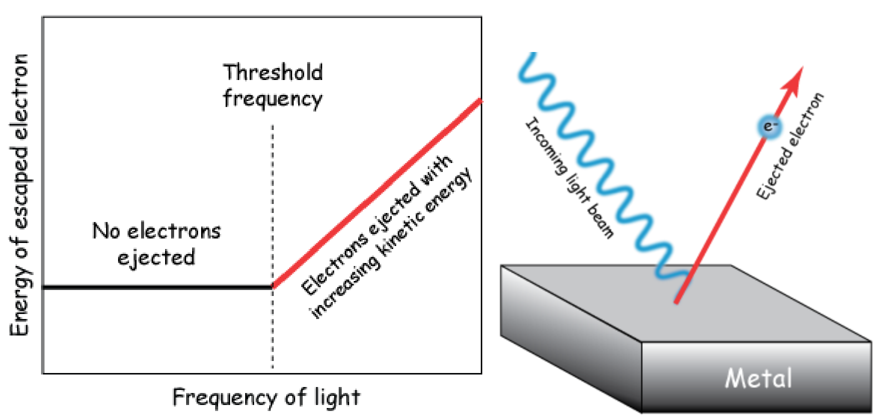
THE PHOTOELECTRIC EFFECT

One last experiment will shed some more light on the behavior of electrons. The photoelectric effect is illustrated on the right. When certain kinds of metals are irradiated with light, electrons, which we presume to be bound to the atoms of the metal, are ejected from the surface and can be collected, run through a wire and measured as an electric current.

When researchers were able to vary the energy of the incoming light beam, they got a surprising result. When the frequency (proportional to the energy of the light) was low enough, nothing happened to the metal. However, once a certain **threshold** was reached, electrons previously bound to the metal atoms were ejected. They became **free electrons**.



Moreover, after the threshold was reached, the ejected electrons left the metal with higher kinetic energies (speeds) in proportion to the increase in frequency. The graph on the left illustrates this.

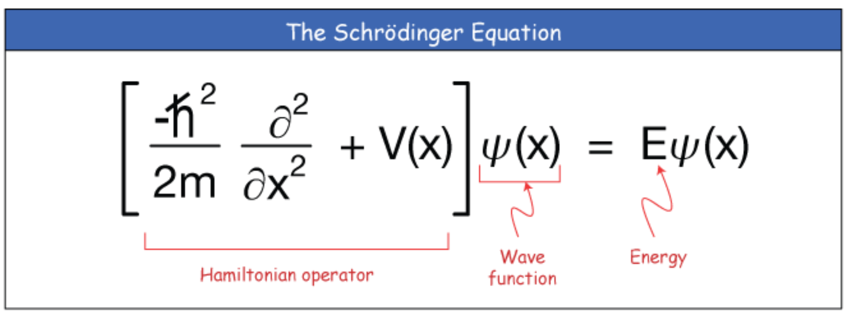
The conclusion of the photoelectric effect experiments was that there was some threshold energy that had to be met before an electron could be pried away from its atom. After that, it behaved as a "free" electron, able to take on any value of kinetic energy at all — like a baseball.

Electrons bound to atoms do not act like free electrons. Free electrons act more like classical particles than bound electrons.

What do these experiments *mean*?

After the turn of the 20th century, all of these experiments were leading a few scientists toward a model of the simplest atom, hydrogen. I won't go through all of the early attempts here. They are covered elsewhere. Suffice to say that they all had at least one flaw, and any useful theory has to predict all properties accurately. Early attempts came close to reproducing the observed energy levels, but didn't get them exactly, and some failed to predict other properties of hydrogen that had been measured.

In about 1926, Erwin Schrödinger, an Austrian physicist known for his work on wave equations, took a look at the models and noted that they looked a lot like his wave equations. He published a series of papers that showed how a wave equation could fit the data perfectly, and correctly predict many other phenomena that had been puzzling researchers. Schrödinger's equation is beyond the scope of the mathematical background you likely have. It is a **differential equation** that requires **calculus** and a few other tricks to solve. Here it is (don't panic!):



Schrödinger's equation is not likely the kind of equation you've seen before. The Hamiltonian operator above [the thing in brackets] "operates" (does some mathematical things) to a "wave function" that represents the electron in the H-atom, and returns to us the energy levels multiplied by the same wave function. Resist the temptation just to cancel $\psi(x)$ from both sides — it's not that kind of equation (ψ is the Greek letter "psi").

What's important about this equation is that it is solved not by numbers, but by functions (the $\psi(x)$). In particular, this equation is solved by a set of 3-dimensional functions called spherical harmonics, which represent, in some sense, the "location" of the electron in the H-atom. Location is in quotes because the electron behaves like a wave when bound to the atom, so its location is ill-defined. (The more advanced reader will note that I've written the *1-dimensional* Schrödinger equation above, but you get the idea).

Here is the equation for the spherical harmonics. Again, don't panic. There's a lot here to understand, and we only have the mathematical background to scratch the surface.

The Sperical Harmonics

$$Y_{\ell}^{m}(\theta, \phi) = N\, e^{im\phi}\, P_{\ell}^{m}(\cos\theta)$$

ℓ and m are indices. $\ell = 0, 1, 2, \ldots$
and $m = -\ell, -\ell+1, \ldots \ell-2, \ell-1, \ell$

The important thing to note about the spherical harmonics is that

(1) They contain a trigonometric function (cosine, in this case), but in three dimensions. That gives them the shapes you will see below.

(2) They are indexed by the **indices L** and **m**. (Note: I am using a capital L in this text, but we generally write a lower-case script L ... it just looks like a one in this font.) In the mathematical world of the spherical harmonics, these are just counting or index variables that make sure we write the functions correctly and in the right order. But in the subatomic world, they become two of our four **quantum numbers** of any electron.

The quantum numbers describe all of the relevant characteristics of any electron, and they arise from the fact that the energies of electrons are not continuous, but quantized, as we learned from our key experiments. Schrödinger's equation accurately predicts all of the properties of the Hydrogen atom.

Source: http://www.drcruzan.com/Chemistry_Electrons.html