**Eric’s Senior Exhibition:**
**Modern Physics**

For my senior project I chose the topic of modern physics, because I’ve had an interest in physics ever since I came to this school, and since then I’ve done a number of projects in physics.  The topic of modern physics was broad enough, though, to let me cover some of the older areas of physics, such as relativity and quantum mechanics, and also encompass some of the newer developments, such as high energy particle physics and string theory.

What I did for my senior project was create a web site, which is shown here. I wanted to make the web site accessible to anyone who had an interest in physics, so they wouldn’t have to have any prior knowledge in physics to learn anything off the web site.  I also wanted to make the web site interactive, more than just a bunch of reports put up on the Internet.  So a majority of my project was spent researching the Java computer programming language, which I then used to create a series of Java applets.  Java applets are essentially computer programs that can be run over the Internet, and I created five of these total. Each one ties in with the concept of the web site, and illustrates a certain concept in physics.

The applet you are seeing here on the screen was designed to illustrate the concept of Laurence contractions and the theory of relativity.  What the theory basically says is that when an object is in motion, it will become contracted and shortened in the direction of its motion, depending on its speed.  Higher speed equals a higher amount of contraction. Also when an object is in motion, it will [gain?] mass according to its speed—it works the same way, more speed is more mass.  So this applet illustrates that you can enter in the number of parameters, such as the speed of the object, the length that it’s measured at when it’s stationary, and also the mass it’s measured when it’s stationary, and then you can calculate the results and see them visually…

Now here’s the object when it’s at rest. And here it is when it’s contracted, going 50 percent of the speed of light.  It’s drawn to scale, and the darker color of the contracted object represents the increasing mass.  So if you were to increase the velocity 75 percent and then calculate it, you can see that it’s contracted quite a bit more, and it’s gained quite a bit of mass, too.  If you go up to 99 percent of the speed of light—which is almost the speed of light itself—there’s a very drastic contraction, and it’s several times its original mass.

So physics like this seems kind of abstract, but physics actually isn't abstract. Albert Einstein once said that the whole of science is nothing more than a refinement of everyday thinking. And this is especially true with physics. We experience physics daily—every day that we're alive—and our minds are constantly storing information about how the world works. And this information makes up our intuition. Our intuition is information that we know without having to consciously think about it.

And here's one way that our intuition can agree with physics. There's nothing in my hands, my hands are both empty, and then I do this—pull a scarf apparently out of nowhere—and immediately in our minds, something tells you that this couldn't happen, that scarf had to come from somewhere! There's a law of physics that describes this—it's called the law of conservation of matter—and it states that matter cannot spontaneously appear and disappear, unless the amount of matter in the universe remains a constant. So what I was doing when I pulled the scarf out of nowhere—maybe you saw it was in my sleeve, actually—was violating that law of physics, and subconsciously, you knew that! How did you know it? It's because every experience that you've had in your life tells you that things just don't appear. And that's your intuition telling you what was actually going on.

Here's another example. I'll do an experiment—I will take this ball and this meter stick, and drop the ball from a height of one meter and measure how high it bounces. Say about half a meter. Now if I were to do this experiment in a different location, say over here [moves a couple of feet to the left], would I get the same results? My intuition's saying yes, and it's right—it bounced about a half meter the second time as well.

Physics describes this type of behavior with the concept of physical symmetry, in this case symmetrical over spatial translations, that is, two different points in space. And once again, our intuition told us what should happen, and it agreed with the laws of physics; when I did the experiment I got the same results. Now you might be thinking, if I did the experiment on the moon, I'd probably have different results. But in this instance, it isn't the laws of physics that's changing, it's the experiment itself. Since the floor that I bounced the ball off of is part of the experiment, if I were to change the floor in any way, it would be a completely different experiment, and different experiments don't always produce the same results.

So these are both ways that physics agrees with our intuition.

But I’m now going to explain a few ways that physics can also defy intuition. If we were examining the motion of objects in the world, we might conclude after observing enough situations that all objects in motion will eventually come to rest.  This agrees with what we see every day. If we were to roll a ball across the floor, it would eventually come to a stop. And when you’re driving a car, if you take your foot off the accelerator pedal, the car will also eventually roll to a halt.  You might even go so far as to say that this is a law of physics—and Galileo did just that; he stated that all objects in motion will eventually come to a halt.

Yet this actually isn’t how the world works!  Isaac Newton corrected Galileo’s law and said that all objects in motion will remain in motion unless they’re acted upon by an outside force.  And when we look closer at the situations—say, the ball rolling on the floor—we have to look at why the ball is coming to a halt.  It’s more than likely because of the force of friction between the ball and the carpet, or the force of air resistance, and if we take away all these outside forces, the ball will in fact keep on rolling.  So the point is that what we see isn’t always a clear picture of reality.  We can’t always go by what we experience in the real world to tell us accurate information about how physics works.

Another example of this is—you’ve probably had the experience of when you’re driving your car and you make a sharp turn, you feel something pull to one side of the car. So if you’re making a left hand turn, you feel yourself being pulled to the right side of the car. And the logical thing to assume is that there’s an outside force pulling us outside of the turn.  This also isn’t what’s going on. What actually occurs is that there’s a force pulling us inward, and we don’t notice this, because when we’re driving in the car, chances are our lower halves are strapped into the car by a seat belt. And when we make the turn, our lower halves are pulled in with the car, but since our upper halves are left free to move wherever we want, they continue to move in the direction that they were. And since that’s where we experience the world from—our heads are on the top of our bodies—we see, we feel that we’re being pulled outward.

Both of these examples are ways that physics can defy intuition on the macroscopic scale—that is, the scale that we experience life on every day.  But physics can also defy intuition in other ways.  And it does so mainly in the branch of physics called quantum mechanics.  Quantum mechanics is the type of physics that deals with the interaction of matter and energy on their smallest scales.

One of the fundamental ideas of quantum mechanics is that all matter existed as “m”s. The origin of the idea of the atom dates back to the time of ancient Greece, when a philosopher named Democratus came up with a thought experiment. He said that if you were to take a piece of matter—say, a block of wood—and cut it in half, then take one of those halves and cut it in half and keep doing this, eventually you'd reach a point where you couldn't cut the matter in half again. And at this point you would have found the atom. This would be the smallest form of matter. And Democratus envisioned the atom as tiny spherical particles, but his idea was ignored, mostly due to opposing views of other philosophers.

And the idea of the atom didn't really become popular again until the advent of modern chemistry, but even with that, the model of the atom didn't really change until 1897, when Joseph Thompson discovered the existence of smaller particles existing within the atom. These particles were called electrons, and Thompson envisioned the electrons residing inside the main mass of the atom. He called this the "plum pudding" model of the atom, because he saw the electrons as tiny plums within a small bowl of pudding. But a few years later this idea was proved wrong by Ernest Rutherford, who discovered that the electrons were actually contained outside the main mass of the atom. He speculated that the electrons were in orbit around the nucleus of the atom, where most of the mass was contained, and the nucleus contained two types of particles, protons and neutrons.

There were other developments in the model of the atom, but all of these require the concepts of quantum mechanics, which in itself was becoming a new popular science at the same time, while the idea of the atom was changing. One of the fundamental ideas of quantum mechanics is that of all energy existing in discrete bits, rather than continuously. This idea dates back to just before the turn of the 20$^{th}$ century, when physicists were having trouble describing how energy was emitted by matter, namely atoms. Their equations all said that when matter was disturbed it would emit energy, and the equations said there would be an infinite amount of energy, which we know can't be true.

So Max Planck, a physicist, solved this problem by stating that instead of energy existing as a continuous wave, it existed only in discrete chunks—little tiny bits that he called quanta. This goes against what we see in the everyday world, because when we shine a beam of light—which is electromagnetic energy—we see a solid beam, no breaks or gaps in it, as we would expect to see if it consisted of just chunks. But if these chunks were small enough, we wouldn't notice the fact that there were gaps in the light—it would just appear continuous to us. So this idea fixed the problems the scientists were having with the emission of energy by matter.

Then in order to account for this new idea, Niels Bohr created a new model of the atom, where the electrons orbit the nucleus—much as in Rutherford's model, but they only orbit in precisely defined shells. Each shell represents a certain energy level, and all the electrons orbiting in that shell have that energy level. The electrons can move between shells either by emitting or absorbing quanta of energy. In order to move up a shell to a higher energy level, the electron would need to absorb a quanta of energy equal to the difference in energy between the shells; in order to move down a shell, it would have to emit a quanta with the energy equal to the difference.

But with this new idea of energy as quanta came the question of what the quanta were. We still have two views of energy—two ways to look at it. We can view it as a particle, and we have experimental evidence that seems to prove this. Say if you shine a beam of light in a straight path, it will continue to move in a straight path until it's deflected by another object, and this is very similar to particle motion. Also when you bounce light off another object, it will bounce off at the angle at which it hits—which is a property of particles—so if you were to bounce a ball off the wall, it would do the same thing.

So these are views of light and energy as a particle. But there's also another way to view it, as a wave. This is illustrated best with this two-slit experiment that is somewhat famous in the world of physics. What the experiment consists of is an opaque screen which light cannot pass through, that has two parallel slits cut into it, two very thin slits. And this is placed in a dark area in front of a wall, and then light is shone onto the screen. What we'd expect to see is two bars of light on the opposing wall, since light can only pass through the screen at the two slits. But what actually appears when we shine the light on the screen is a pattern resembling this [vertical lines], and the only way to explain this pattern is to consider the existence of light as a wave. What this pattern is called is an interference pattern—if you consider light as a wave, when you shine the light at the screen, at each slit in the screen the light would defract, meaning it will spread out. When the slits are close enough together, the defracted light can interfere with the defracted light from the other slit.

There are two types of interference, constructive interference and destructive interference. [Explains them…goes on to explain in detail the two-slit experiment.]

Another new idea that comes from the view of light and energy as quanta is the uncertainty principle. The uncertainty principle states that there will always be some inaccuracy in our measurements in this area. This is due to the fact that in order to observe something, we have to disturb it. And when we see an object, we're not actually seeing the object itself, we're seeing the light that's bounced off of it and hitting our eyes. When the light bounces off the object, it disturbs it in a very small way, and this is too small to notice on the macroscopic scale, but on the quantum scale it has a profound effect. [Gives example with electron.]

So thus we can know position, momentum, but we can never know them with complete accuracy. And along with these approximate measurements, if you want to describe quantum systems—which are basically situations containing more than one object on the quantum scale, such as an atom with several particles—you have to have the mathematics of probability to do so. And the effects that this has on the world are probably best illustrated in Schrodinger's Cat Experiment. [Explains experiment with graphics.]

With these experiments, I've shown that what we see in the world, and what our intuition tells us should be true, isn't always correct. Much of quantum mechanics defies intuition, but much of other theories of physics doesn't defy intuition, it agrees with it.

So why is our intuition accurate sometimes but not others? It's all because our intuition comes from what we experience, and since we never experience the world on the quantum level, we have no basis for judging what should happen due to the laws of quantum mechanics. In other areas—such as the example of objects appearing to always come to a rest—we have to examine them closer to find out what's really going on.

In short, what we perceive in the real world, we can't really rely on, because our perception most of the time is inaccurate, and we have to investigate further to find out what's really going on. I think it's important to explore physics and keep on learning why the world works as it does, because through that we can gain a better understanding of the world and how it was designed.

I'd like to say thanks to a few people who have helped me with this project…

Questions:

My favorite area? I would have to say particle physics. I like learning about how the world interacts on the tiniest, tiniest scales.

I'm planning on going to college and majoring in physics—what area I'll pursue as a career I'm not quite sure yet.

How did I get interested in physics? It probably came from the fact that I was interested in science fiction for such a long time. Much of the science fiction that I read contained information on physics and other sciences, and I wanted to learn more about it.

How did I do my research for this project? Lots of reading—I read quite a few books, online articles, and some research journals.