The colours of white

How do you like the rainbow colours you can see on a CD when sunlight reflects on it? Kind of pretty, don't you think?

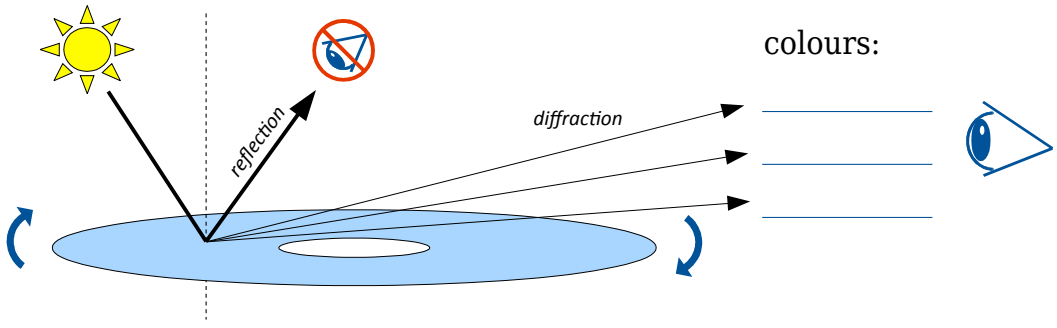
Sure, they are nice. But there is more to it: the physical effect behind it is also extremely useful. It is an excellent way to separate different wavelengths. And the light in each wavelength can tell us its own story: about the light source, where it comes from, and the material it has passed through on its way. Hence, if light was a book, then looking at the spectrum (the different wavelengths) is like reading its pages.

You already know this physical effect from the double slit experiment. As you probably remember, the directions of the maxima depend on the wavelength of the light. Different wavelengths will therefore produce maxima in different directions. However, two important details differentiate the diffraction on a CD from the double slit: 1) Instead of two slits, one can use many slits with the exact same distance between them. This obviously allows for more light to pass through the lattice. 2) It is not mandatory that the light passes *through* the lattice, the effect is the same in reflection: instead of the transparent areas, you have reflective surfaces, while the rest either absorbs or scatters the light.

A CD is mainly a flat mirror with very small dents. At these dents, less light is reflected than on the blank areas – which encode the information. These dents are located on a long spiral, with a regular spacing of exactly 1.6 µm between the lines. Due to the strict regularity of scattering lines on a reflective ground, a CD acts as a nice diffraction grating and produces the colours you see.

1 Take a CD so that you can see a lamp in the reflection. Then slowly **tilt the CD** towards you. Approximately when the reflection of the lamp disappears at the upper end (pointing away from you), you should see the first diffraction order as a stretched light stripe in rainbow colours. As you tilt the CD, which colour appears first and which colour is last?

2 Which wavelength is deflected under a larger angle: the shorter one (blue) or the longer one (red)?



3 With this simple technique of tilting a CD, you can now analyse the spectra of different light sources. If you look very carefully, what difference do you note between sunlight and the light of a neon tube or energy-saving lamp?

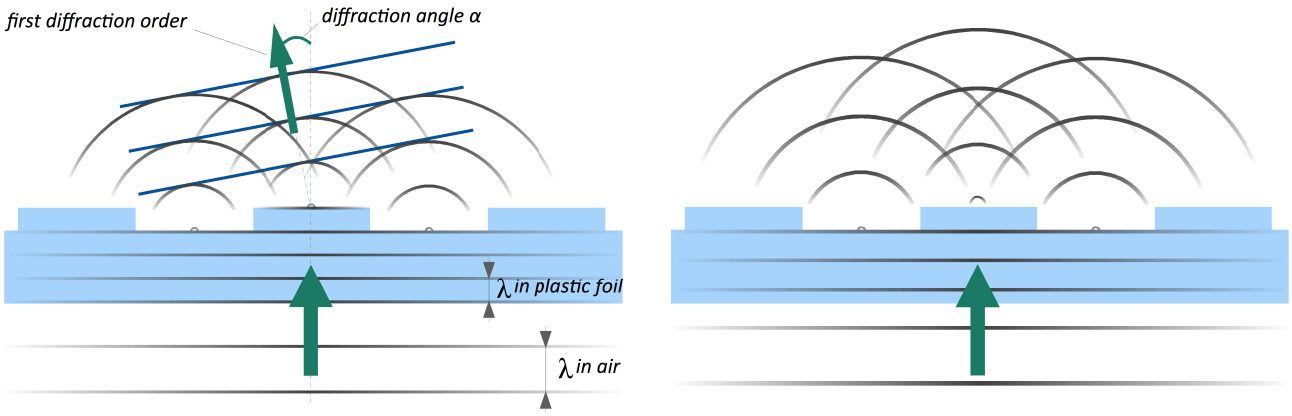
4 You have probably noticed that the spectrum of a neon tube or an energy saving light bulb is not continuous, but consists of just a few wavelengths. Which **separate colours** have you seen? Write each one on a separate line and leave a bit of space to the right.

In the following experiment we will measure the wavelengths that correspond to the colours you listed above. A CD is very useful to for *seeing* the spectrum, but it is not the most convenient means of *measuring* it. Thus, you will now build **your own spectrometer.** Instead of a CD, we will use a transparent foil with many parallel grooves at an exact distance of 1 µm. Please pick up this foil very carefully, only touching it at its edges and look through it around you. Can you see colour fringes?

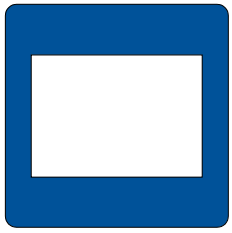
5 How does the diffraction work with this foil? Actually, the physical effect is again the same as in the double slit experiment. The most important difference is that the foil lets more light through. The diffraction orders are therefore brighter and easier to see.

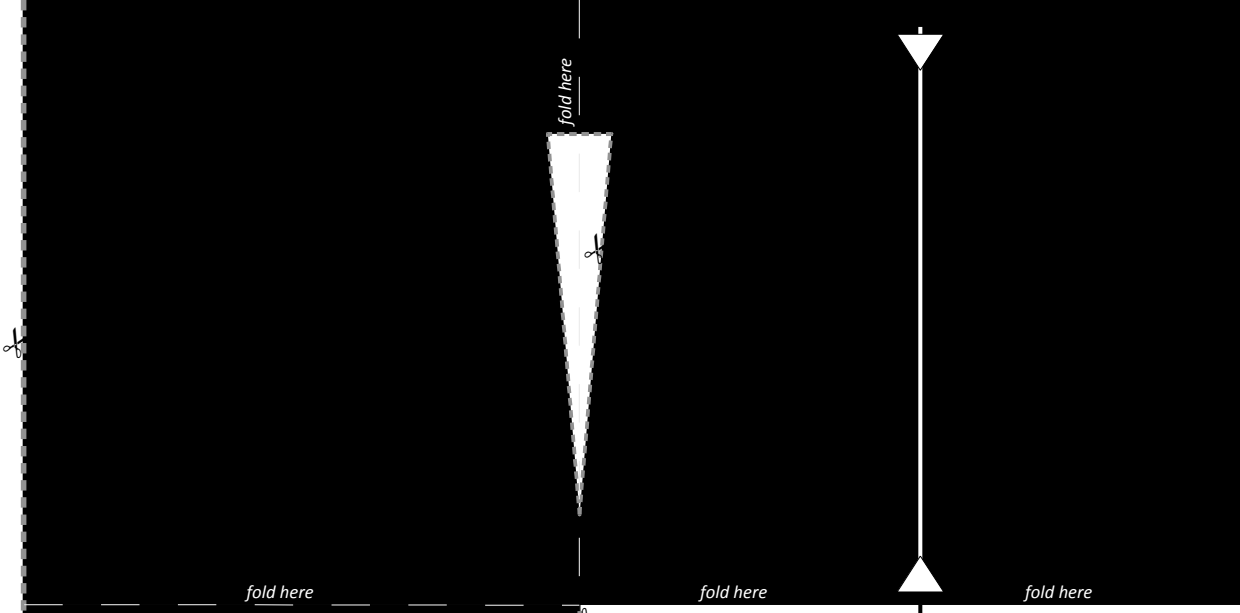
In the double slit experiment most of the light is blocked by the mask. A first step to improve this is to use more slits. These must be exactly equally spaced. But even so, all the light that hits the black bars is lost for the observation. In the diffraction foil, these black bars are replaced by bars in which the foil is a little bit thicker. The light travels about 33% slower in the foil than in the air. So when the light that passes through the thicker areas reaches the back surface of the foil, the light that had passed through the thinner areas is already a bit ahead. If the difference in thickness is well-adjusted to the period of the bars, the waves from both areas interfere constructively under an angle which depends on the wavelength of the light.

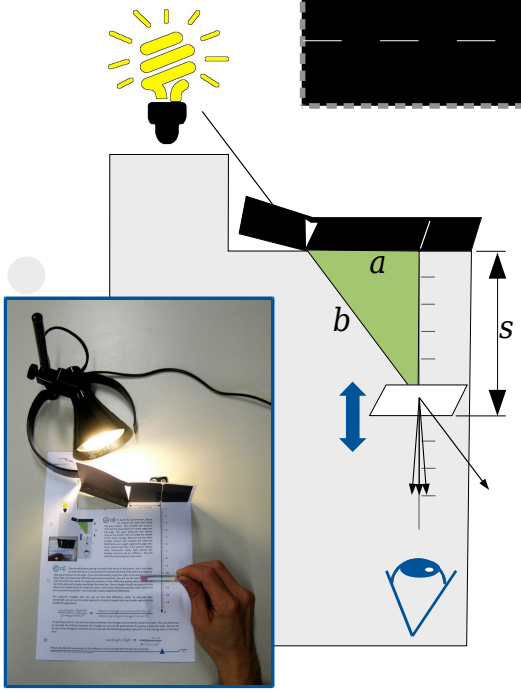
6 The following figure illustrates the wavefronts of light passing through a diffraction grating – like the foil you have in your hand. Use the right drawing to predict the change in the diffraction angle α for a larger wavelength: The longer the wavelength, the _____ the diffraction angle.

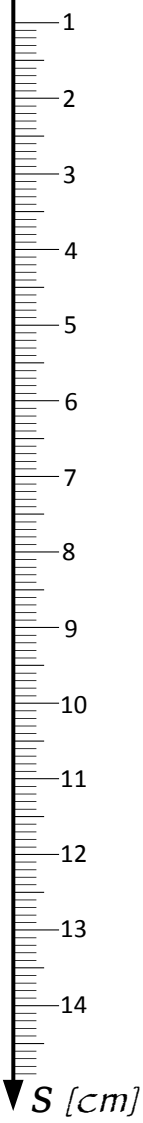


7 The grooves in the foil are too small to see with the naked eye. Still, you can know how they are **orientated** on the foil. Just think of the double slit experiment: how were the slits orientated relative to the diffraction pattern? Draw at the frame to the right the orientation of the grooves as lines and the direction in which the spectrum diffracts as arrows:









8 To build the spectrometer, please cut around the black field along the gray dashed lines marked with scissors. Then fold the black field along the lower edge onto the page. Fold again, along the thin dashed lines at the bottom left and along the middle of the white triangle. Next, cut out the white triangle marked with scissors and make the field stand up at a right angle to the page. Your result should look like the picture. Mount some translucent sticky tape behind the triangle cut-out to act as a diffusor – this will make the measurement much easier.

9 Take the diffraction grating and hold it, as shown in the picture. Ask a classmate to check that both the black field and the grating are kept perpendicular to the page, you take the measurement. If you now look exactly along the scale at the white line in the black field, and move the diffraction grating back and forth, you will see the spectrum shifting over the white line. Mark the respective positions of the diffraction grating where you see the tip of the coloured triangles overlaying the white line. These triangles should correspond to the colours you listed above (4). Note the colour next to the respective position mark. And try to be as accurate as possible – one millimeter makes a significant difference.

The colourful triangles that you see are the first diffraction order. To calculate their wavelength, we can use the same approach of similar triangles, which we already applied to the double-slit experiment:

$$\frac{\text{wavelength of light } (\lambda)}{\text{grating period } (d)} = \frac{\text{distance triangle cut-out to white line } (a)}{\text{distance grating to triangle cut-out } (b)}$$

The grating period is 1 µm and the distance between the triangle cut-out and the white line is 4.5cm. Thus, you only need to calculate the distance between the triangle cut-out and the point at which the grating crosses the scale. You can do this by using Pythagoras' theorem. You will end up with the following equation (please fill in the missing value on the blue line):

$$\text{wavelength of light} = \frac{____ \cdot 4.5\ \text{cm}}{\sqrt{s^2 + (4.5\ \text{cm})^2}}$$

Please calculate the wavelength of the different colours and add them to the list in point 6.