Waves and Particles

Our problem appears to be getting even more confusing than before. What can it all mean?

Once again we will take advantage of hindsight to provide an additional part of the puzzle. The photoeffect has shown us that our idea of waves - at least electromagnetic waves - has misled us. What is the difference between waves and particles? When is something a wave and when is it a particle? These questions had been important earlier in deciding whether light was a wave or not. In fact the conclusive experiment to show that light is a wave had to do with interference and diffraction properties of waves compared with the straight-line motion of free particles.

A particle, by Newton's laws, in the absence of some force travels in a straight line. If a barrier is placed in its path it may be blocked completely, deflected somewhat, or completely unaffected.

A wave, on the other hand, acts completely differently. Here the unblocked part acts as a secondary source of the wave and the result is that the wave can "bend" around behind the object, or be diffracted.

Most importantly, however, if we were to allow _two_ (or more) holes in our barrier, for the particles what would happen is that there would simply be two streams of particles left after the block

and the distribution of particles after the block would just be the sum of two distributions for one hole each. However, for a _wave_ passing through the same blockage, there would be a _different_ effect. The two waves after the objects not only can add up, but _cancel_ each other, so that in certain places nothing is left. This is called interference.

The difference between the wave pattern and particle pattern is that _nowhere_ after the block will two particles cancel each other - they can _only_ add more particles, but two waves can cancel each other out. It was the observation of such interference by Young in), which clearly identified light as a wave, and not a particle.

We can perform this experiment with particles - say marbles or billiard balls as often as we want, and there will never be an interference pattern - places where particles could have appeared when only one hole in the barrier is there, but not if there are two holes. However let us repeat this experiment with the smallest particle we can think of - the electron. We can do the experiment with an old TV tube. This just consists of a piece of metal that can be heated to "evaporate" electrons, and an electric field to give them a high velocity. If we turned the intensity of our electron beam down low enough we could see individual flashes of light at various places on the screen, indicating the arrival of single electrons at a specific point on the screen at a specific time. Now if we want to repeat the above experiment we must put some barrier with small holes in it in front of the electrons' path. In fact we will use the smallest holes we can get, which are the spaces between the atoms of a crystal of some material - say aluminum. But if we look at the pattern that this produces, it is not the pattern of holes between adjacent atoms! It is exactly the same as the pattern we would get from an analogous pattern of holes if we used a wave! If someone hadn't told us that we were using particles, we would have concluded that we were seeing interference of waves. In fact we cannot conclude otherwise. We are observing interference effects on the screen, a clear indication of waves. And yet we know these electrons are particles, because we would see them striking the screen individually, at specific places, if we reduced the intensity of the beam sufficiently.

Curiouser and curiouser! Particles seem to act as waves, and waves act like particles! What are we to make of this?

Physics at the Crisis point

What has happened to our beautiful, consistent picture of nature? What is wrong? Why do we keep on coming up with either wrong predictions or inexplicable experimental results? Clearly we have reached some sort of crisis point, and we need to re-examine what we understood and what we thought we understood. Even though this "crisis point" was reached almost three quarters of a century ago, we can still see in it much of the most exciting and satisfying aspects of physics - that of a problem that has to be solved, and through which we hope to gain in understanding.

What is it that nature is trying to tell us through our various experiments and calculations? Let's lay out everything we have looked at so that the problems can be pinpointed as closely as possible.

Current Status of "Physics"

Initial Successes

a) prediction of GAS LAW

b) concept of Heat and kinetic energy

c) explanation of phases of matter — gas, liquid, solid

d) concept of E-M radiation and radiative heat transfer

In writing these down, we notice that they are all to do with "gross" descriptions of nature - that is they don't really describe properties on the most microscopic scale. Indeed it was only when we went on to attempt more microscopic descriptions that we began to find inconsistencies and incorrect predictions.

Microscopic Failures

1) blackbody radiation — wrong prediction at high frequency end (radiation from atoms)

2) model of atom — should radiate continuously but doesn't (motion of electrons)

3) Photoeffect
   a) radiation not accepted by material below cut off frequency
   b) radiation arrives in discreet fashion

4) Electron scattering — electron acts like a <u>wave</u> when passed through a very narrow collimator (atomic spacing)

Now that we see all the information we have collected we must decide what <u>both</u> the successes <u>and</u> failures indicate. From the existence of quite a few correct predictions (many more than we have looked at) it is reasonable to conclude that our approach has not been completely wrong, but most probably some aspect of it requires some modification. This may seem like a silly question to have asked ourselves, but it <u>was</u> seriously asked, and in fact must always remain at the back of our minds.

Having decided that only a modification to our thinking is required, we have to decide <u>what</u> to modify, and <u>how</u>. From looking at the second table of facts, two candidates immediately appear; radiation or motion. If we think about it, however, we will recognize that there is really only one; radiation <u>is caused</u> by the motion of charged particles, so that motion alone could be causing the problems we have run into. The problem of properly describing motion lies in the microscopic, or atomic, size scale, as we were successful in our large scale descriptions. Now for the question of how to modify our picture. What is there about the microscopic picture of motion that we have been missing so far? The answer to that must be found in our experiments, somehow. In fact, having narrowed our questioning so closely, we can quickly see which experiment must be telling us precisely what is wrong. As the problem, we have decided, is concerned with motion on a very small size scale, then the electron scattering experiment has to contain our desired information. Indeed it is a flat statement of fact. On a very small size scale electrons act like a wave. Whatever this means, it is an observational fact, and we must incorporate this fact into any microscopic description of nature. Unless we can think of a reason why not to (which we can't!), we will also have to allow for this possibility for any particle which is moving under similar circumstances.

Even though we don't know at this point what it really means when we say that a particle acts like a wave, or how it could happen, we at least know that we must try to incorporate both particle and wave aspects into our description of microscopic behaviour. What this really means is that in some way a picture must be made that can be consistent with the idea of the existence of particles and, simultaneously, be consistent with the existence of waves. We will try to do this in the simplest possible way to start with; completeness can come later if success is obtained in wedding these two seemingly mutually exclusive aspects of nature together.

The most reasonable problem to start this new approach on is the model of the atom; it is common to all other problems. In dealing with the atom, we must be careful to choose a picture whose "language" is common to both particles and waves. In fact the "word" common to both particles and waves is Energy. It is perfectly reasonable to think of a particle as containing or carrying energy, and it is equally possible to think of a wave in the same way. Therefore the model of the atom that we choose should be an energy picture.