Scattering, Light, Particles, Waves, and Structure
What do they have in common?
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1 Scattering

Baseballs scatter from bats. Billiard balls scatter. Sonar scatters from boats. Radar scatters from planes. In ultrasound, sound scatters from organs in your body. Light scatters from clouds to make sunsets and water droplets to make rainbows. And scattering has been responsible for understanding the structure of atoms, molecules, nuclei, and nucleons, even finding the "quark" substructure of neutrons and protons.

Scattering is a theme which runs through much of physics. And not just straight-line "particle" scattering. When the thing being scattered is close in "wavelength" to the thing being scattered from, we have to think of the thing being scattered as a wave. Even you can be considered a wave... but your "wavelength" is so small that for practical purposes you are always considered a "particle" or "projectile" (as you have already noticed).

2 Light, waves, and scattering

But in some cases wave motion is important. Today we are going to observe light scattering from "apertures"... diffraction gratings, a hair of a colleague, and finally an "unknown". Light can be treated as either a straight line "particle" or as a wave. In cases where it is considered as a "wave", when it scatters, it does not scatter uniformly, but "bunches" up in some places, but nearly disappears in others. If you have already studied waves, you will understand this bunching and disappearing as "constructive" and "destructive" interference of the waves from different parts of the "aperture". If you have not studied waves, it will seem very odd to you, but we will see that it really happens, and then when (or if?) you study waves later you will (I hope!) remember that you really saw it happen.

The formula which describes light scattering will be somewhat different for different kinds of apertures but is always something like:

$$sin(\theta) \approx n * \lambda/d$$

where: λ is the "wavelength" of the light; and d is the size of the object (or "aperture") being scattered from. For some apertures theta is the angle of bending from straight ahead at which we see maxima, or the light "bunched up"; for others theta is the angle of bending at which we see minima, or the light nearly disappearing. But in all cases the light scattering pattern (or "diffraction pattern") spreads out more for smaller size apertures, and spreads out more for larger light wavelengths. n is some integer (the bunching happens at more than one place: n can be 0,1,2,...);

3 $sin(\theta) \approx n * \lambda/d$ How to measure?

We will use some lasers, with wavelength about 620 nm, some apertures, and a meter stick to observe the wave scattering of light. We will put the aperture close to the laser, and measure some feature if the light scattering (or "diffraction") pattern on a screen. We will measure either the "maxima" (places where the light is bunched up) or "minima" (places where there is almost no light). Put the screen some convenient distance, about a meter, away from the aperture, in order to give the bunched pattern space to spread out, so that we can measure it. From the distance to the screen (L), and the position of the maxima (max) [or in some cases the minima (min)], we can measure $tan(\theta) = max/L$. If the angle is less than 20 ^{o}, $tan(\theta) \approx sin(\theta)$.

"Apertures" to test:

1. A "diffraction grating". This is a small sheet of clear material (plastic in our case, glass or quartz for those used in research), with many small lines or grooves made in the plastic, at very small spacings. Check the nominal spacing of the grating lines (from information written on the grating) and use the grating spacing to find the wavelength of your laser. Shine the laser pointer on the diffraction grating, and use $sin(\theta) = max/L$.

2. Next substitute a hair from one of your partners and find out how thick it is, by using the same idea. Attach the hair to a piece of paper or

cardboard to hold it in place, and shine the laser on it. [For the hair, the formula is slightly different: use $tan(theta) = min/L$, where min is the distance between the straight ahead and "minima" or dark spots in the light scattering pattern.] Are the hairs of your different colleagues the same?

3. For the two apertures above, look to see how the light scattering pattern changes as the aperture is rotated (still keeping it in the plane perpendicular to the laser ray).

4. Finally, try the "rose colored glasses" which come with your kit. What pattern do you see? From the pattern can you guess something about the structure of the rose colored glasses?

Look at a plain light through the glasses. Since different wavelengths (λ) are associated with different colors and bend differently (have different θ), can you say anything about why it is that you see a spectrum of light when you look through the glasses?

4   How does this relate to elementary particles and my research?

This same idea of wave scattering can be used for elementary particles, and one of the ideas in my field of research is to find what the smallest pieces of matter are and what their structure is. You may have heard of "quarks"... which come in different "flavors"... up, down, strange, charmed, top (or truth) and bottom (or beauty). These were all found in some variation of scattering.