5-31-05

Dear Oisin,

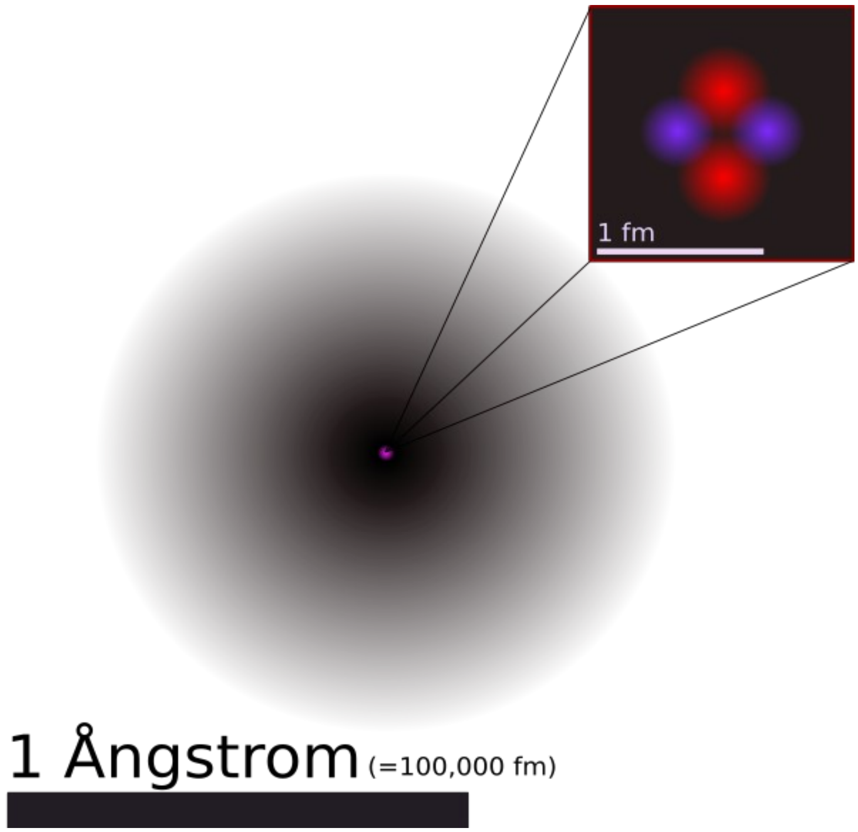
It's evening now, the third day of my stay in Bonn. Already it feels like the days will go by quickly. Tomorrow I'll move into my office at the Max-Planck-Institute for Mathematics.

Max-Planck Institute, above the post office

I guess I promised to tell you about Mr. Max Planck. Remember how Mr. Newton was concerned with the motion of the moon, the planets, and so on? These are all very big things. Gravity, you see, is only noticeable when very big things are involved. It's hard to believe, but there is a force of gravity between any two objects in the universe, for example, between you and me, and between you and Niall. However, that force can't really be felt because we simply aren't big enough. (But it can be measured even for small objects using precise instruments in a laboratory.) But the earth, for example, is very big, so the gravitational force coming from it is quite significant, even for ordinary objects. So if you try to jump up, the gravitational force between you and the earth will pull you back down. Similarly, the moon goes around the earth because gravity holds in it its orbit each time it tries to fly off. The large-scale motion of pretty much anything in the universe can be accounted for using Newton's law of gravity. The mathematics of Newton's law can be used, for example, to figure out when Halley's comet will come near the earth again, or exactly in which direction we should throw a space probe so that it will reach Mars. It even tells us about very, very big objects, like the galaxies made up of billions of stars, and how they come to look as they do, with all those pretty spirals, or bars, or oval disks. It's also wonderful that Newton's law, which tells us all that, can be written down in one line. Maybe I'll do that for you, even if you can't understand it right now:

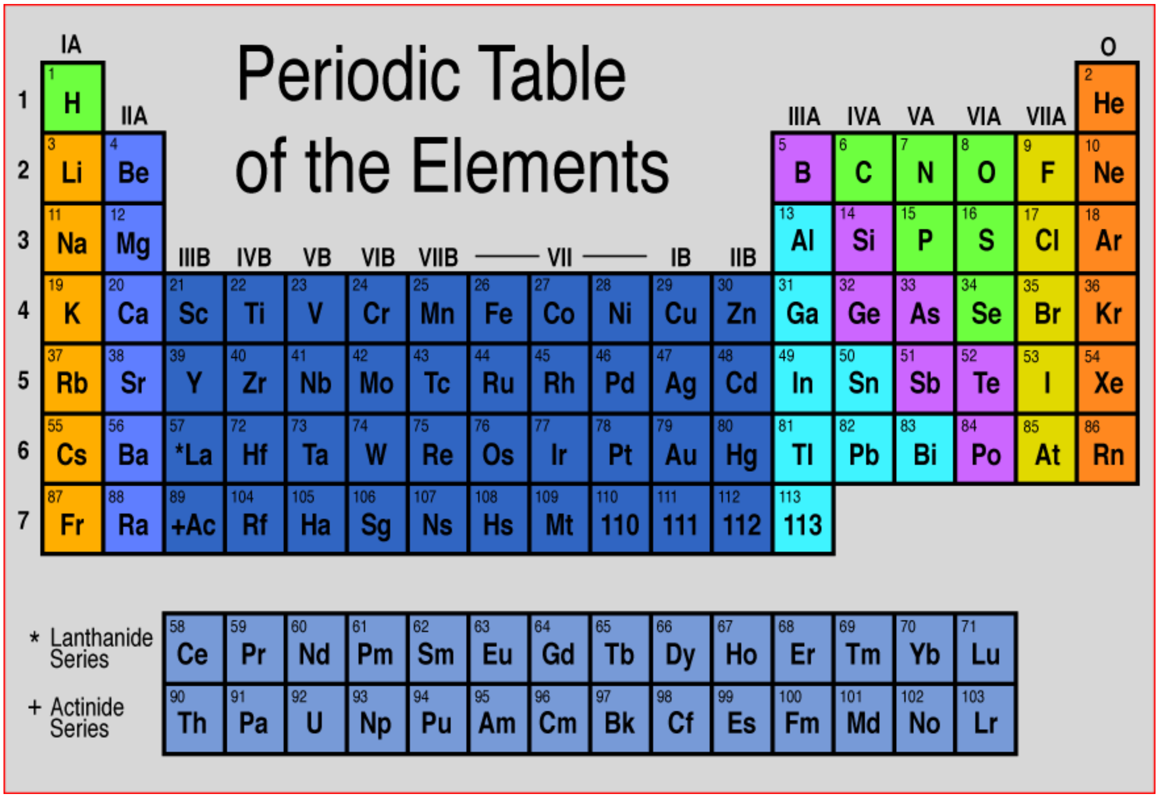
$$d^2x/dt^2=\Sigma_i \; GM_i/r_i^2$$

That's all! Just those few symbols contain the basic principle for figuring out so many marvelous things. Isn't it almost like magic? Mr. Newton certainly should have run around naked when he figured that out, except he was probably too much of a proper English gentleman to do so. In modern times, it's mathematical equations like this that people try to find that will explain all kinds of complex phenomena in the universe. Now what about Mr. Planck? In some sense, his investigation went in a direction opposite to that taken by Newton. He figured out the laws governing the motion of very, very small objects, like electrons, neutrons, protons, photons, etc. Well, he did with many other people, but the key idea in modern times came first from Mr. Planck. As you know, electrons, neutrons, and protons make up an atom. The idea and the name of an atom goes back to ancient Greece, where we seem to end up whenever we start discussing some interesting things. You see, many Greeks philosophers beginning at least with Thales were very concerned with finding out the essence of things. That is to say, they wanted very much to know what everything was made out of. You might ask, why should they be made of anything other than what they are? Why shouldn't a cat just be a cat, a tree a tree, and a rock be a rock? What is all this business of being made out of something else? When you think about it, it really is a curious question, to ask what something is made of. But it was exactly this question that was important and natural. You see, on the one hand, it was easy to observe that even everyday objects could be broken down into something that seemed more fundamental. Sometimes, it was because people themselves had made it out of simpler things, the way a toga might be sewn together from fabric which, in turn, was woven out of many tiny threads. But then, when you took apart a leaf, it turned out also to be composed of thread-like fibers in addition to moisture and pulp. If some people bothered to look at it more closely, they might also see the pulp resolving into many small cell-like segments. A rock which seems solid at first sight can be broken with a hammer into small fragments, that can then be pounded into powder, seemingly as fine as we would like. On the other hand, one could take tiny particles of sand and dirt, mix them with lime, and mold them into bricks that can be used to build a house. And so it went with many other things. They had a tendency to be made of smaller things, which in turn could be resolved repeatedly into more basic components. Eventually, theories came about according to which everything in the world could be broken down into earth, water, air, and fire which were called the four elements. Why those four? I really don't know, except they do seem somehow more important than everyday objects. (I also read somewhere the idea that these elements just correspond to our notions of solids, fluids, gas, and light.) And then some argued that the other three elements could all be made out of fire. Still others said that it was water that was the most fundamental. As the different ideas were thrown about over a long period of time (much of this was even before the time of Socrates and Pericles) I think it was Democritus who eventually came up with the idea that there should in fact be something else altogether even more fundamental than the four elements, out of which everything was built up, like all the different structures that can be made of simple lego blocks. That is, he proposed the idea of the atom. It was supposed to be too small even to be seen. I really don't know where Democritus could have gotten such a curious idea. We would have to ask the historians of science what they think. In any case, the theories from those times are very hard to get at because so few written accounts survive. I believe many descriptions of these theories were passed down through the writings of Aristotle, who lived a good deal after Democritus. Well, anyways, there was that idea, and it survived through many centuries and was made very useful in the twentieth century, about 2500 years after Democritus had proposed it. The point is that Democritus and his colleagues had many good ideas, but they couldn't put their ideas into useful form because they didn't think to combine them with mathematics.



Helium Atom

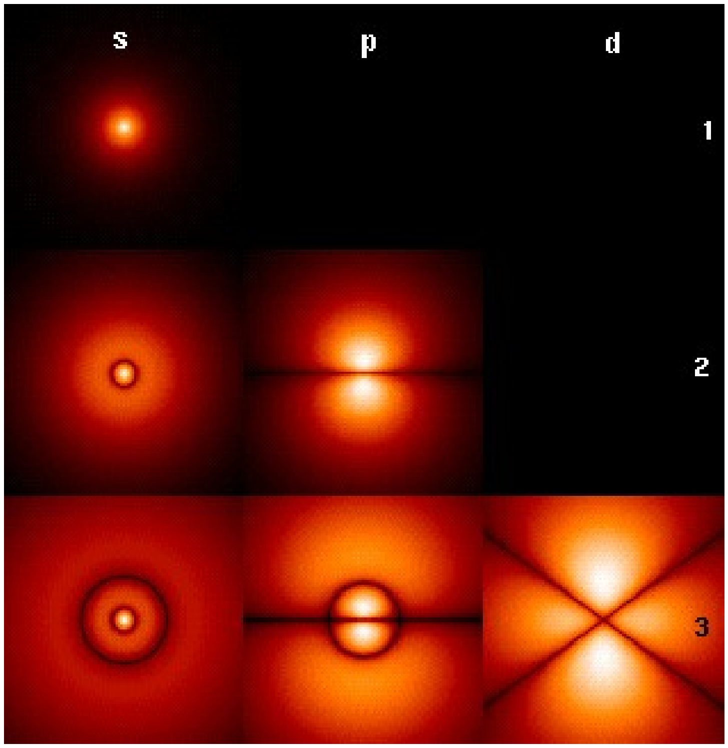
It's kind of strange when we think back on it. After all, not far from Democritus, and living not so long before him on the island of Samos, was Mr. Pythagoras, who thought that numbers were the most fundamental objects in the world, and that everything could be built up from them in some mysterious sense. So you just needed to put the ideas of Democritus and Pythagoras together to come up with a thoroughly modern theory of the atom. Of course this is a bit of an exaggeration. Ideas need to develop over many centuries and combine in intricate ways with other ideas before they mature into useful theories. For example, Archimedes and his great ideas came a few hundred years after Democritus, and it was probably around then that many people started to take the practical applications of mathematics seriously. However, if you study them carefully and then observe them from an objective distance, it's quite remarkable how much modern scientific theories of the atom resemble simply a combination of Democritus and Pythagoras. Well anyways, it was Mr. Planck who began the long process that led to a modern mathematical theory of the atom and, as it turns out, the smaller things that even an atom is made out of. These days, we speak about many different kinds of atoms, depending on how many protons are inside them.



To be precise, what Mr. Planck figured out was a mathematical theory of something called `black-body radiation'. That is, he was able to correctly determine the formula that tells you exactly how much light of each color comes out of something very black like a piece of coal trapped inside a dark hole if you bombard it with a lot of light rays and then let it sit for a while. The mathematics he used indicated that light came off of the piece of coal in small packets of definite color, instead of a continuous stream. That, in fact, was the key idea. Normally, if you turn on a flashlight in a dark room, the light will seem to stream out of the bulb, almost like flowing water. But it actually comes out in small packets that are call `photons' and there are only so many distinct colors possible for the photons. Mr. Einstein also had some version of this idea earlier, but Mr. Planck's work made it much more definite. Sometime later, the basic equation that governs the motion of atoms was found by someone named Erwin Schroedinger. That equation looks something like this:

$$d\Psi/dt=(\Delta+C/r)\Psi$$

The theory that these people, Mr. Planck, Mr. Einstein, Mr. Schroedinger, and some others like Mr. Heisenberg, Mr. Bohr,... came up with together is called quantum mechanics. And it's that Mr. Planck that the institute here is named after. All of our understanding of the motion of small objects as well as exactly how these small things come together to form the big things that we can touch and see, that is to say, the rules for which lego blocks can fit with which others and in what ways, is based upon quantum mechanics. One of the biggest puzzles in science these days is exactly how the theory of big things can be combined with the theory of small things. That is, people would like to understand precisely how gravity can be combined with quantum mechanics and come up with a theory of `quantum gravity'. No one knows how to do this. It's almost as if we now are in the situation that Democritus used to be in, working without the right sort of mathematics that will make the ideas fall into their proper places. That's why many people are thinking and thinking all their lives and every hour of the day about this problem. You can try as well sometime. But of course, you need to study so much before you can really begin.



Electron in hydrogen atom

There's something funny about the theory of small things. Some people think that it comes of thinking too hard about taking things apart. That is, these people take seriously the objections I wrote at the beginning. They might say, for example, that understanding exactly how Mr. Blake's brain is made out of atoms won't tell us how he writes such beautiful poetry. Understanding the precise composition of a cat won't tell us why it is so cute. This is probably all correct, although the sense in which it is correct needs to be thought through carefully. However, we should notice that there is also a strange way in which the theory of atoms in fact brings things together rather than takes them apart. I think Democritus, for example, was well aware of this. You see, if we say that there is something very fundamental out of which everything is made, then we can also say that everything is basically the same. After all, I'm essentially the same as a flower or a rock or a star, since it just happens that we're put together in somewhat different ways out of the same building blocks. Maybe even the division into distinct objects is itself artificial, since my skin connects to the air that connects to the rock and then the flower that receives energy from a star. Parmenides, for example, was a philosopher who was a bit older than Socrates. He lived in the city of Elea and the school of philosophy he founded is called Eleaticism. He is famous for saying `All is one.' He thought our perception of all these different things was nothing but an illusion. They may not have thought so themselves, but one might say that the idea of Democritus is not far from that of Parmenides.

Parmenides, by Raphael

If you look hard enough from this perspective, you just see a swirling turmoil of small particles in an enormous cloud of energetic motion that clumps together here and there into transitory forms that we think of as `objects' that are around for a short while before dissolving back into the mass of motion, and so on. Even very concrete things sometimes give us pause to think this way, such as how all kinds of food grow out of the soil and how gold is made only in the explosion of a star that shoots out huge clouds of dust particles which come back together into more stars and planets, and then on some of those planets, living things grow and die and reproduce and evolve until eventually some of them start gazing longingly back at the stars, philosophizing and wondering what they are made of and how.

Orion Nebula

Of course, if you think too hard about all this, you might just fall asleep, dissolve into the sunlight, and never wake up! So thank goodness we usually forget about all the atoms and the stardust and the universe, and enjoy eating our pirate booty and reading books at night.

Here is just the beginning of another poem by Mr. Blake:

To see a world in a grain of sand
And heaven in a wild flower,
Hold infinity in the palm of your hand
And eternity in an hour.

Good night Mr. O
Mr. D.

Hand with reflecting globe, by M.C. Escher