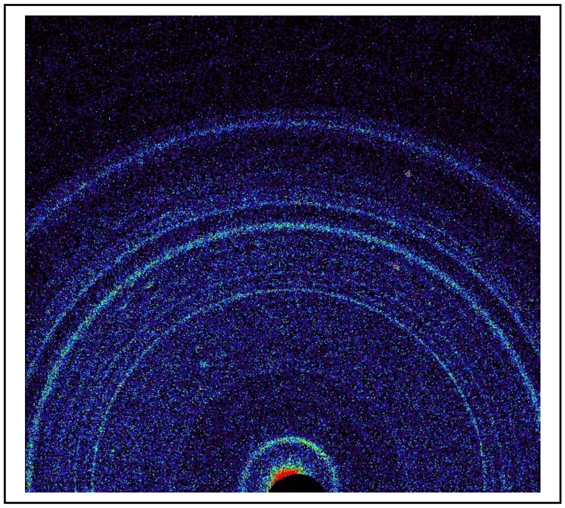
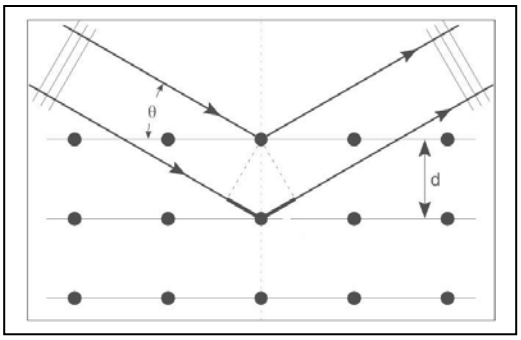


The Curiosity Rover recently used a technique called X-ray Diffraction Crystallography to determine the identity of compounds found in a rock sample on the surface of Mars. The image to the left shows what this data looks like. The exact radii of these rings, and the locations of spots along these rings, serve as a fingerprint of the shape of the mineral compound in space. We all know how human fingerprints work, and even 'DNA' fingerprinting is commonly mentioned in TV programs like NCIS or CSI. But how does this technique work?



The figure to the left shows a beam of light striking the surface of a crystal with 15 atoms arranged into three parallel planes. The light strikes the atoms and is 'diffracted' into a new direction defined by the angle θ.

If two beams of light are out-of-phase by 90 degrees, when they are added together, the crests of one wave interfere with the troughs of the other wave and you end up with no light. If they are in-phase, they will add together, you get the light intensified and you also get a ring of light!

The diagram shows the added distance that the lower ray gains by being diffracted through the angle θ.

Problem 1 – From the information in the diagram, what is the extra distance, s, traveled by the x-ray light in a crystal lattice where the planes are separated by a distance d?

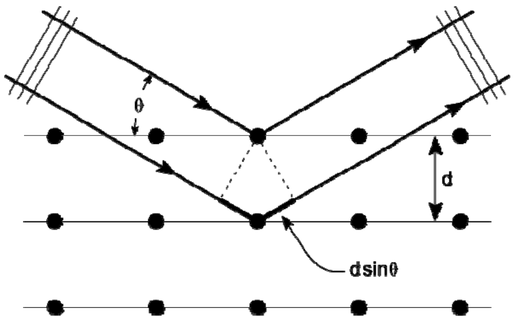
Problem 2 - If the light struck the crystal exactly face-on ($\theta=90^{o}$) how much extra distance would the second beam travel compared to the first beam that was reflected only from the top surface?

Problem 3 – If the wavelength of the x-ray light is L, what is the relationship between L and s so that the wave crests exactly match up?

Problem 4 – Suppose that in the Curiosity data, a diffraction ring is detected at an angle of incidence $\theta=2^{o}$. The Curiosity instrument uses X-rays with an energy of 6.929 keV, which have a wavelength of 1.79×10^{-10} meters. What is the separation, d, of the crystal planes in the mineral sample?

Problem 1 – From the information in the diagram, what is the extra distance, L, traveled by the x-ray light in a crystal lattice where the planes are separated by a distance d?

Answer: From the diagram below, **s = 2d sin θ**



Problem 2 - If the light struck the crystal exactly face-on ($\theta=90^{o}$) how much extra distance would the second beam travel compared to the first beam that was reflected from the top surface?

Answer: **s = 2d**

Problem 3 – If the wavelength of the x-ray light is L, what is the relationship between L and s so that the wave crests exactly match up?

Answer: The wavelength is L and for the waves to exactly match up, the two waves can either be shifted by s=0, or by **one full wavelength** s = L. So the first non-zero condition is that L = 2 d sinθ and so

$$\mathbf{d = \frac{L}{2\sin\theta}}$$

Problem 4 – Suppose that in the Curiosity data, a diffraction ring is detected at an angle of incidence $\theta=2^{o}$. The Curiosity instrument uses x-rays with an energy of 6.929 keV, which have a wavelength of 1.79×10^{-10} meters. What is the separation, d, of the crystal planes in the mineral sample?

Answer: d = 1.79×10^{-10} meters/($2\sin 2^{o}$) so d = **2.56×10^{-9} meters**.