significance of the war. Even though the political ideologies of Douglass and Lincoln had merged, emancipation was still in the name of the war effort. Lincoln used this Emancipation Proclamation as a “military necessity” to save the Union: “If the federal government wanted to win the war, it had to take measures like emancipating the slaves, so it could destroy the enemy’s war foundation.”⁵¹ But on the other hand, the Emancipation Proclamation also demonstrates

that Lincoln was moving closer to attaining racial goodwill. His moral ideology would not begin to catch up to that of Douglass' until the Gettysburg Address, but the Proclamation was nevertheless a milestone in the process of emancipation.

The day August 10, 1863 would be the pinnacle of the relationship between Douglass and Lincoln. On this day, Douglass went to Washington to meet with Lincoln for the first time. While there, Lincoln's behavior towards Douglass revealed much about how he felt about him and how his views towards blacks had changed. As the first black man ever personally invited into the White House by the President, Douglass was treated with the utmost respect. He was especially impressed with Lincoln's directness: "remembered that the President looked him in the eye.... For the first time, Douglass expressed a personal identification with Lincoln."⁵² As for the growth of Lincoln towards the slavery issue, on this occasion, Douglass "felt that Lincoln 'showed a deeper moral conviction against slavery that I had ever seen before in any thing spoken or written by him.... Evidence conclusive that the [Emancipation] proclamation, so far at least as he was concerned, was not effected merely as a [military] necessity."⁵³ Douglass appreciated Lincoln for treating him like an equal, which is indicative of Lincoln's gradual attainment of a deeper moral conscious.

At this moment, Douglass respected Lincoln, which was a complete turnaround from his blatant outrage expressed publicly through his newspapers. Over the course of the rest of the war, Douglass and Lincoln met on several occasions to discuss the situation of the ex-slaves and their future in the United States. Because of these personal meetings, Lincoln and Douglass' relationship had a chance to grow more profound. After the Emancipation Proclamation, Lincoln still considered colonization as a viable option to deal with the black presence. But, to Douglass, black enlistments in the military was the strongest option to attain total emancipation; he believed that the ex-slaves had to "embrace the opportunity to serve in the military to fulfill and protect their status as American citizens, to prevent a pro-slavery compromise between the Union and the Confederacy, and to be a part of the 'ennobling and soul enlarging' war for black liberation."⁵⁴ Douglass eventually started to bring Lincoln to consider black enlistments: "Douglass explained...that 'if this war...has any lesson for the American people it is to show them the vanity and utter worthlessness of all attempts to secure peace and prosperity while disregarding and trampling upon the self-evident rights and claims of human nature."⁵⁵ Soon, Lincoln and Douglass' moral ideologies started to merge as Lincoln was giving the ex-slaves more rights, such as including them in the military. Douglass saw this as "an important aspect of the emancipation process...had been the integral contributions of black soldiers: the black liberation army."⁵⁶

Naturally, the announcement of the Emancipation Proclamation facilitated the growth of Douglass' respectful admiration of Lincoln. Although he began to express his newfound praise of Lincoln while Lincoln was still alive, Douglass' deep respect for Lincoln was best expressed in the years after his assassination. In Douglass' speech at the unveiling of the statue of Abraham Lincoln in Washington on the 21st anniversary of Lincoln's death, Douglass' true feelings came out: "Our faith in him was often taxed and strained to

the uttermost, but it never failed...we were at times stunned, grieved, and greatly bewildered; but our hearts believed while they ached and bled."⁵⁷ He later declared that honoring his memory is important because "under his rule and inspiration we saw the Confederate States, based upon the idea that our race must be slaves...battered to pieces...in the fullness of time, we saw Abraham Lincoln...penning the immortal paper, which, though special in its language, was general in its principles and effect, making slavery forever impossible in the United States."⁵⁸ Although his praises of Lincoln are significant, still more significant is Douglass' understanding that Lincoln's slowness to deal with the slavery issue was actually necessary caution: "Had he put the abolition of slavery before the salvation of the Union, he would have inevitably driven from him a powerful class of the American people and rendered resistance to rebellion impossible. Viewed from the genuine abolition ground, Mr. Lincoln seemed tardy, cold, dull and indifferent; but measuring him by the sentiment of his country, a sentiment he was bound as a statesman to consult, he was swift, zealous, radical, and determined. Though Mr. Lincoln shared the prejudices of his white fellow-countrymen against the negro, it is hardly necessary to say that in his heart of hearts he loathed and hated slavery."⁵⁹

Even though Douglass and Lincoln had not met until the summer of 1863, their relationship is vital in order to understand how Douglass felt about the political climate, Lincoln, and emancipation. It is clear that the war brought together their political ideologies, which ultimately paved the way for each to appreciate the other in a deeper sense. The fusion of their political ideologies not only shows that both men changed greatly, but also paved the way for their moral ideologies to merge. Because they had grown to share a deep respect for each other, Lincoln and Douglass were able to overcome their own misconceptions about each other's character. When Lincoln died, he left Douglass his favorite walking staff as a sign of his profound appreciation and gratitude. Douglass also commemorated Lincoln by hanging a portrait of him in his home in Washington, D.C. The relationship between Abraham Lincoln and Frederick Douglass was a milestone in American history that would positively influence the future of race relations.

Author's Note

The publication of my paper in the Journal for Undergraduate Research marks not an end, but rather a beginning. Until recently, I was unaware of a new work on the subject of the relationship between Frederick Douglass and Abraham Lincoln. The *Radical and the Republican: Frederick Douglass, Abraham Lincoln, and the Triumph of Antislavery Politics* by James Oakes expands on the subjects and issues I raise here, shedding new light on the Douglass-Lincoln relationship during the antebellum and Civil War years. By bringing Lincoln and Douglass together, as I have also done, Oakes tells the story of how these two men stood alongside each other during an immense historical struggle. Although it is unfortunate that this publication was released after the completion of my paper, it is my hope that my paper will challenge others to read Oakes' work.

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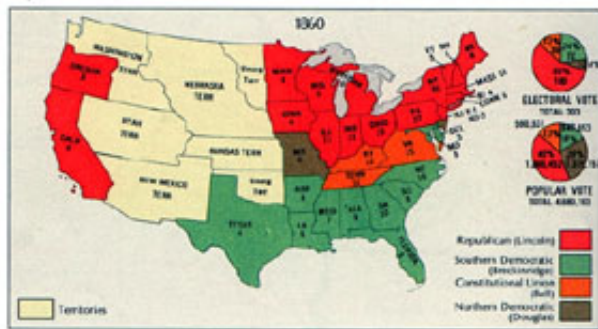
1. Benjamin Quarles, "Abolition's Different Drummer: Frederick Douglass," In *Blacks in the Abolitionist Movement* edited by Bracey, Meier, and Rudwick, Belmont, California: Wadsworth Publishing Company, Inc., 1971, p. 17-18

APPENDIX

Map of Presidential Election of 1856



Map of Presidential Election of 1860



2. Moral suasion was used as an argument to end slavery, because the abolitionists felt that thinking people who were basically good people in America could be persuaded by argument that slavery was wrong; that it was wrong for moral reasons; that it was wrong for religious reasons; that the ideals on which the nation was founded were perverted by the institution of enslavement. What the abolitionists didn't realize was how deeply embedded in the social, economic, and political structure slavery was. They didn't realize how powerful the slaveocracy was. And they didn't realize how much racism had embedded the fabric of American life. (Margaret Washington, "Margaret Washington on Moral Suasion," *Africans in America*, <http://www.pbs.org/wgbh/aia/part4/4i2981.html>, 21 October 2006.)

3. Waldo E. Martin, Jr. *The Mind of Frederick Douglass*. The University of North Carolina Press: Chapel Hill, NC and London, 1984. p. 20

4. Letter to George Thompson, February 18, 1860. University of Rochester Dept. of Rare Books.

5. Wu Jin-Ping, *Frederick Douglass and the Black Liberation Movement: The North Star of American Blacks*, New York and London: Garland Publishing, Inc., 2000, p. 57

6. Letter to William Seward, April 23, 1863. University of Rochester Dept. of Rare Books.

7. Martin, Jr. *The Mind of Frederick Douglass*. p. 34

8. Jin-Ping, *Frederick Douglass and the Black Liberation Movement*, p. 66

9. Passed in 1850, the Fugitive Slave Law stipulated that all runaway slaves were to be returned to their masters. In addition, any federal marshal who did not arrest an alleged runaway slave could be fined \$1,000. Blacks suspected of being a runaway slave could be arrested without warrant and turned over to a claimant on nothing more than his sworn testimony of ownership. A suspected black slave could not ask for a jury trial nor testify on his or her behalf. Any person aiding a runaway slave by providing shelter, food or any other form of assistance was liable to six months imprisonment and a \$1,000 fine. Those officers capturing a fugitive slave were entitled to a monetary reward, which in turn encouraged some officers to kidnap free Negroes and sell them to slave-owners.

10. http://teachpol.tcnj.edu/amer_pol_hist/fi/000000b9.htm and http://teachpol.tcnj.edu/amer_pol_hist/fi/000000bd.htm

11. "The Late Election." *Douglass' Monthly*. Ed. Frederick Douglass. December 1860. p. 370

12. Jin-Ping, *Frederick Douglass and the Black Liberation Movement*, p. 67

13. Corinne Hoexter, *Black Crusader: Frederick Douglass*, Chicago, New York, San Francisco: Rand McNally & Company, 1970, p. 147

14. Abraham Lincoln, "Speech at Ottawa." Delivered in Ottawa, IL as part

of the Lincoln-Douglass Debate. August 21, 1858. Rpt. in *The Views and Sentiments of Henry Clay and Abraham Lincoln on the Slavery Question*. p. 2

15. Lincoln, "Speech at Jonesboro." Delivered in Jonesboro, IL as part of the Lincoln-Douglass Debate. September 15, 1858. Rpt. in *The Views and Sentiments of Henry Clay and Abraham Lincoln on the Slavery Question*. p. 2

16. *Ibid.*, p. 65

17. William E. Gienapp, *Abraham Lincoln and Civil War Movement: A Biography*, New York: Oxford University Press, 2002, p. 64

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The Battle of Fallujah: Lessons Learned on Military Operations on Urbanized Terrain (MOUT) in the 21st Century

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Military operations on urbanized terrain (MOUT) is defined by the Department of Defense (DoD) as “all [operations] planned and conducted across the range of military operations on, or against objectives within, a topographical complex and its adjacent natural terrain, where man-made construction or the density of noncombatants are the dominant feature.”¹ An urban environment features three main characteristics: a complex man-made physical terrain; a population of significant size and density; and an infrastructure that supports the population and perhaps the region or nation.² With the continuous growth of urbanization all around the world (based on a World Bank study, 79% of the world population lived in an urbanized environment in 2002)³ and change in the nature of warfare in the post-Cold War era, (4th Generation Warfare, or 4GW), it is inevitable that the military will conduct MOUT in the Global War on Terrorism. The Battle of Fallujah differentiates from other MOUT examples in modern military history due to the new technologies of the information era, which add both new advantages and disadvantages into the fighting. The Battle of Fallujah is certainly a milestone in the revolution of warfare.

MOUT in Modern Military History

Although urban fighting has been mentioned as early as about 500 B.C. when Sun Tzu warned that “the worst policy is to attack cities,”⁴ it was not until the 20th Century that the urban combat became common in fighting war. Before the Second World War, both in Napoleonic Warfare and Trench Warfare, most of the main battlefields were found in an open field where the two armies could line up their troops in formation or defense perimeter. In some incidents of siege, the defense would mainly focus on the outer wall of the city and not civilian residences. In other cases, rebels would start firefights in the streets, as the Communist’s rebellion in Germany right after the First World War.

A rare example of urban fighting is the Battle of Shanghai in 1937 between China and Japan. On 11 August 1937, German-trained Chinese 87th and 88th Divisions moved toward Shanghai using trains and trucks along with other mechanized artillery and tank units. The object was to open the second front at Shanghai to avoid any significant campaign in the open fields of northern China that would favor Japan’s mechanized troops

and to gain more international attention, as many Westerners resided in foreign settlements of Shanghai. The Chinese fought the Japanese Special Marines and the 3rd Fleet in Shanghai for more than three months with many modernized combined arms including tanks, artillery, air crafts, and torpedo boats. Despite the heavy casualties, Chinese infantry were able to break through the Japanese defenses many times with German Stormtroop Tactics (*die Stosstrupp Taktik*) under the command of a German advisory group led by General Alexander von Falkenhausen, but failed to hold their positions due to intense Japanese naval gunfire support.⁵ The fighting in the foreign settlements in Shanghai demonstrated, for the first time, the devastating effects that modern warfare had in urban sectors.

However, the concept of fighting in cities did not receive much attention from the major military powers until the middle of World War II. Due to the belated mobilization and modernization of the U.S. Army, Americans focused on basic training to have an adequate number of personnel to meet the needs of the battlefield. Until January 1944, there were no doctrines providing guidelines to the soldiers on how MOUT should be conducted. When the Allies drove through France, the tactic commonly used was rapid movement with massed firepower in an effort to shock the defender and in the hope that the enemy would either be killed or would surrender. However, this tactic would have only worked against a disorganized enemy.⁶ Throughout World War II, only well-coordinated combined arms were able to conquer well-fortified cities like Berlin.

During the Korean War, most fighting did not happen in major cities except in Seoul. The Marine Corps was responsible for the difficult task of retaking Seoul from the hands of well-positioned North Koreans. During the battle, the Marines identified enemy strongholds and guided tanks to break through enemy strong points with firepower. Then Marine riflemen cleared the surrounding area to eliminate any enemy survivors. However, the main focus of the military was still on fighting a possible Communist armored invasion in Europe, not fighting in an urban environment. The situation continued until the Tet Offense of 1968 during the Vietnam War. Marines in Hue City were caught in an unfamiliar fighting environment for which they were not trained. Most of them had plenty of experience in the natural jungle, but not in the urban jungle.

One battalion commander even tried, hurriedly, to scan through the manuals and review them before he left for the mission. The casualty rate was high; many companies, mounted on trucks, drove straight into the city until they were ambushed. Soon, tactics were improvised, and tanks were utilized. The Marines were able to react due to their outstanding training and organizational structure. After the war in Vietnam, the Army published the Field Manual 90-10, Military Operations on Urban Terrain (MOUT) in 1979, but it failed to integrate lessons learned from history. The responsibility of MOUT still fell solely on the shoulders of the infantry until the late 90s.⁷

Fallujah: The Terrain and People

On 18 March 2003, Coalition forces launched initial air strikes against Saddam Hussein and a full-scale ground invasion of Iraq followed the next day. Within a month, Saddam was overthrown from power, and Pentagon spokeswoman Victoria Clarke announced the termination of Saddam's regime on 14 April.⁸ Most of the Iraqi people celebrated their liberation from Saddam's tyranny on the street, except in cities of the Al Anbar Province, which is also known as the Sunni Triangle. Among the 25 million Iraqis, only 5 million of them are Sunnis. However, ever since the Baath Party was in power in 1959, the Sunnis have controlled the political power in Iraq. The Sunnis refused to believe that Saddam had been overthrown, while the city of Fallujah was a source of Baath Party supporters.⁹

After the defeat of the First Gulf War in 1991, Saddam targeted the weakness of the local tribal system to strengthen his authority by providing just enough privileges and resources to keep those Sunni tribes loyal to him.¹⁰ Saddam's propaganda also instilled hatred and fear against Shiites and Americans within Sunni tribes during that time.¹¹ Fallujah has a long-standing reputation as a city with a tough, exclusive culture. As embedded reporter Bing West describes it, "ask Iraqis about Fallujah, and they roll their eyes: Fallujah is strange, sullen, wild-eyed, badass, just plain mean... Wear lipstick or Western-style long hair, sip a beer or listen to an American CD, and you risk the whip or a beating."¹² Those are the people whose hearts and minds American soldiers and Marines tried to win.

Fallujah is about 40 miles west of Baghdad right next to the Euphrates with about 300,000 local residents living in a 30 square-kilometer urbanized area.¹³ The city itself was well-constructed, with roughly two-thousand blocks of civilian residences, government buildings, industrial sectors, and civil infrastructure, and the six-lane Highway 10 running through the center of the city. Fallujah is also well-known as "the city of a hundred mosques" for the forty-seven mosques in the city, and fifty-five more in the suburban area. The Americans gave nicknames to each section of Fallujah after New York City. The wealthy residence in the north was "Manhattan," the poor section in the south was "Queens," and one of the bridges on the Euphrates, which connects the hospital and the city, was the "Brooklyn Bridge."¹⁴ The highly urbanized terrain and not-so-American-friendly local population made Fallujah an ripe location for insurgency.

The Tension and Pacification

On 28 April 2003, Saddam's birthday, a mob of about one hundred people waged an anti-American demonstration in the city. The mob accused American soldiers of spying on women

with night-vision binoculars and showing pornography to Iraqi children. Gunmen blended into the crowd firing AK-47s into the sky in front of the 82nd Airborne Division headquarters. The security guards from the 82nd Airborne took this as an act to show bravery rather than a hostile move, so the soldiers did not respond. The same night, a platoon-sized 82nd Airborne detachment in a local school was fired upon from the roof of nearby buildings by three identified gunmen. Two separate sergeants reported enemy fire by radio, and the company commander thought the situation was urgent and authorized return fire, which killed 15 civilians including women and children under the fog of war. Although it was proven to be a conspiracy planned by a former Baathist against the Americans six months later, it was already too late. Seven major Western news media had reported the incident and focused on the civilian casualties and cultural conflicts. None of them questioned why those Iraqis protested against Americans just a few days after Saddam was out of office.¹⁵

Iraqi civilian casualties enraged the local population. The next day, angry mobs were screaming: "All Americans leave Iraq!" outside of the mayor's office.¹⁶ The mayor, Taha Bedawi, although he was a supporter of the Coalition himself, could not take the public pressure and asked the 82nd Airborne to leave Fallujah. The unit that came to relieve the 82nd Airborne was a company from the 3rd Armored Cavalry Regiment. The cavalrymen patrolled along the highway and streets everyday and encountered repeated firefights even though Americans tried to keep a low profile. To solve the problem, the highest military authority of all of the coalition force, the Joint Task Force (JTF) decided to make Fallujah "the most occupied city in Iraq,"¹⁷ by replacing the two-hundred man cavalry with the fifteen-hundred man 2nd Brigade, 3rd Infantry Division (3rd ID). Using the intelligence provided by the CIA, the 3rd ID conducted major search-and-sweep operations for weapons and arms-dealers with the support of armored vehicles. Sometimes a whole section of the city could be locked down for hours.

The 3rd ID also tried to win the "hearts and minds" of the local people by making personal contacts with the local population, although the presence of armored vehicles was intimidating. Americans found the less wealthy Fallujans from south of Highway 10 to be much more friendly than the northern communities. However, smashing down a door in the middle of the night to search for insurgents and foreign fighters was not the best entry tactic. It often terrified the families and created more hostile Fallujans. The 3rd ID also helped with local infrastructure repairs and tried to create more job opportunities. However, the insurgents also worked hard to sabotage the results and frighten the American-friendly civilians. In one incident, when the men of 3rd ID spent days to build a soccer field in downtown Fallujah for the local people, insurgents destroyed the field soon after Americans left. "What kind of people loot dirt?" an American soldier asked.¹⁸ Even the mayor himself feared that acting pro-American could get him in trouble.

The 3rd ID also ran into trouble when they only had a budget of 150,000 dollars per week, while Fallujah needed 150 million dollars to reconstruct the infrastructure and local economy. There were also 70,000 unemployed Fallujans, an easy recruiting source for the insurgents. The Fallujans expected Americans to do more, while 3rd ID already offered everything

they had. Neither the State Department, nor the new Iraqi Government had provided enough support for the military in the pacification process. The local authority had failed to gain the support of the people over the terrorists because the people followed their tribe and mosque leaders, not the mayor.¹⁹ By September, when the 3rd ID turned authority over to the 82nd Airborne again, Fallujah still had a broken economy and tribal war, and was “the most hostile place in Iraq.”²⁰

On March 2004, then Lt. Gen. James T. Conway had led the 1st Marine Expeditionary Force (I MEF) back to Iraq from the States to replace the 82nd Airborne.²¹ Gen. Conway and the Commanding General of the 1st Marine Division (1st MarDiv), then Maj Gen. James N. “Mad Dog”²² Mattis made their plan for Fallujah while they were back in the States. The tactics the Marines focused on were showing Iraqis respect and training new Iraqi forces. The Marines of 1st MEF started working toward these goals before deployment. They were taught how to live and train with the Iraqis by Vietnam Veterans, learned simple Arab phrases and local customs from experts, and were required to read the Marine Corps Small War Manual. Marines even prepared cases of toys for the Iraqi children from the States. Unfortunately, when the 1st MEF had just taken over Fallujah from the 82nd Airborne in the last week of March, an unexpected incident changed the plan.²³

On 31 March 2004, four American Blackwater security operators, who made a shortcut through Fallujah without informing the Marines during a supply run for a UN food contractor, were ambushed by insurgents at the northwest part of the city. The Blackwater operators were ex-special forces veterans, but all four of them were killed, and their burned corpses were mutilated at the “Brooklyn Bridge.” Because the Marines were not informed ahead, the only thing they could do was to get an Unmanned Aero Vehicle (UAV) launched to transfer real-time image from the scene to the headquarters. The picture of burned American corpses hanging on the “Brooklyn Bridge” spread around the world, and a political decision was made: Americans needed a quick retaliation to deter their enemies. Regardless of Gen. Conway’s stance against any hasty reaction, the order came from the top of the chain of command. Hence, the Marines had to throw their original stability and support operations (SASO) plan away and prepare to attack a city of 280,000 people.²⁴

From 5 April to 30 April 2004, the Coalition forces launched “Operation Vigilant Resolve” as the response to the death of the four Blackwater operators.²⁵ The operational goal was to eliminate insurgency within the Al Anbar Province. Other supporting operations were also conducted in areas around the Syrian border and the suburbs of Baghdad to isolate insurgents from foreign support.²⁶ Operation Vigilant Resolve was also the first MOUT conducted by Americans since Hue City that specifically used tank-infantry combined tactics. On the next day, the 1st Battalion, 5th Marine Regiment (1/5) and 2nd Battalion, 1st Marine Regiment (2/1) started moving into Fallujah supported by Company C, 1st Tank Battalion, and the newly formed Iraqi National Guard (ING).²⁷ Many Marines did not understand why they were being ordered to attack a city without any solid strategic plan, such as post-combat SASO and public service restoration.²⁸ At the same time, fighting broke out all around the Al Anbar region, such as in the city of Ramadi.

The major engagement continued until 2000 hours on 9 April, when all of the Coalition forces ceased fire and regrouped in anticipation of peace talks between the provisional Iraqi government, Fallujah leadership, and the insurgent representative.²⁹ At the same time, 2/2 and 3/4 had been called to Fallujah to support the operation in case the peace talks failed. Co. B, 1st Tank Battalion, was also on its way to cover the shortage of tanks, but did not arrive until late April.³⁰ The local residents used the time to evacuate the wounded and the dead. A local hospital official claimed that there were already 600 civilians killed with 1,250 more wounded.³¹ Iraqi government criticized the U.S. military’s action as “illegal and totally unacceptable...It is a form of mass punishment.”³² Regardless of the fact, an Iraqi official had sent an e-mail to American Ambassador Bremer to urge the Americans to continue the attack two days earlier.³³ U.S. military spokesman Brigadier General Mark Kimmitt insisted that the Coalition forces were doing everything they could to minimize the collateral damage, but the insurgents were firing from civilian buildings and holding residents as human shields.³⁴

It was confirmed during the time there were about 20,000 insurgents in Fallujah using hit and run tactics against Marines as an act of attrition. During the cease-fire period, insurgents continued to launch provocative attacks. Some Iraqi Police and National Guard were also helping insurgents by smuggling ammo and weapons into Fallujah. Insurgents also used Red Crescent Ambulances to drop off ammo and weapons and then pick up dead bodies.³⁵ On 19 April, the Coalition forces claimed that they had reached an agreement with the local Fallujah leaders to defuse tension in Fallujah. However, the fighting resumed the next day while the Sunnis claimed that they had already turned in the heavy weapons as agreed.³⁶ The local leader had little control over many insurgents as they were not organized and came to Fallujah in small groups with their own leaders.³⁷ Due to political concerns, during the rest of Operation Vigilant Resolve, Marines were ordered to hold the cordon, but not to advance despite encountering fierce engagements.³⁸ The whole operation ended with an agreement of transferring the security responsibility to the hastily formed Fallujah Brigade (FB) to collect the weapons from insurgents.³⁹

Operation Al Fajr

After Marines pulled out of Fallujah, the FB failed to accomplish its mission and turned over a few truck-loads of unserviceable rifle and mortars. The insurgents then had total control of the entire city. However, due to the failure of the FB, the Iraqi government could no longer blame Americans for the chaos in Fallujah. Marines saw the opportunity and launched a campaign of psychological operations (PsyOps) around Fallujah, which successfully turned the hearts and minds of the residents against the insurgency. At the same time, Al Qaeda leader Abu Musab al-Zarqawi, local insurgent leaders Abdullah Janabi, and Omar Hadid had turned Fallujah into the supply center of terrorist and suicide-bombers in Iraq. Fortunately, due to the lack of American presence in the city, different groups started fighting each other for dominance. During the summer, one of the battalion commanders of the FB, Lt. Col. Sulieman was beaten to death by the insurgents. The continuous theft of

weapons, vehicles, and equipment from the FB bases signaled that the FB had already lost its ability to function. The death of Lt. Col. Sulieman and other pro-coalition officers further softened the Iraqi government's support of local Fallujah leaders. In September, the Coalition Forces started to prepare for the assault on Fallujah.

The operation was originally named Phantom Fury by I MEF during planning, but was later renamed by Iraqi Prime Minister Ayad Allawi as Operation Al Fajr (meaning "new dawn" in Arabic).⁴⁰ Phase I of the operation included converting Camp Fallujah into I MEF Headquarters, and Navy combat engineer "Seabees" built the East Fallujah Iraqi Camp for the arriving Iraqi battalions. 1st Force Service Support Group (1st FSSG) started the build up of supplies for supporting I MEF operations for no less than 15 days. PsyOps group started urging the residents of Fallujah to leave the city in an effort to reduce the civilian casualties, while releasing deceiving information on the operation to mislead the insurgents. PsyOps went well, and there were fewer than 500 civilians left in the city when the Coalition forces charged in. Ninety-one embedded reporters representing 60 press media were allowed to acquire any information that did not risk the mission. The public affairs section was ready with press releases to give an update on the operation and counter any possible enemy propaganda from sources such as Al Jazeera. Seven Marine battalions and two Army battalions started moving toward Fallujah. Six ING battalions would fight side by side with the Americans, unlike Operation Vigilant Resolve where the majority of the ING refused to be deployed. The total number of assault forces, including air support, was about 12,000 personnel. Coalition forces in the province also conducted operations to seal up Fallujah, which expanded the total personnel in the area from 32,000 to 45,000 people.⁴¹

After careful operational planning and reconnaissance, starting on 7 November 2004 at 1900 hours (7:00 p.m.), Phase II of Operation Al Fajr consisted of 12 to 24 hours of electronic, aviation and artillery attacks on specific insurgent targets that were identified during Phase I. I MEF intelligence estimated about 3,000 to 4,500 insurgents in the city with 306 identified defense positions (Pillboxes). Thirty-three mosques were used by the insurgents. The initial strike would soften the insurgents' defenses and exhaust them both physically and mentally before the Army and Marine battalions launched the ground assault. The last part of Phase II was conducted by a combined task force to control the two bridges on the Euphrates to completely prevent insurgents from escaping.⁴²

The next morning, six Army and Marine battalions and six Iraqi battalions under Regimental Combat Team 1 (RCT-1), and RCT-7 broke into Fallujah from the northern side of the city and started Phase III of the operation. Army 2nd Calvary Squadron, 7th Regiment, 1st Calvary Division (2-7, 1st Calv.) and 2-2, 4th ID were the penetrating forces, which broke enemy defense like two hammers. The tanks and Bradley fighting vehicles provided superior fire power and armor protection. Marine and Iraqi battalions followed and cleared insurgents from house to house. The original plan was to reach the center of the city within 72 to 96 hours, but the assault troops gained momentum in action. RCT-7 achieved the goal in just 14 hours, and RCT-1, in 43 hours. The RCTs were able to reach the southern side of the city on 11 November and started the

search and attack period of the operation. The Coalition forces divided the city into different sectors and searched them one by one. While Phase III continued until 23 December 2004, Phase IV had already initiated in the sectors that were cleared.

Phase IV focused on humanitarian relief and reconstruction in Fallujah. I MEF established a civil-military operation center (CMOC) at the old government center and three humanitarian distribution sites to provide relief supplies to the returning residents. I MEF estimated that 87,620 residents of Fallujah received supplies from those distribution sites. Seabees and civil-affairs teams entered the city to help the residents return to their homes and repaired the infrastructure in Fallujah. On 23 December, I MEF claimed that the city would officially reopen for Fallujans. Vehicles and personnel entering the city were searched for security purposes. Iraqi government workers and civilian contractors flooded into Fallujah for the reconstruction effort, which helped lower the 60% unemployment rate in Al Anber Province.⁴³ The Coalition completely regained control of Fallujah. About 3,000 insurgents were either killed or captured in the final siege of Fallujah.⁴⁴ Unfortunately, al-Zarqawi had escaped from Fallujah before the final siege had commenced.⁴⁵ Seventy Americans were killed in action and 609 were wounded in Operation Al Fajr. The total American casualties in Fallujah from April to December were 151 dead and more than a thousand wounded.⁴⁶

Lessons Learned: Combined Arms in MOU

Although the use of armored vehicles had great success in Fallujah and other Iraqi cities, armors are not necessarily invincible in MOU, as evidenced by the Russian attack on the Chechen city of Grozny on 31 December 1994. The 131st "Maikop" Brigade was the first unit to enter the center part of the city. There was no initial Chechen resistance when Russians entered the city at noon. The Russian infantry then dismounted from the vehicles and moved into the local train station. The armored vehicles were parked along the streets as a reserve force. The Chechens suddenly started firing rocket-propelled grenades (RPGs) from the roofs and basements of nearby buildings. The Chechens first destroyed the lead and rear vehicles to block the street with wreckage. The Russian armor column were trapped in the street and hopeless as the tanks could not point their guns either high or low enough to fire at the Chechens, and the infantry fighting vehicles (IFVs) and armored personnel carriers (APCs) failed to support the tanks. By the time the brigade managed to break away from the city, the Russians had lost almost 800 men, 20 out of their 26 tanks, and 102 of their 120 other armored vehicles.⁴⁷

The Russian experience is a perfect example of the consequences when the armor and infantry fail to coordinate in a combined arms operation in an urban environment. During the Cold War, Russians also forgot their World War II MOU experience of Stalingrad and Berlin. It took the Russians a total of five years to remember the history and to develop equipment and tactics specifically based on their experiences in World War II and Grozny. In 1999, Russia retook Chechnya with combined arms tactics.⁴⁸

During the search and attack phase in Fallujah, Marine Corps tanks advanced through the streets while riflemen cleared the surrounding houses. Marines would always call up tanks for direct fire support when they encountered enemy pillboxes

in Fallujah. Forward observers and scout/snipers helped to guide the tanks forward into positions to fire at insurgent strongholds.⁴⁹

Some of the small Marine units (platoon and squad level) in Fallujah used concepts similar to the Stormtroop tactics that Germany first put into action in 1918, later used by the Chinese in Shanghai in 1937 and then in the German Blitzkrieg in World War II. Those well-trained small units infiltrated the insurgent defense lines and then launched surprise assaults with high speed and well-coordinated fire support, which destroyed enemy defenses and helped the main assault. Then Marines would call in superior firepower to support those platoons or squads to maintain momentum. Eventually Marines rooted out insurgents from isolated strongholds or hideouts if the insurgents chose to hold position. Despite the fact that maneuver warfare was emphasized in the Marine Corps as one of the fundamentals, many Marines and soldiers were trained to fight from house to house in MOUT, which resulted in many casualties due to the close range of combat. Maneuver warfare seemed to be another alternative as enemy small units would be either isolated in pockets or retreat, which may have subsequently lowered the collateral damage on civilian properties.⁵⁰

The M-1 Abram tanks in Fallujah demonstrated superior armor protection against insurgents' RPGs unlike the Russian tanks.⁵¹ However, there were still things to be improved as the Army developed tank urban survival kits (TUSK) to ensure the survivability of the crews and the M1A2 tanks in the age of rapid urbanization. TUSK focus on providing better protection for the crews while manning the machine guns and better night vision/thermal/optic devices, which is similar to the Firepower Enhancement Program (FEP) Marines have for the M1A1s.⁵² While the tank-infantry phone on the Marine M1A1 FEP proved very useful during the Battle of Fallujah, the best way for infantry to guide the tank against identified targets would be either a M203 grenade launcher or a M-16 service rifle with tracers. Without direct guidance on target, tanks will have to risk the chance of firing at the wrong target, which creates collateral damage. It is also too risky for a single tank to operate by itself. Isolated tanks will be an easy target if the infantry fails to clear the surrounding buildings fast enough. Tanks in pairs can cover each other with fire power and rescue the disabled tank if needed. It is vital for infantry and tanks to coordinate and support each other for mutual survival in MOUT; good communication is the key.⁵³ From experience, the 120mm main gun with high-explosive anti-tank (HEAT) round is the best weapon for armor in MOUT to minimize collateral damage as the 12.7mm machine gun with armor piercing rounds often penetrate through too many walls. A 120mm gun with HEAT rounds can restrict damage to a single room while killing everyone in the room.⁵⁴

The shoulder-launched multipurpose assault weapon (SMAW) has proven its value as the best weapon the infantry currently has to breach a hole in the wall or direct fire into small windows, which the insurgents were firing from. In Fallujah, Marines preload the SMAW before maneuvers to provide instantaneous suppressing fire when they encounter ambush. SMAW teams would usually occupy high ground to fire at any insurgent they saw. Marines have suggested that more SMAWs be deployed, and current ammunition be improved. The crews

also demand the M-4A1 Carbine as the secondary weapon since the M-9 pistol has too short an effective range and the M-16 service rifle is too long for a SMAW team to carry around. Due to the design of the warhead, the M-136 AT-4 anti-armor weapon also proved to be ineffective in an urban environment except against enemy armored vehicles.⁵⁵

The AC-130U gunship demonstrated its great value to the boots on the ground. Its precision fire support from the sky during both day and night suppressed fortified moving insurgent targets. The sophisticated fire control system with massive amounts of ammunition on board gives AC-130U the ability to provide a steady close air support (CAS) without the need of forward air control (FAC) unlike other fixed-wing aircrafts. Ground units only need to provide both friendly and target positions, and the gunship will take care of the rest.⁵⁶ Different cannons on AC-130U provide more choices of weaponry with smaller blast radii than bombs; hence they have lower risk of damage to friendly units and civilians.

With the UAV technology today, it is even easier to acquire target coordination and real-time footage without risking the lives of Marines.⁵⁷ The victory of Operation Al Fajr was the result of a joint effort from all three services. Due to the complex terrain of MOUT, it is very hard for high-speed fixed-wing aircraft such as the F-18 to identify friendly units and enemies on the ground. Hence ground units still need FCS and good joint operation capabilities, which require junior officers to understand the organizational structure and capabilities of the Army and Air Force. Creating liaison officer training or even an officer exchange program can help tie the three services closer together and benefit joint operations, such as coordinating CAS from different branches. Some suggested the creation of an Army/Air Force liaison officer training program in The Basic School (TBS).⁵⁸

Lessons Learned: Civil Affairs in Counter-Insurgency

Civil-military operation was something the Coalition forces did not prepare for when they charged into Iraq. Neither the 82nd Airborne nor 3rd ID really understood the tribal system nor conducted SASO properly. Thus, tension with the local people tightened, which gave certain local factions and terrorists opportunities to control the local people either through fear or bribery and so started the insurgency.⁵⁹ An unstable society caused local economic downfall and the tribal war caused great friction in the reconstruction of economy and infrastructure. Those factors created more unemployment, which fueled the insurgency.

The incident on 28 April 2003, might have been avoided if there had been civil-affairs units specializing in crowd control. Unfortunately, there was no solid plan for SASO. Looting on government and Baath Party buildings happened all around Iraq (except the Sunni Triangle) when Saddam's regime collapsed. Units such as military police, civil affair teams, or other government agencies could handle this kind of situation much better than infantry could, whose primary mission is to suppress the enemy with firepower.⁶⁰

It is important to understand that the U.S. military can help establish a democracy, not be the democracy. The military is specialized in fighting war, not governing. As a famous quote from the 1995 film *Crimson Tide* states: "We are here to preserve democracy, not to practice it!"⁶¹ Other governmental

or non-governmental organizations that specialize in politics, economics, or culture need to be more involved in Iraq. It is true that those organizations are vulnerable against insurgents. Sometimes they can even interfere with the military chain of command. However, the military can only be a force to assist in nation building.⁶² Once the insurgency is removed, organizations such as the United Nations and Red Cross should move in to help get the lives of local residents back on track. The State Department needs to provide more experts in language and culture, sometimes even diplomats to help the military in civil-affairs operations and international joint operations as there is an urgent need for professional civil-affairs personnel.

Project Metropolis (ProMet) of the Marine Corps Warfighting Laboratory (MCWL) continues developing tactics, techniques, and procedures (TTP) to meet the needs of Marines in MOUT. MCWL provides pre-deployment exercises to help familiarize Marines with MOUT and SASO. Marines are now better prepared for combining civil affairs with conventional arms, which increases the chance to defeat insurgency around Iraq and win the hearts and minds of the Iraqi people.⁶³

Whether to communicate with Iraqi government personnel or improve relationships with the local community, basic linguistic skills are required as not all Iraqis, whom Marines encounter, speak English. Pre-deployment language training for simple phrases in Arabic has many positive effects on different operations in Iraq. The most significant effect of better linguistic skills is the improved relationship with the local community, which is the fundamental key of winning hearts and minds.⁶⁴ A greeting or simple dialogue in Arabic decreases the cultural differences and once the communication bridge is built, acquiring human intelligence (HumInt) from local people in support of SASO is possible. HumInt exploration teams that specialize in interrogation and Arabic obtained a tremendous amount of insurgent information in Fallujah from April to November. Based on the intelligence, the Coalition forces were able to identify insurgent locations, plan precise air/artillery strikes to destroy those targets, and eventually liberate Fallujah from the hands of insurgents.⁶⁵ I MEF's pre-deployment training made differences in the civil affairs operation aspect in Fallujah compared to the previous Army units.

The military is already losing the information operation in Iraq. Negative images from Iraq flood into the States, cause controversy, and make it difficult for Americans to support the war. In April 2004, the media coverage on the fighting in Ramadi focused on the number of American lives lost, not that the insurgents had failed in their planned offensive. The insurgents successfully used the press to create a second Tet Offensive.⁶⁶ In the other incident, Marines called in air support to stop the continuous insurgent shooting from a mosque in Fallujah. When the Marines got into the mosque half an hour later, insurgents had already cleared casualties and corpses from the scene. Four embedded reporters reported the same story in their respective papers. However, the footage of the air strike being repeatedly played in America, and Al Jazeera reported twenty-six civilians killed in the strike. Therefore, the lead press story on 7 April was that the Americans bombed a mosque and killed civilians.⁶⁷ On the other hand, when the Coalition

forces ceased fire for peace-talks two days later, it received little notice from the media.⁶⁸

Between 6 and 13 April, the Coalition Provisional Authority counted 34 stories on Al Jazeera that "hyped, misreported or distorted battlefield events."⁶⁹ As censorship is one of the social taboos today, the military needs to take the initiative to rebut those negative reports. Fallujah presented a great example of information warfare with the military granting maximum information to the embedded reporters. According to Gen. Conway, 95 percent of the news coverage from embedded reporters was accurate.⁷⁰ The Military should consider providing more opportunities for embedded journalists within deployed units for a more balanced coverage on Iraq.

The challenge now would be to minimize loss of civilian life and property in MOUT since the Global War on Terrorism will most likely continue fighting in urban terrain. Civilian casualties have multiple negative effects on the war. On the home front, with the technologies of today's media, the news of any civilian casualties can spread world-wide instantly and cause a possible disaster on information operation. At the frontline, one single civilian casualty can create a more hostile local population regardless of the cause, which will make everything difficult for the American military to proceed with its mission. The support from the American public and the Iraqi people is the center of gravity in this war against insurgency. Without the support of either one, the Marines will never come home with victory.

New Technologies in MOUT Revisited

On 4 September 2004, in Tal Afar, Iraq, an OH-58 D Kiowa Warrior reconnaissance helicopter went down. Both pilots were injured but managed to escape the wreckage and crawled to a nearby rock wall for cover. Scout platoon, 5th Battalion, 20th Infantry Regiment, 2nd Infantry Division (Scout Plt., 5-20 INF, 2nd ID) Stryker Brigade Combat Team followed the GPS guided electronic map and found the downed helicopter. Thanks to GPS technology, the scout platoon was able to check the location of the friendly convoy in real-time base. UAVs constantly updated the newest enemy strength and location. Co. B 5-20 INF, 2nd ID, rushed its way into the city, toward the crash site. Insurgents attempted to set up road blocks to delay Co. B in an effort to gain time for the others to overrun the scout platoon. Learning the situation from images provided by UAVs, Co. B immediately coordinated with the joint tactical air controller for CAS. An F-16 fighter dropped a GBU-31 GPS-guided Joint Direct Attack Munitions (JDAM) and leveled the roadblock that was in Co. B's way along with the insurgents guarding the roadblock.

With Co. B rushing into the crash site, the insurgents on the streets and the roof-tops were wiped out by automatic weapons. Army infantry then cleared the surrounding buildings room-by-room with the support of Stryker Fighting Vehicles. Because of the Interceptor Body Armor (IBA) with Small Arms Protect Insert (SAPI) plates, the casualties of Americans were minimized. Then a heavy expanded mobility tactical truck (HEMTT) and a palletized load system flatbed truck along with the Army recovery team came in and recovered the downed helicopter.⁷¹ It was nothing like Operation Erin on 3-4 October 1993, at Mogadishu, Somalia: no more convoys getting lost in the city, and no more American corpses being

dragged on the street. The entire mission went quickly and smoothly due to the technological improvements and lessons learned from Somalia. The Tal Afar operation again proved that with the proper use of technologies, MOUT is no longer an equivalent of disaster.

Conclusion

The Battle of Fallujah was an ultimate test for the U.S. military improvement in MOUT after the disaster in Somalia 1992. Many argued that the military is still spending too much on Cold War era equipments and not enough in preparation to fight the 4GW. However, ill-equipped insurgents and terrorists or some undeveloped third-world-country may not be the only enemy the United States may engage in the future. To completely transform current military for 4GW may mean losing the flexibility when facing an unexpected need in the future. The experience in Fallujah along with other Iraqi cities showed that some of the conventional weapons are still very useful in fighting small wars. Some enhancements or modification may be needed on both equipment and training for the conventional units, but nothing major. The 4GW has limits and weaknesses as well. The insurgent cannot escape if surrounded. Their supply will be cut off, and conventional forces like infantry and armor are required to root the insurgents out in Fallujah.

The MOUT doctrines and TTP are being updated by MCWL and the Marine Corps Center of Lessons Learned (MCCLL) as well as other service branches. The Small War Manual has proven very useful for the current situation in Iraq and is being recommended by many veterans such as Gen. Conway who came back from Iraq.⁷² In the Battle of Fallujah, there was no revolutionary change in the modern warfare, but only lessons learned and problems confirmed from experience and history as a process of evolution. From Fallujah, the counter-insurgency came to a new page as Gen. Mattis said: "Shoulder to shoulder with our comrades in the Army, Coalition Forces and maturing [Iraqi] Security Forces, we are going to destroy the enemy with precise firepower while diminishing the conditions that create adversarial relationships between us and the Iraqi people."

While keeping in mind the Battle of Fallujah as a milestone in the evolution of warfare, the Marines, Sailors, Soldiers, and Airmen need the support of American people to accomplish their mission regardless of different points of view on the war in Iraq. Troops do not just want to go home, they want to go home with the feeling that they have done something good for the world.

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Diffusion through Reversibly Associating Polymer Networks

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Many natural macromolecules, like proteins and DNA, are equipped with site-specific, non-covalent molecular interactions. These interactions lead to intricate secondary structures such as the double helix, self-assembled phospholipid membrane bilayers, and precisely folded protein structures that are vital to life and rely on non-covalent interactions to “guide” molecular organization. Mankind has begun to borrow such concepts from nature to engineer responsive materials. In recent years, for example, the use of strong, highly directional hydrogen bonds has enabled polymers with temperature-tunable architectures to be engineered.^{1,2} Site-specific hydrogen bonding and ionic interactions in solution can lead to aggregation, gelation, or sudden viscosity changes that are triggered by slight changes in polymer concentration, pH, or temperature.³⁻⁵ In the melt, rigid and elastic polymer networks can be reversibly transformed into a low viscosity polymer melt simply by heating. This new materials concept is playing an important role in the development of recyclable (thermoplastic) elastomers.⁶⁻⁸

The quest to fully understand structure-property relationships of polymers decorated with hydrogen bonding groups has opened a new field at the interface of polymers and supramolecular chemistry. Our laboratory has synthesized novel polymer networks which contain both covalent crosslinks and non-covalent crosslinks (Figure 1). Non-covalent crosslinks arise from the presence of ureidopyrimidone (UPy) side-groups, which are well known to undergo strong, yet reversible, H-bond association.^{9,10} At low temperatures, the rate of H-bond dissociation is slow, and the material behaves as if it is

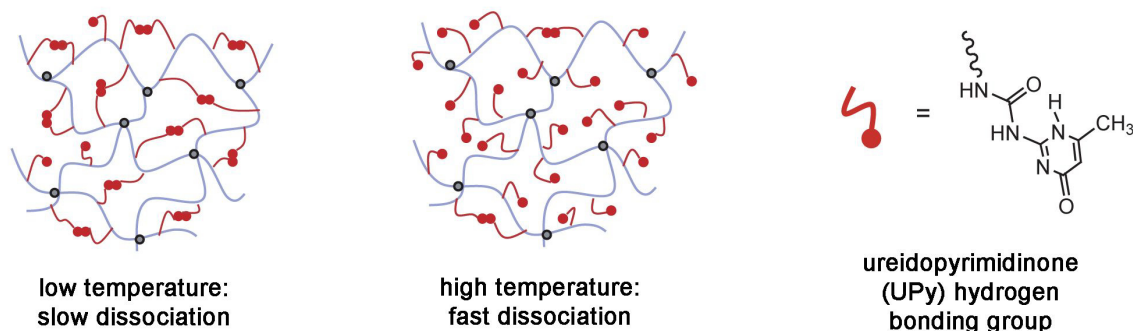
highly crosslinked—like a rigid solid. At higher temperatures, H-bond dissociation is fast, and the material behaves as if it only contains covalent crosslinks—like a soft elastomer. Consequently, mechanical properties show unusual temperature dependence. Shape-memory responses of these and similar networks have been carefully studied.^{11,12}

While a great deal of research has focused on controlling polymer rheological properties, to our knowledge no studies have examined how reversible association affects molecular transport. The primary goal of our research is to determine how the rate of molecular transport across dynamic hydrogen bonded networks depends on temperature. We hypothesize that the presence of long-lived hydrogen-bonds will decrease the rate of molecular transport at lower temperatures. A secondary question we raise is how the molecular size of the penetrants influences molecular diffusion. To address this issue, molecular transport of ethanol across polymer networks is compared to that of a much larger organic dye.

Experimental Approach

Dynamic networks were synthesized using free radical polymerization of butyl acrylate (BA), a crosslinker (trimethylolpropane trimethacrylate, TMP-TMA), and a UPy-functionalized acrylate monomer. Details of chemical synthesis are described elsewhere.¹¹ The current study focuses on two samples: a network containing only covalent crosslinks, **NW**, and a dynamic network, **DNW** which is composed of a small fraction (2 wt %) of UPy-functionalized monomer. Sample

Figure 1: Cartoon depicting architecture of dynamic networks at low and high temperature. Molecular transport through networks is hypothesized to depend strongly on temperature.



Sample	BA (backbone monomer)	TMP-TMA (covalent crosslinker)	UPy-acrylate (reversible crosslinker)
NW	98.5	1.5	0
DNW	96.5	1.5	2

Table 1: Composition of dynamic networks; all values are on a mol % basis.

compositions are summarized in Table 1.

To study molecular transport through synthesized networks, sorption-desorption (S-D) and resorption-redesorption (RS-DS) of ethanol were performed on networks with and without UPy side-groups. Experiments were repeated at several different temperatures ranging from 20 to 60 °C. Dry samples containing UPy side-groups were swollen in ethanol. Samples were periodically wiped dry and weighed to determine the amount of ethanol uptake. This procedure was repeated until the network polymers were saturated with ethanol. Desorption and redesorption were performed under a dry nitrogen blanket until the sorbed ethanol was fully removed. For polymers not containing UPy side-groups, data were acquired only up to 50 °C, because these networks started to fracture at higher temperatures.

To study mass transport of larger molecular penetrants through dynamic networks, permeation studies were conducted. Ethanol-swollen polymer networks, ~1 mm thick, were placed between two water-jacketed, temperature-controlled glass chambers. Initially, chamber A was filled with a dye solution [0.1 mM 4-(Dicyanomethylene)-2-t-butyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran, DCJTb, $M_n = 453.6$ g/mol] in ethanol, and chamber B was filled with pure ethanol. Both chambers were well stirred, and the amount of dye in chamber B was measured with a custom-built photo-detector. Runs were repeated for several different temperatures ranging from 20 to 60 °C. A drawing of the experimental apparatus is

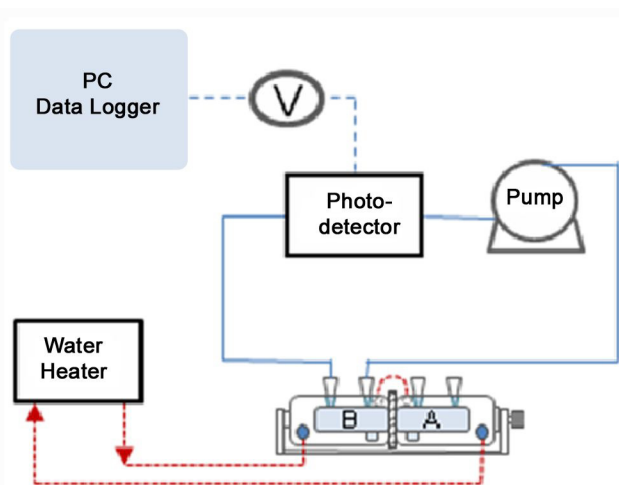


Figure 2: Experimental apparatus used to study dye diffusion across solvent-swollen, dynamic polymer networks.

shown in Figure 2.

Results and Discussion

Solvent Sorption. Ethanol sorption data acquired at different temperatures are shown in Figure 3 where ethanol uptake (Q_t) is defined as

$$Q_t = \frac{\text{mass of EtOH sorbed} / M_w \text{ of EtOH}}{\text{mass of polymer}} \times 100. \quad [1]$$

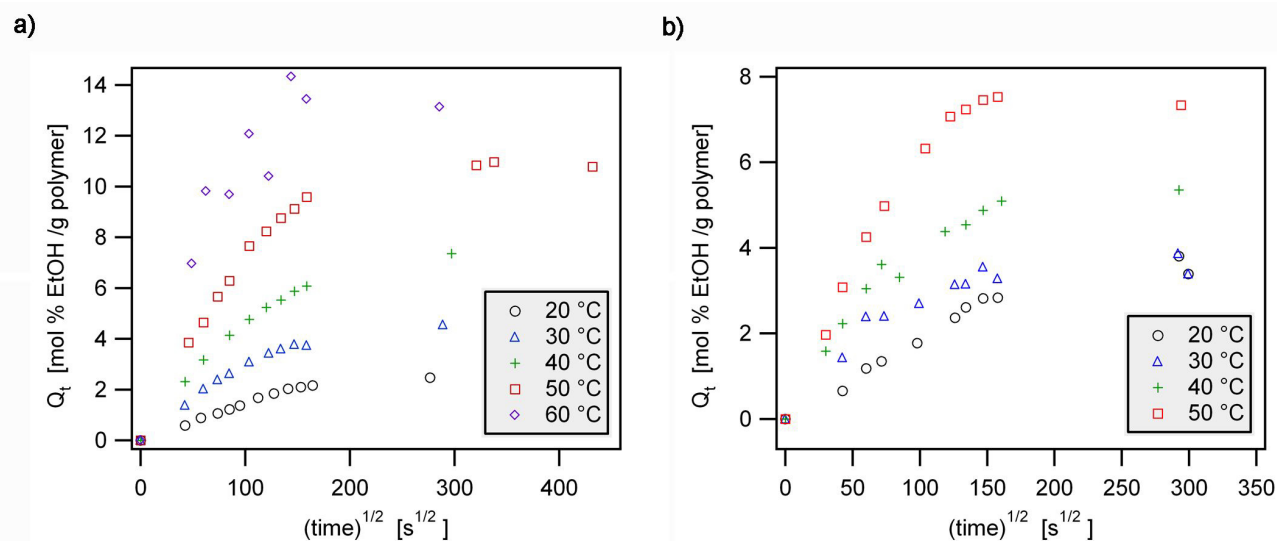
With increasing time, samples become saturated with ethanol, and Q_t approaches an equilibrium value of Q_∞ .

At short times, data are nearly linear, and, in this regime, the diffusion coefficient of ethanol D_{Et} describing transport into the network polymers can be determined from mass-uptake data¹³ by

$$D_{Et} = \pi \left[\frac{h\theta}{4Q_\infty} \right]^2 \quad [2]$$

where h is the initial thickness of the polymer, θ is the slope of a plot of Q_t vs. $t^{1/2}$ (at short times), and Q_∞ is the fractional

Figure 3: Ethanol uptake curves for a) UPy-functionalized networks (DNW) and b) unfunctionalized networks (NW). Measured values of ethanol uptake (Q_t) are plotted versus $t^{1/2}$ for different temperatures.



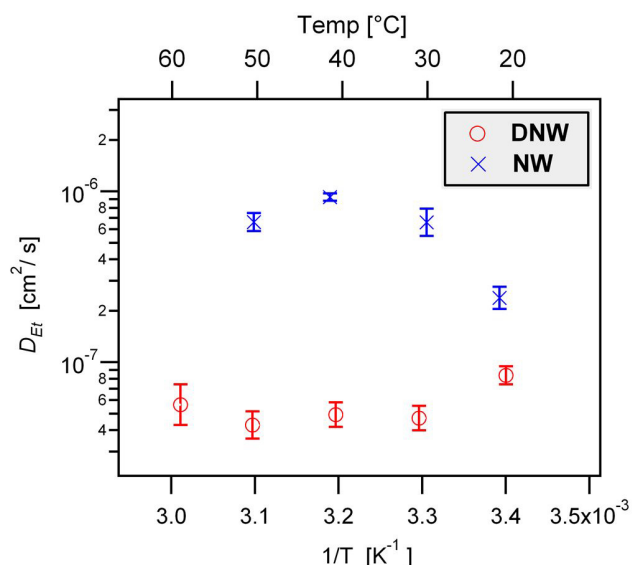


Figure 4: Temperature dependence of ethanol diffusivity (D_{Et}) through UPy-functionalized networks (DNW) and unfunctionalized networks (NW). Error bars were determined by “propagation of error” analysis.

uptake of solvent at infinite time. Diffusion coefficients were measured at several different temperatures, and results are summarized in Figure 4. Measured values of D_{Et} through conventional networks (NW) are on the order of 1×10^{-6} cm^2/s . These values are on the same scale as the diffusion coefficients of linear alkanes measured through styrene-butadiene crosslinked rubber membranes.¹⁴ Interestingly, diffusion of ethanol into functionalized, dynamic networks (DNW) is about an order of magnitude slower than diffusion into conventional networks (NW). This suggests that either the presence of UPy groups, or the presence of additional, hydrogen-bonded crosslinks, interferes with mass transport.

Figure 4 also shows that mass transport of ethanol into the network polymers depends weakly, if at all, on temperature. This is a little surprising because other studies of penetrant diffusion through crosslinked networks^{14,15} show diffusion to be thermally-activated, i.e., faster diffusion occurs at higher temperatures. However, these studies all involved penetrant molecules that are much larger than ethanol. The lack of temperature dependence in Figure 4 suggests that ethanol transport is determined by solvent-polymer interactions, and not by the

presence of crosslinks. Obstruction-scaling models support this view and show that network obstructions become less important when penetrant molecules are smaller than the characteristic length scale of the network mesh.^{16,17}

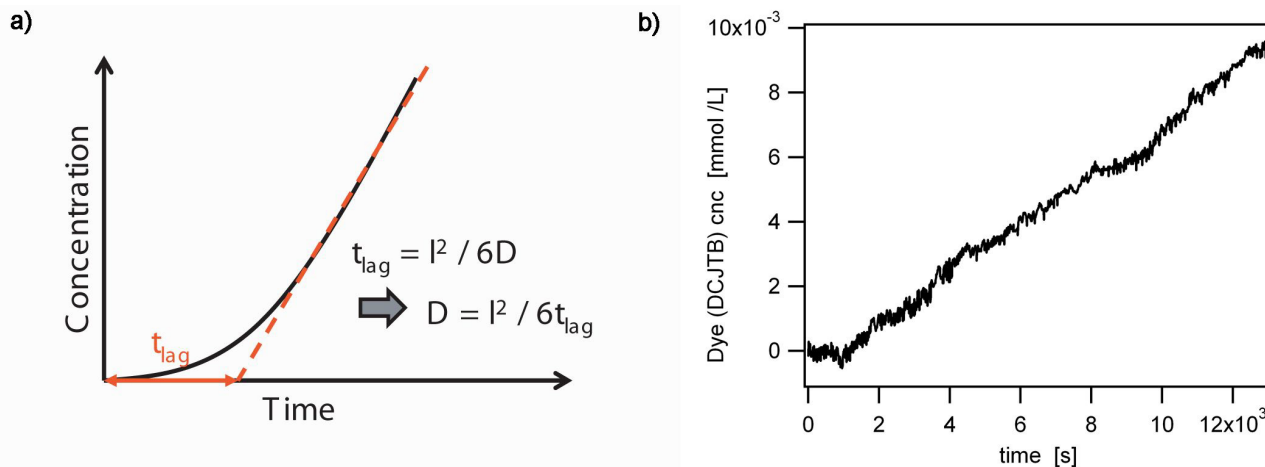
Permeation Studies. To examine transport of larger molecules through dynamic networks, permeation experiments were performed using a large dye molecule (DCJTB, $M_n = 453.6$ g/mol). Diffusion coefficients for DCJTB (D_{Dye}) through synthesized networks were determined by using the time-lag method.¹⁸ This method assumes that both chambers are well-mixed and that solute is only initially present in chamber A (See Figure 2). Briefly, the cumulative amount of solute transferred through the membrane Q_t , is related to the diffusion coefficient by

$$Q_t = V_{B0} C_B(t) = \frac{A_x D_{dye} C_{A0}}{l} \left(t - \frac{l^2}{6D_{dye}} \right) \quad [3]$$

where V_{B0} is the initial volume of chamber B, $C_B(t)$ is the dye concentration in chamber B, A_x is the membrane cross-sectional area, C_{A0} is the initial dye concentration in chamber A, and l is the membrane thickness. Figure 5b shows a typical plot of experimental data in the form of concentration vs. time. Diffusion coefficients, D_{Dye} , were determined from the x-intercept of a tangential line fit to experimental data, also known as the “time lag” ($t_{lag} = l^2/6D_{Dye}$). For each run, the membrane thickness was measured in the dry state, and the ethanol-swollen membrane thickness, l , was estimated using results of ethanol solvent-sorption studies.

Measured diffusion coefficients of dye diffusing through UPy functionalized networks (DNW) are summarized in Figure 6. The rate of dye transport increases with increasing temperature and exhibits much greater temperature dependence compared to that of ethanol. The activation energy for diffusive transport was 42.3 kJ/mol based on the slope of the best-fit line to D_{Dye} versus $1/T$. This activation energy is significantly higher than the activation energy of linear alkanes diffusing through traditional, styrene-butadiene crosslinked networks (~ 20 kJ/mol).¹⁴ Interestingly, the measured activation energy is more comparable to the energy barrier of UPy dimer dissociation of 70 kJ/mol¹⁹ (measured in CHCl_3). This suggests that dye transport through reversibly associating polymer net-

Figure 5: Overview of time-lag method: a) schematic showing how permeation data are analyzed to determine molecular diffusivity, b) typical experimental data acquired on a dynamic network membrane. The time-lag is defined as the x-intercept of a linear fit to data at later times.



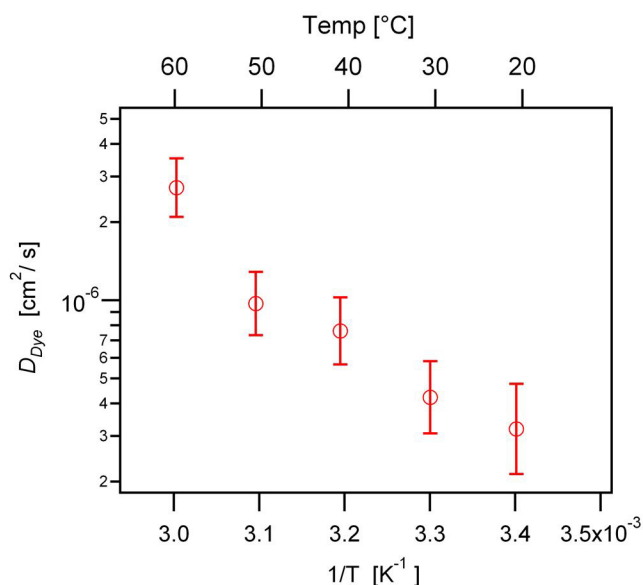


Figure 6: Temperature dependence of dye diffusivity through UPy-functionalized networks (DNW). Error bars were determined by “propagation of error” analysis.

works may be controlled by the rate of H-bond dissociation. At low temperatures, H-bond dissociation is believed to reduce mobility and interfere with mass transport of dye through the functionalized polymer. At high temperatures, the rate of dissociation is so fast that dynamic crosslinks do not interfere with transport.

Conclusions

Solvent sorption and permeation experiments were conducted to assess how molecular diffusion through dynamic networks depends on temperature and on molecular size. Ethanol diffusion through networks with and without UPy (hydrogen bonding) side-groups showed little, if any, temperature dependence. On the other hand, mass transport of a larger molecule (a dye, DCJTb) through networks containing UPy side-groups is clearly a thermally-activated process. The activation energy for this process is about 45 kJ/mol and is comparable to the activation energy of H-bond dissociation (of UPy side-groups). Therefore, experiments support the notion that mass transport may be limited by the rate of dissociation of hydrogen bonded side-groups. However, to confirm this hypothesis, more studies need to be conducted.

Further development of polymers with temperature-sensitive permeabilities may result in important applications. Transdermal medicine patches, for example, are envisioned to target the drug delivery to infected areas of wounds, assuming that infected tissue has a slightly higher temperature than healthy tissue. Another potential application is that of the “smart” labels, which are able to track the temperature-exposure of perishable goods through the diffusion of a dye.

Acknowledgement

This project was funded by Professor Richard Eisenberg and by the Department of Chemical Engineering, University of Rochester. The author acknowledges Andrew Hilmer for providing Figure 2.

Appendix

Calculation of Error Bars for Sorption Experiment

For the error analysis of the diffusion coefficients of the sorption experiments, propagation of error was used to determine the error bars. First, some of the basic formulas of propagation of error will be discussed. For expressions of Z representative of $Z=A\pm B$, the error, ΔZ , is calculated as:

$$\Delta Z = \sqrt{(\Delta A)^2 + (\Delta B)^2} \quad [A1]$$

For expressions of Z representative of $Z=AxB$ or $Z=A/B$ the error, ΔZ , is calculated as:

$$\Delta Z = Z \sqrt{\left(\frac{\Delta A}{A}\right)^2 + \left(\frac{\Delta B}{B}\right)^2} \quad [A2]$$

For expressions of Z representative of $Z = \ln A$, the error, ΔZ , is calculated as:

$$\Delta Z = \frac{\Delta A}{A} \quad [A3]$$

Next, diffusion coefficients are determined by equation [2] for solvent sorption. The error in polymer thickness, Δh , was determined by making 10 random measurements of a polymer and using the standard deviation of the measurements as the error of polymer thickness. The error in the slope of plot Q_t vs. $t^{1/2}$, $\Delta \theta$, was determined by using the LINEST function in Excel. Since the molar uptake of solvent/g of polymer, Q_∞ , was experimentally determined by:

$$Q_t = \frac{(m_{p+EtOH} - m_p) M_w}{m_p} \times 100 = \frac{m_{EtOH} / M_w}{m_p} \times 100 \quad [A4]$$

where m_{p+EtOH} is the mass of polymer with the sorbed ethanol, m_{EtOH} is the mass of the sorbed ethanol, m_p is the mass of the dry polymer, and M_w is the molecular weight of ethanol, $m_{EtOH} = m_{p+EtOH} - m_p$. Knowing the two errors, Δm_{p+EtOH} and Δm_p , which are estimated to be about 0.0001 g, the error, Δm_{EtOH} can be determined by:

$$\Delta m_{EtOH} = \sqrt{(\Delta m_{p+EtOH})^2 + (\Delta m_p)^2} \quad [A5]$$

From Δm_{EtOH} and equation [A5], the error of Q_∞ is determined by:

$$\Delta Q_\infty = Q_\infty \sqrt{\left(\frac{\Delta m_{EtOH}}{m_{EtOH}}\right)^2 + \left(\frac{\Delta m_p}{m_p}\right)^2} \quad [A6]$$

Similarly, the error of $(h\theta)$, can be determined by:

$$\Delta(h\theta) = (h\theta) \sqrt{\left(\frac{\Delta h}{h}\right)^2 + \left(\frac{\Delta \theta}{\theta}\right)^2} \quad [A7]$$

Subsequently, the error of $(h\theta/Q_\infty)$ is determined by:

$$\Delta\left(\frac{h\theta}{Q_\infty}\right) = \left(\frac{h\theta}{Q_\infty}\right) \sqrt{\left(\frac{\Delta(h\theta)}{h\theta}\right)^2 + \left(\frac{\Delta Q_\infty}{Q_\infty}\right)^2} \quad [A8]$$

Therefore, the error of D is determined by the expression:

$$\Delta D = D \sqrt{\left(\frac{\Delta\left(\frac{h\theta}{Q_\infty}\right)}{\left(\frac{h\theta}{Q_\infty}\right)}\right)^2 + \left(\frac{\Delta\left(\frac{h\theta}{Q_\infty}\right)}{\left(\frac{h\theta}{Q_\infty}\right)}\right)^2} = D\sqrt{2} \frac{\Delta\left(\frac{h\theta}{Q_\infty}\right)}{\left(\frac{h\theta}{Q_\infty}\right)} \quad [\text{A9}]$$

This leads to the error used for the error bars:

$$\Delta(\ln D) = \frac{\Delta D}{D} \quad [\text{A10}]$$

Calculation of Error Bars for Permeation Experiment

For the error analysis of the diffusion coefficients of the permeation studies, propagation of error was also used to determine the error bars, and the same basic formulas discussed in Appendix A were used. The diffusion coefficients of the permeation studies were determined by the time-lag expression. The error of thickness of polymer, Δl , was determined by the same method for the Δb discussed in Appendix A. Therefore,

$$\Delta(t^2) = (t^2) \sqrt{\left(\frac{\Delta l}{l}\right)^2 + \left(\frac{\Delta l}{l}\right)^2} = (t^2) \sqrt{2} \frac{\Delta l}{l} \quad [\text{A11}]$$

The tangential straight line which was added to the plot of concentration vs. time can be expressed as $y=mx+b$, where y is the concentration and x is time. Then $\Delta t_{lag} = -b/m$, and

$$\Delta(t_{lag}) = (t_{lag}) \sqrt{\left(\frac{\Delta b}{b}\right)^2 + \left(\frac{\Delta m}{m}\right)^2} \quad [\text{A12}]$$

Therefore, the error of D is determined by the expression:

$$\Delta D = D \sqrt{\left(\frac{\Delta l^2}{l^2}\right)^2 + \left(\frac{\Delta t_{lag}}{t_{lag}}\right)^2} \quad [\text{A13}]$$

This leads to the error used for the error bars:

$$\Delta(\ln D) = \frac{\Delta D}{D} \quad [\text{A14}]$$

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