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Friends, relatives and members of the class of 2009: Good afternoon. It is my privilege, on behalf of the faculty in Chemistry, to acknowledge the accomplishments of our graduates in this final address. It is also a unique opportunity: I doubt I will ever again be able to claim Oprah was my warmup speaker.

I will always have a special connection with this graduating class. We arrived on campus at the same time, in the summer of 2005. Through those four years, we have shared many of the same experiences-both good and bad. We moved together into this wonderful building, the French Family Science Center, whose facilities enabled much of the research that became part of your educational experience. And together we went through the whirlwind which was the spring of 2006. Looking back on those times, I think we all learned some valuable lessons: for example, the difference between popular perception and truth, even if those perceptions were reinforced on the evening news. Very likely, you learned this without anyone ever discussing it in lecture. And that experience will serve you well, as you leave the “proctored” phase of your educational experience in college. You do not leave behind the need to continue lifetime learning-and often you will learn more in chaotic and challenging times than in calm ones.

There is one experience we did not share, however. In my four years here I have taught over 1000 students, but as timing would have it, none of you ever took a class from me. So today, I am going to change that with a microclass. Consider this your last lecture, in the tradition of some other institutions; but this lecture will be quite different from the ones you have had. First of all, don't worry; it will be much shorter. But it will also differ in a more fundamental way. Faculty members, particularly in the sciences, are supposed to know the answers. Indeed, my extraordinarily talented colleagues know most of what is known, about most of the subdisciplines of chemistry. Those of you who engaged in research understand that this knowledge has limits-and that pushing those limits is the job of a great university. But in general, the research enterprise functions by asking well defined questions, and by developing clearly delineated approaches to answer those questions. I am going to take these few minutes to take you farther than that-to the realm where science confuses, and even baffles. I would like to give you just a glimpse of a different take on science-what it tells you about reality-and to discuss what that means today at graduation.

Some people believe that science is irreconcilably in conflict with philosophy and religion. I am not a professor of either philosophy or religion, but I can tell you that this conflict often arises because of misunderstandings- a little scientific knowledge can be a dangerous thing. So, let's start from a simple premise. If you recall the first year physics courses you took, you saw how the dynamics of matter could be described by forces and fields. Our limitations in predicting how far a ball will fly and where it will land are dictated only by our lack of precision in understanding the initial conditions, and in quantifying the forces along the way. There is no fundamental limit to our ability to specify all of these quantities, and no fundamental randomness-only a lack of measured knowledge of the interactions. Measuring them more and more accurately inevitably leads to a longer prediction of how the ball moves.

Now mix that with your chemistry courses, where you understood that molecules are fundamentally collections of protons, neutrons and electrons, interacting by simple forces; in fact, molecular dynamics simulations take exactly this approach. Add in what you learned in molecular biology courses, where you were shown that astonishingly complex processes in living systems can be understood as applied chemistry. You now have an overwhelmingly precise and powerful method for understanding how systems evolve.

You also have a philosophical problem. In a universe of perfectly defined particles and forces, the evolution is also perfectly defined. Actually predicting that evolution gets more and more complex the longer you wish to make the prediction, but only because you need ever finer knowledge of the initial states and interactions, not for any fundamental reason. And forget the measurement question-since the beginning state exists, as do all of the forces, the final state is perfectly predicted. So from this perspective the universe is perfectly deterministic-the past exactly dictates the future.

But in a deterministic universe, there is no point in congratulating you for your accomplishments-it was predetermined that you would be here, before you took your first class, before your parents were born, before dinosaurs roamed the earth. There is no point in thanking your parents and friends for their support-it was predetermined that they would provide it. And there is no point in worrying about the challenges the world faces. They either will or will not be solved, and that outcome was predetermined- before you took your first class, before your parents were born, before dinosaurs roamed the earth.

A deterministic universe is an extremely depressing place. Of course, you can choose to believe in a God who endows you with the ability to make free choices; but in that case, you have to believe that God constantly reaches down and

scrambles the laws of physics, even when you decided which flavor of Locopop to enjoy, and then it is hard to see any rationality.

This is not on its face a preposterous conclusion. If we were speaking a century ago, I would have had to tell you, as a scientist, you had found the only answer science could accept. But our understanding changed dramatically with the advent of quantum mechanics. Today you see quantum mechanics predigested in your textbooks, adapted to let you understand the structure of a hydrogen atom or a molecule-but the picture of reality it paints, which you won't find in those books, is much more interesting. So, I leave you with your final homework assignment. Some day, when you are full of confidence and convinced you understand the world, grab a glass of wine, sit down at a computer, and Google one phrase-"quantum eraser". You will discover that science has shown it is possible to change the past. Admittedly, the changes are relatively minor-you can't redo that MCAT question, take back the stupid comment you made to your girlfriend, or affect the things that really matter in life. And today, experiments have only shown changes going back a short time, say a microsecond. But that's not a fundamental limitation-as you dig deeper, you will encounter thought experiments such as Wheeler's delayed choice experiment, where what you do today alters what happened a billion years ago-and in your lifetime, that experiment will probably be done.

Don't worry, there won't be a problem set on this assignment. I wouldn't know how to grade it. Those ideas should bother you. They certainly bothered Einstein, who thought about experiments similar to these before they could be done, and as a result spent the last twenty years of his life trying to disprove quantum mechanics. He failed-as has everyone else in the last century. It seems, indeed, the universe is more subtle to understand than anyone might have guessed. But there are some things we can grasp. All these experiments, and many more, are extensions of what you learned as Heisenberg's Uncertainty Principle-again, usually in a predigested form with a simple equation in a textbook. But here is what that principle says. Our picture of the universe is like a digital photograph: at high enough resolution, you encounter pixels that you cannot see inside, even in theory. And at that level of resolution-past what can be measured-quantum mechanics says there is no reality. So suddenly the dilemma of determinism goes away. It is not just that there is a limit to your ability to predict the future, because you cannot measure the present accurately enough-it is that past a certain level of accuracy, you cannot say that a state exists.

So the present and past influence the future, but do not control it. You are to be congratulated on your accomplishments, because you chose to exert your efforts-it was never mandated by the past. You worked hard to be here today. The people in the audience might be surprised to note how many of our students are in the top

25%, 15% or even 5% of the graduating class, but we are not: we know that Chemistry students excel at their other courses as well. Your parents are to be thanked for their sacrifices, some of which you likely will never know, that helped you become the fine young men and women you are today.

Most importantly, the challenges of the future are yours, and ours, to solve. Do not ever let anyone tell you that today's challenges are too hard to address-this is one place where a bit of seniority gives perspective. Professor MacPhail is celebrating the conclusion of his 25th year on the faculty, with an extraordinary dedication to the teaching mission. When he graduated from college, the United States and the Soviet Union were locked in a cold war, with 40,000 nuclear weapons ready to fly. If you didn't lose sleep then, you weren't paying attention. We know today for sure that there were times when one simple misstep would have led to nuclear Armageddon. Professor Bonk is celebrating his 50th year on the faculty; when he was growing up, the world was locked in a hot war that would ultimately take 50 million lives, and where the very future of civilization hung in the balance. Our challenges today are different, but certainly not harder.

You can, and should, choose to change the world, in ways big and small. The world needs you to apply what you have learned here from us, and more importantly what you will learn on your own, to handle the challenges of the future. There is still much to discover. And, finally, remember that we call this Commencement for a reason-as you begin your life beyond Duke, I hope that by your choices you make us even prouder of you in the future than we are today. Congratulations, good luck and godspeed.