A wave of what?

The good qualitative and quantitative agreement obtained by the Bohr picture of the hydrogen atom is of a basically different kind to any of the Newtonian predictions, for example the gas law precition. There, we started with a basic confidence in that we understood everything we were describing - everything that was included in our calculation. For the Bohr atom this is not at all the case. We know that we have no idea about what the so-called wave is. We have just said we believe that in some way particles act like waves. Also, we have still used, basically, the $\vec{F} = M\vec{a}$ formulation of nature (since energy came from this formula) even though we cannot be sure that it should still be applicable (to waves).

Perhaps we should take courage at the success we can achieve from a basically shaky picture; perhaps on the other hand we should expect further troubles from having failed to break away sufficiently from our old thoughts. What we must do in any event is attempt to get some idea of what the nature of this wave is, and see what other consequences it should bring. To get an idea of the nature of this wave, we must surely go back and think more carefully about the electron scattering experiment.

Single Slit Diffraction

What was it that we actually saw in our comparison of light and electron scattering? For the *light* scattering experiment we saw a pattern of the brightness or intensity of light on a screen. The detail of the brightness pattern depends on the wavelength of the light relative to the slit dimensions and spacings. (This could readily be confirmed by a proper calculation, but we need not do that.) In the *electron* scattering experiment we also saw a pattern of brightness on the screen. In this case the brightness was caused by electrons striking the screen and making it flash. We also decided that we were recording definite positions for the strikes, and at specific times (it was really being caused by particles striking in the sense that we usually understand that, *not* as waves).

Now we can mentally redo that basic experiment in a less complicated arrangement, and see more clearly what is going on. If we shine a light wave on a *single slit*, whose width is somewhat wider than a wavelength of light we will see on the screen the so-called *diffraction* pattern

There would be a central maximum of intensity, with a width which is determined by the ratio of the light wavelength to the slit width (as our calculation would show, if we did it). Also, if we were able to repeat this experiment with *electrons*, we would find a similar result; we would get a pattern of strikes

whose distribution would look like the intensity pattern for the light. The height of the curve at any point would tell you the fraction of the total number of electrons that passed through the slit that you would find *at that* point.

Now; what would happen if we were to repeat the electron experiment *one electron at a time*? We would get a single strike - somewhere. *We don't know exactly where*. All we know is that if we continue doing it one at a time the same pattern as before will build up. What does this mean? It means that for a single electron passage our curve represents the *probability* of that electron striking a particular position on the screen. That probability, analagous to the intensity for light, is determined by the *wavelength* of the particle in exactly the same way the light pattern is determined by the *wavelength* of the light. The wavelength of particles controls the probability of finding the particle in a particular place. *It* is a *probability wave*!

Problems with waves

The Uncertainty principle

It is difficult to fully comprehend what a particle - wave really must be. In fact it is not really clear that anyone yet has a proper understanding of all the consequences of what we have just uncovered. Certainly many people have given the subject much thought and many heated arguments - even up to the present day!

Perhaps some of the basically difficult and, to some, almost unacceptable aspects of the problematical nature of particles can be pointed out by the following. The single electron single slit scattering experiment is saying that it is not possible to say with absolute certainty where the electron is - or where it will strike the screen after it has passed through the slit. There is a basic, unavoidable uncertainty associated with the whereabouts of the electron. That statement, of course, is really just a restatement of the meaning of the electron wave. It is not possible to know, to more than a probability, where the moving electron is.

The uncertainty is related to how accurately the electron's position was known when passing through the slit - i.e. the slit width. Furthermore it is a well-known, fairly easily calculated and simply demonstrated fact that for a wave when the slit size is comparable to the wavelength, the narrower the slit is, the greater the width of the diffraction (scattering) pattern is.

This statement, the narrower the slit, the wider the diffraction pattern must also be true for particles (probability waves). The mathematical formulation of that fact is

$$\Delta p \; \Delta x = \frac{h}{2\pi}$$

that the product of the uncertainties of position and momentum in a given direction can be no less than Planck's constant divided by about six. It can be more if we make errors in our measurement, but according to our belief that particles act like waves it can never be less. This relation, first formulated by Heissenberg, is called the Heissenberg uncertainty principle. It in effect says that we can never know with perfect accuracy where an object is going and where it has been. This isn't important for large objects that we are used to dealing with, since the fractional uncertainty can become exceedingly small due to both large mass and dimension, but when we try to be accurate for small things like atoms, we are completely misled in thinking that we can make precise predictions of the path a particle will take. When this is true