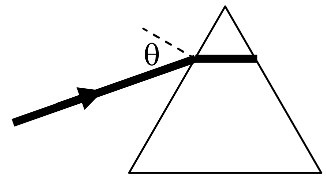
**Homework Set #1** **Due: 1-16-12**

The first four problems are, hopefully, review problems in optics. Normally this material is taught in introductory physics courses but, if this is new, feel free to see me. It's easy to learn.

**1)** An equilateral prism is made of glass with an index of refraction of 1.7. **(a)** Find the input angle θ such that the light travels parallel to the prism base inside the prism. **(b)** What is the output angle of the light when it exits the prism back into air?




A prism configured this way is said to be at "minimum deviation" and has properties that are useful for some applications, including inside laser cavities.

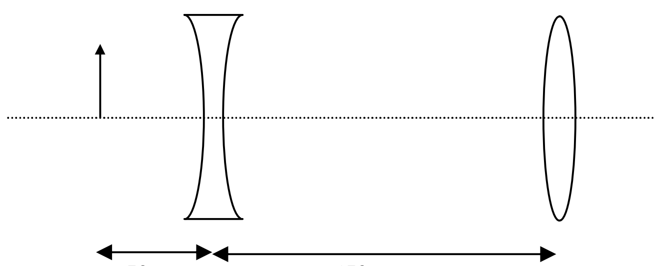
*Review:* When light travels from one medium (#1) to another (#2) across a sharp interface, it refracts according to Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$. The angles are measured with respect to the normal to the interface. The index of refraction of air is about 1.0003 and can usually be taken to be unity.

**2)** An arrow is followed by a diverging lens and a converging lens. The two lenses together form an image.

**(a)** Where is the final image? (Specify distance from the converging lens and whether it is to the left or right of it.)

**(b)** Is the final image real or virtual? Which way is the arrow's image pointing: up or down?

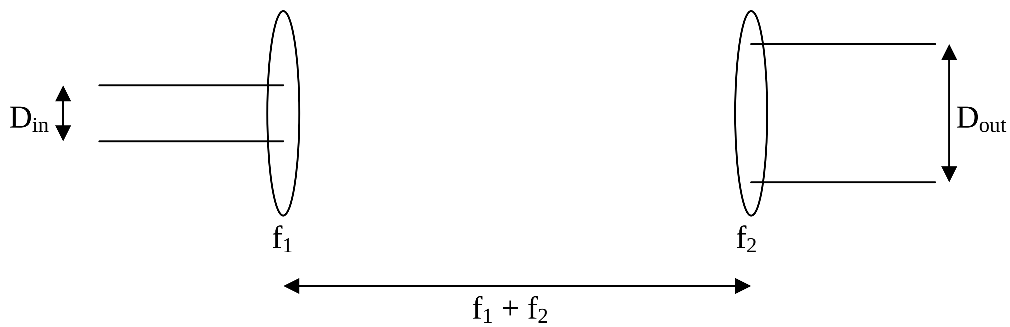
**(c)** What is the magnification of the system?




*Review:* If f is the focal length, o the distance to the object and i the image distance for a given lens: $1/f = 1/o + 1/i$. All distances measured from the center of the lens. Sign convention: the object distance is positive if the object lies before the lens and the image distance is positive if it comes after. A positive image distance means the image is "real" – you can see it on a card or screen. A negative image distance means the image is "virtual" – the output light appears to be coming from the image, but a screen placed at the image will not show one. The magnification $m = -i/o$. A negative magnification means the image is inverted. For multi-lens problems you handle the first lens first, and then use the image of the first lens as the object for the second lens. Note this means the second lens's object can come after the second lens itself.

**3) The beam expander.** Two lenses are separated by a distance equal to the sum of their focal lengths. A *collimated* beam (one consisting of, to good approximation, parallel rays) enters from the left with beam diameter $D_{in}$. The figure shows the situation for the cases where both lenses are positive and $f_2 > f_1$. **(a)** Show by ray tracing that the beam that exits the system is still collimated, but has a larger diameter. **(b)** Show that $D_{out} = (f_2/f_1)\, D_{in}$.

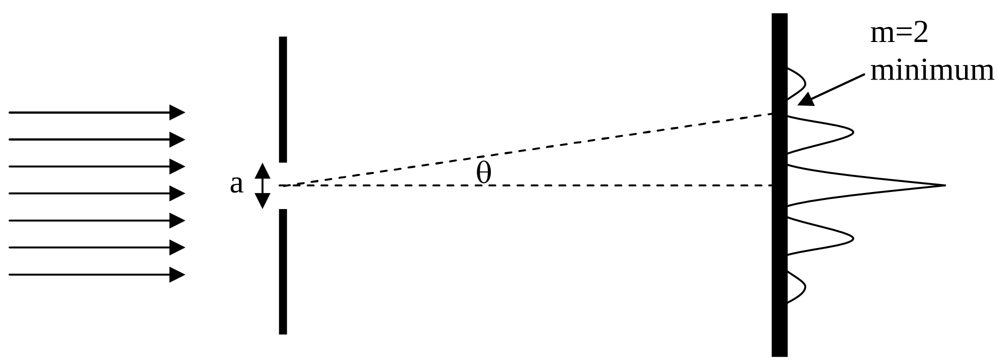
This is a commonly used configuration of lenses, sometimes called a telescope. If you work in a laser lab, you'll likely have to use one. These results hold even if one of the lenses is negative, so long as $f_1 + f_2 > 0$.




**4) (Text problem 1.6)** A (nominally) collimated beam from a ruby laser ($\lambda \approx 694$ nm) is sent to the moon after passing through a telescope of 1 m diameter. Calculate an <u>approximate</u> value of the beam diameter on the moon assuming that the beam has perfect spatial coherence. The distance between earth and moon is approximately 384,000 km.

*Here's a start*: We know from single slit diffraction theory that a collimated beam passing through a slit will diffract, creating a central bright fringe on a screen far away surrounded by weaker fringes to either side. The minima between bright fringes is given by: $a \sin\theta = m\lambda$, where a and $\theta$ are defined in the figure, $\lambda$ is the wavelength and m = 1,2,3… Often small angles are involved and we can use $\sin\theta \approx \theta$, and thus: $\theta \approx m\lambda/a$.

If the beam is not uniform or if a spherical aperature is used instead of a slit, we will have $\theta \approx \beta\,(m\lambda/a)$, where $\beta$ depends on the specific situation, but is of order unity. If the beam is incoherent, the beam will diverge more severely and in a more complicated fashion.




**5) (Text problem 2.5)** The $R_1$ laser transition of ruby has, to a good approximation, a Lorentzian lineshape of FWHM width 330 GHz at room temperature. The measured peak transition cross-section is $\sigma = 2.5 \times 10^{-20}\ cm^2$. The index of refraction of ruby is n = 1.76. Calculate the radiative lifetime, $\tau_R$. (Recall that $A = 1/\tau_R$.)