Talk for the Rotary Club, March 1998

Hello, my name is Brian Blais, and I am a physics graduate student at Brown University. My advisor is Leon Cooper, who received the Nobel Prize for his work on the theory of superconductivity. Since he cannot make it this morning, I will be giving a talk in his stead. After his work on superconductivity, he shifted the focus of his work to the study of the brain. It is this topic, *Physicists Studying the Brain*, that I want to talk about today.

One doesn't usually associate the study of the brain with physicists. Usually one thinks of cosmology, or nuclear physics, or subatomic particles when one thinks about the work of physicists. But not usually the brain. This reminds me of something I heard a few years ago. Did you know that each of us is made up of, maybe, a dollar fifty worth of chemicals? Certainly we don't expect to be able to go to a chemical store, buy a handful of chemicals, and make a person. That would bring new meaning to the phrase "some assembly required". Though this is clearly absurd, there are many physicists who take a similar perspective on biological systems, including the brain. Throw together millions of particles, and the fundamental laws of physics and...**poof**...as a consequence, we get consciousness. This point of view is an extreme form of reductionism and though it is probably *true*, it is not very informative.

I prefer to take a slightly different take on reductionism. I do believe that even the complex behavior of the brain is a consequence of the fundamental laws of physics, but it is only one such consequence. We would like to know more about this particular consequence, in contrast to the other possible consequences. To put it another way, consider the electrons, protons, and neutrons that make up matter to be like the letters of the alphabet. We can then write a number of different novels using these letters, just as we can get many different complex phenomena out of the electrons and protons. Saying that any particular novel is made of letters is a true statement, just not very informative. We'd like to know what makes this novel we call the brain different than others. The search for understanding of complex systems is then similar to literary criticism.

Now, how do we go about trying to understand the brain, from a physicists perspective? Theoretical physicists seek to have theories which simplify, as Einstein noted when he said that "theories should be as simple as possible, but no simpler". It would seem an almost impossible task to present a simple theory of the brain, given it's almost overwhelming complexity. The initial goal, then, is to get a model which identifies the qualitative features of the problem. Instead of looking at the letters of the novel, we look at paragraphs or pages. This brings into a whole host of other concepts: themes, plot, characters, etc. In a similar way, when we seek the qualitative features of the brain, we may bring in many other concepts.

An example of this process can be seen in Newton's law of gravitation, used to explain the motion of the planets. At the time people were beginning to realize that the planets move in nearly circular orbits around the sun, but that the detailed motion is still reasonably complicated. Some planets, like Mercury (the innermost one), have motions that weren't even understood until this century! If Newton had tried to understand all of the details of planetary motion, all at once, it would have been an impossible task: the details would be overwhelming. But, there was the important *qualitative* feature that the planets moved in nearly elliptical orbits. Newton had to ask himself, "What are the *minimum* assumptions that can achieve this qualitative behavior?" It was this approach which led him to the law of gravitation, which is one of the fundamental laws of physics.

When modeling the brain, physicists use the same approach. Models are proposed which address the *qualitative* properties first, and only refined later when necessary. For example, we can start by looking at the smallest independent parts of the brain, the neurons. Each of these incredibly complex cells contains a myriad of ion channels, receptors, and neurotransmitters all working together, each cell adding one piece to the process we call thinking. But remember, we are choosing not to look at the letters of the novel, but at pages or paragraphs. This means that we are ignoring many of the details of the problem. We can model neurons as simple circuit elements, with inputs and outputs, and some very rudimentary processing inside. In the standard physics fashion, this ignores many details of the way the neuron functions but it captures some of the qualitative features. We can then ask ourselves, what minimum assumptions do we require in our model to get some of the basic properties of the neuron, such as learning and memory. We can then use these simple model neurons to form a network, and again ask ourselves what minimum assumptions are necessary to get such things as cognition out of the interaction of many simple units. We use the minimum assumption rule, so that we don't drown in the details.

The model must always refer back to experiment in order to determine which properties are the ones found in nature. The job of the experimentalist is to tell us what is out there in the world. This is in contrast both to what is *not* out there in the world and what we would *like* to be out there. Theorists who are not in contact with this are spinning their wheels, because our imagination and the world need not agree. The job of the theorist is to tell the experimentalist what the possible consequences of different assumptions can be. If we start a novel with "It was a dark and stormy night...", what does that imply about the plot or the themes? Without the theorists the experimentalists may not know which tests are the most critical in order to distinguish different consequences, ie. different novels.

There are many examples in physics where a large group of very simple units combine to give behavior qualitatively different that the individual components. Diamond is qualitatively different than individual carbon atoms. People are qualitatively different than individual cells. When dealing with the brain, heated debates arise about concepts like consciousness, intelligence, and the soul. As with all debates of this kind, the differences fade in the cool, calm light of scrutiny and understanding. It was once believed that organic compounds obeyed different physical laws than inorganic compounds; that a "vital force", as it was called, was responsible for the production of organic compounds. This sharp distinction faded, when it was shown that organic compounds are all compounds of carbon, and no "vital force" was needed to explain their properties. So too will the sharp distinction fade between conscious and non-conscious, or intelligence and non-intelligence, when a better understanding is achieved.

For the physicist, the brain is a large system of interacting elements perhaps like the atoms in a solid or the stars in a galaxy. The goal is the same, but the approach needs to be slightly tailored for the particular problem. It is not enough for us to write down the rules for subatomic particles and hope to get any understanding of the brain. We need to start at a much larger scale, but realize that at every point the models we propose are still subject to the fundamental laws of physics. We still need to use the letters of the alphabet to write our novel, but from then on we might get Hamlet, or a Harlequin Romance. Only the steady and careful quest for understanding, with simplicity always the guiding theme, will we hope to solve the problem of the brain.