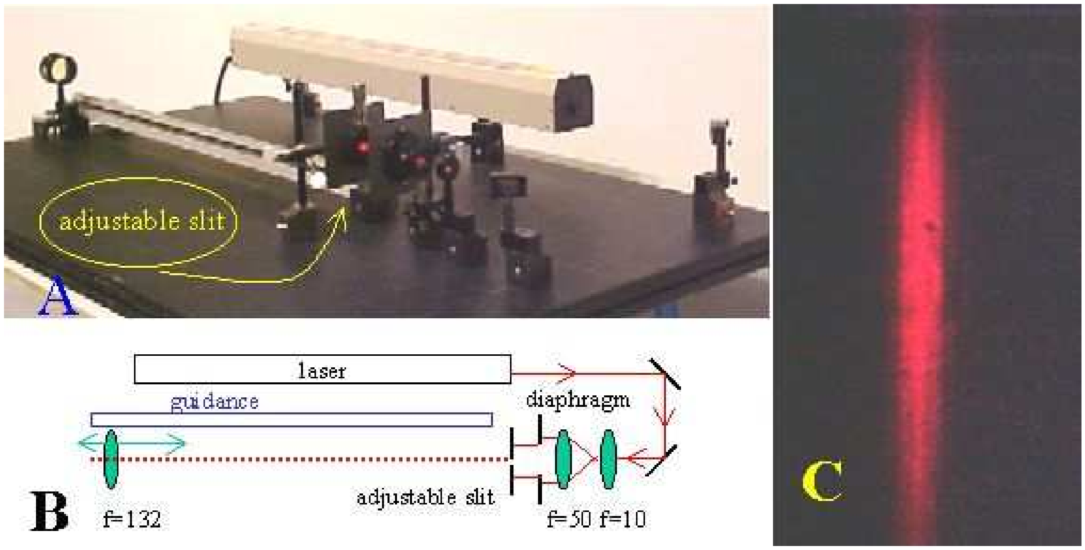
Diffraction(2b), single slit

Aim: To show diffraction on a variable single slit.

Subjects: 6C20 (Diffraction Around Objects)

Diagram:



Equipment:

- Steel table.
- Magnetic clamps, used to fix the components to the steel table.
- Laser, 50mW.
- Two surface mirrors (1/10λ).
- Lens, f=+10mm.
- Lens, f=+50mm.
- Adjustable diaphragm.
- Slide holder.
- Lens, f=132mm.
- Opticail rail, l=1m, as guiding ruler.
- Variable slit with vernier adjustment.
- Overheadsheet with Figure1.

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Presentation: Preparation
The demonstration is set up as shown in Diagram:
-The two mirrors are positioned in such a way that the laserbeam passes parallel to the table.
-The two lenses (+10mm and +50mm) are positioned at an intermediate distance of 60mm. Having passed these lenses, the laserbeam is broadened. Take care that the broadened beam is still parallel to the table.
-The lens of 132mm can easily be shifted in this beam up and down using the carefully positioned guidance rail.
Demonstration
The set-up as described in "Preparation" is shortly explained to the students. The most important in this explanation is that the slit will be placed in a broadened beam and that the adjustable slit will be illuminated by plane waves.
The laser is switched on. A spot of 2 cm projects on the wall (see "Diffraction(2a) in this databse). The +132mm-lens is placed at the end of the guiding ruler, to project an enlarged image of the interference-pattern as it will be "seen" around 85cm (1m-132mm) behind the slit. The broadened and enlarged beam projects as a spot on the wall (diameter of the spot is around 40cm). The slit is closed and positioned in the beam. (By means of an overheadsheet it is shown to the students what the geometrical projection will show to us (see Figure1): When the wall is at a distance as indicated in this figure, then the slitwidth *a* is projected 20 times larger on the wall. So when the slitwidth is 0,1mm, then we will see a width of 2mm.)

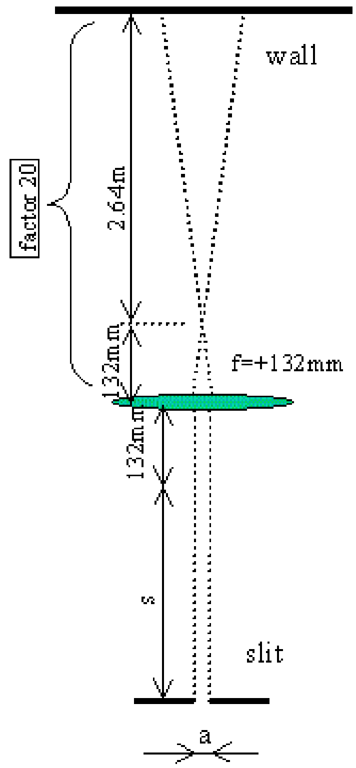

Figure 1

Slowly, the slit is opened to 0.1mm: A broad band of light appears, still faint but visible to all, and: much broader than the geometrical band of light would be! We estimate around 20cm, a hundred times wider than expected! Increasing the slit width, we observe:

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-slit at 0.2mm, band of light = 15cm, first subsidiary maxima appear;
-slit at 0.3mm, central band of light = 8cm, four subsidiary maxima on both sides;
-further opening of slit compresses the observed diffraction pattern;
-slit at 0.7mm, central band of light = 1cm, around 10 subsidiary maxima on both sides (see DiagramC; reality is much better than this photograph).
At this 0.7mm slit width the first subsidiary maxima are almost as intens as the central maximum. Usually here we stop the demonstration (see Remarks).

Explanation: When the slit is 0.1mm and the geometrical projection would be only 2mm wide, clearly light is bending, broadening the band to 20cm.
Many textbooks give a detailed explanation (see Sources). We consider Figure2.

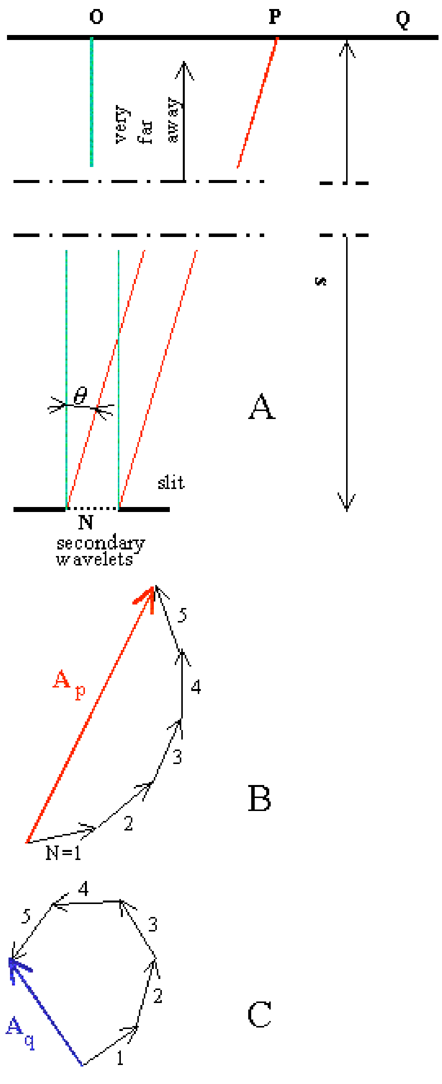

Figure 2

At P, N secondary wavelets superimpose, having a pathdifference of $\frac{a}{N}\sin\theta$. Applying phasor addition (see Figure2B), A_P is the resultant wave amplitude at P. At O, the total amplitude of the

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secondary wavelets will be the arclength in that phasordiagram, since all vectors then have the same phase. At Q (θ is larger) the phasedifference between the "individual" secondary wavelets is larger and the phasordiagram (Figure2C) shows that the total amplitude can eventually be zero.

Analysis gives for the intinsities (I_θ) (see textbooks): $\frac{I_\theta}{I_0} = \left[\frac{\sin\left(\frac{\pi a \sin\theta}{\lambda}\right)}{\frac{\pi a \sin\theta}{\lambda}} \right]^2 = \left[\frac{\sin\alpha}{\alpha}\right].$

Minima occur at $\sin\alpha=0$, so when $\alpha=n\pi$, and maxima at $\alpha = \left(\frac{2n+1}{2}\right)\pi$. The intensities of these maxima are then given by $\frac{I_\theta}{I_0} = \frac{\sin^2\alpha}{\alpha} = \frac{4}{(2n+1)^2\pi^2}$.

n=1 gives $I_1=0.045I_o$;
n=2, $I_2=0.016I_o$, etc.
So, the subsidiary maxima are comparatively weak, but yet clearly visible as the demonstration showed.

Remarks:

- The +132mm lens is positioned at a distance of about 1m away from the slit. This means that on the wall an image is projected of a point around 85 cm (1m-132mm) away from that slit. In that way it is assured that the diffraction pattern is far field Fraunhofer pattern. Increasing the slitopening beyond 0.7mm will transfer the projected pattern into a Fresnel diffraction pattern, spoiling (complicating) our demonstration. The transition form Fraunhofer to Fresnel diffraction occurs in this set-up at around (see Figure1): $s=a^2/2\lambda$, s=85cm, so a=1mm. In this single slit introductory demonstration we should not go beyond that width. (See the demonstration "Fraunhofer-Fresneldiffraction" in this database.)

Sources:

- Hecht, Eugene, Optics, pag. 442-447
- Mansfield, M and O'Sullivan, C., Understanding physics, pag. 325-327
- Young, H.D. and Freeman, R.A., University Physics, pag. 1167-1169
- Giancoli, D.G., Physics for scientists and engineers with modern physics, pag. 890-893