Massachusetts Institute of Technology - Physics Department

Physics - 8.02 **Assignment #10 (#11 Optional)** May 1, 2002.

We strongly recommend that you read about a topic before it is covered in lectures.

Lecture Date	Topics Covered	Reading from Giancoli
#32 Fri 5/3	Review Exam 3	
Mon 5/6	**Exam 3** covering assignments 7, 8 & 9, and all material covered in reading assignments and in lectures through 4/26 **(last names A-K in 26-100, L-Z in Walker)**	
#33 Wed 5/8	Double-Slit Interference Interferometers	Sect. 35-3 through Sect. 35-5 Sect. 35-7
#34 Fri 5/10	Gratings - Resolving Power Single-slit Diffraction - Angular Resolution Human Eye - Telescopes	Chapter 36 through Sect. 36-8
#35 Mon 5/13	Doppler Effect - the Big Bang - Cosmology Binary Stars - Neutron Stars - **Black Holes**	Sect. 16-7 (Vol. I) & 37-12 *Take Notes!*
#36 Wed 5/15	***Farewell Special***	***Bring a friend***

The first 4 problems are due before 4 PM, Friday, May 10 in 4–339B. This is the latest due date that is allowed by MIT's rules.

The remaining problems are **optional**; they have no due date. They cover the material of the last four lectures, and are only meant to help you in studying and digesting the content of these four lectures.

Always carry one of your linear polarizers with you so that you can observe the high degree of polarization in both primary and secondary bow whenever you see a rainbow. Also observe the polarization of the blue sky (90° from the sun).

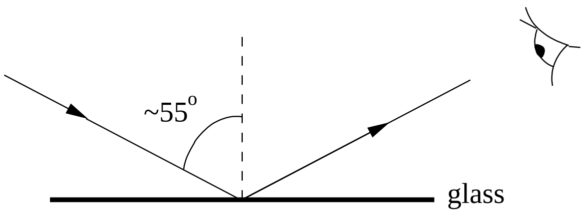
Problem 10.1

Linear Polarizers - Home Experiment.

Your "optics kit" as handed out in lectures contains 3 "greenish" linear polarizers, one clear plastic grating and three color filters. *Avoid finger prints on your grating!*

First determine the direction of polarization of the three linear polarizers. There is no obvious way to do this using these plates only.

Turn on a light and observe the reflection (glare) of the light off a shiny surface which could be plastic, water, or glass, *but not metal!* Move the shiny surface (or the light source) until you are observing the glare at an angle of about 55^o (see figure). The light that you now see is strongly linearly polarized.

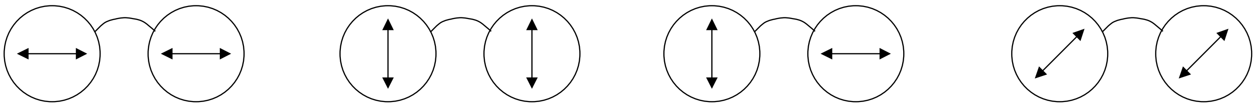


(a) Why? In what direction is it polarized?

Now hold one of your linear polarizers in front of one eye (close the other) and rotate it in its own plane. You will see the glare come and go.

(b) Determine from this experiment the direction of polarization for each of your three linear polarizers.

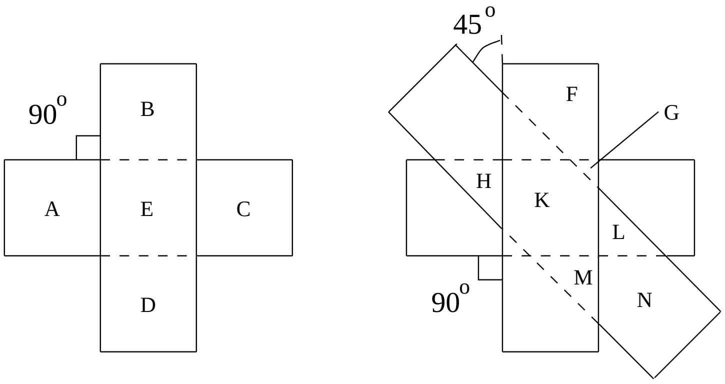
(c) If you had to design a pair of polarized sunglasses would you choose the direction of polarization as indicated in figure a, b, c or d or would you choose another way and why?



a b c d

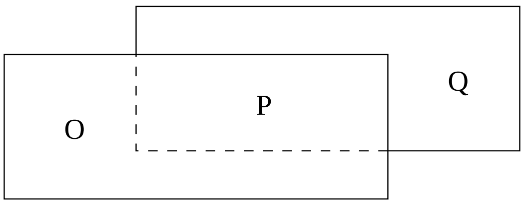
If you happen to have a pair of polarized sunglasses, you can now (using your polarizers) measure the direction of polarization of your glasses. Of course, even without your polarizers you could have determined the direction of polarization of your glasses with the above method.

Hold in front of one eye (close the other) two “crossed” polarizers (see left figure below).



Now stick a third linear polarizer *in between* the two plates; you have now turned darkness (area E) back into light (area K)!

(d) Calculate the light *intensity* per unit area (in terms of I_o, which is the intensity of the unpolarized light as it strikes the polarizer) that you will see from the areas A, B, C, D, E, F, G, H, K, L, M, and N when the situation is as shown in the figure above right. Notice the 45^o angle. Assume that your polarizers are “ideal” (HN-50) so that light intensities per unit area from the areas O, P and Q in the figure below would all be the same ($\frac{1}{2}\, I_o$). You can check, by experiment, that this is not so (your polarizers are HN-38).



(e) Now recalculate for your HN-38 polarizers the light intensities from the areas marked F, G, H, K, L, M, N, O, P, and Q and check whether there is reasonable agreement between your calculations and your observations.

Try to get hold of some cellophane (from a friend's pack of cigarettes — *I hope YOU don't smoke* — or book wrapping or a wrapping from a box with chocolates or ?). Put a piece between two crossed polarizers and rotate the cellophane in its own plane. Look through the polarizers into a bright light (one eye closed). Repeat this with a piece of cellophane which is wrinkled and folded so that at some places you have two layers and at others one, or three, or more. *You will now see very nice color patterns.* At night you can project them on your walls! Rotate the cellophane (without rotating the polarizers) and notice a change in colors. Also change the 90^o angle between your polarizers to different angles. I am not asking you to explain this phenomenon (called birefringence), but I wanted you to enjoy this. We will not cover it in lectures. If you can't find cellophane, try it with pre-stretched plastic kitchen wrap (cellophane is much prettier though).

Problem 10.2
Brewster Angle I.
Giancoli 36-49.
This is the reason why rainbows are so highly polarized! Recall the geometry as discussed in my lecture on rainbows.

Problem 10.3
Brewster Angle II.
Giancoli 36-66.

Problem 10.4
Circularly Polarized Light.
Circularly polarized light is incident on an "ideal" (HN-50) polarizer. Which fraction of the light intensity gets through. Is the light that makes it through linearly polarized?

The problems below are optional; they have no due date. They cover the material of the last four lectures, and are only meant to help you in studying and digesting the content of these four lectures (in preparation for the Final Exam). Solutions to these problems will be posted on the web by Wednesday, May 15.

Problem 11.1
Single slit diffraction.
Giancoli 36-9.

Problem 11.2
Gratings - Physics and Candle Light - Home Experiment.
Your grating has 1000 lines per mm. **Isn't that amazing? Compare the spacing with the wavelength of red light which is about 0.63 μm!** The grooves are made on the transparent plastic film; keep your fingers off the plastic! Note, $1\,\mathring{A} = 10^{-10}\,$m.

(a) Calculate the spacing d between adjacent lines (grooves).

(b) Calculate the angle θ between zero order and first order maximum for red (6300 $\mathring{A}$) and for blue (4500 $\mathring{A}$) light, and calculate the angle (in first order) between the red and the blue.

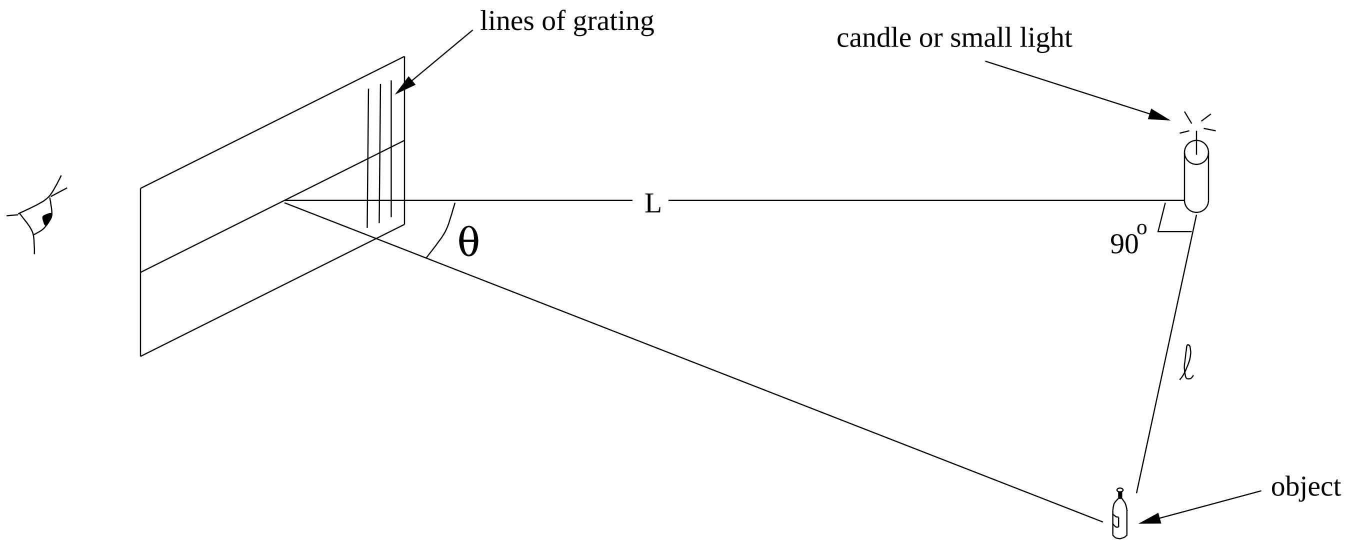
(c) Calculate how many orders there are in the red and how many in the blue? Notice, for large angles: $\sin\theta \neq \theta$.

When it is dark outside, and all lights are off in your room, light a candle or switch on a small bright bulb (2nd best). Hold the grating in front of one eye (close the other). Look at the candle and observe spectra. Rotate your grating (in its own plane) until the lines (grooves) are vertical. You should now see the 1st order spectra on the left and right side of the zero order.

(d) What colors do you observe in the zero order spectrum?

(e) How many maxima do you see in red and how many in blue? Compare this with your predictions under b. (Use your filters to avoid confusion due to possible overlap of different colors from different orders.)

(f) Place an object a distance ℓ away from the candle (as in the figure below) until you see the red light of the first order maximum in the same direction as the object (use your red filter). Measure the distances L and ℓ. Calculate from this the angle θ (see figure). Compare your result with that under b.



(g) Observe the two first order spectra as before (grooves in grating vertical). Now rotate the grating about the vertical; you observe an increase in θ. Why?

Use your grating to analyze the various spectra of street lights. The mercury lights show a remarkable spectrum!

Problem 11.3
Diffraction, interference and angular resolution of 2-element interferometers.
Equation 36-9 holds all the "secrets" of diffraction and interference for single-slits and double-slits. This is true for the entire range of the electromagnetic spectrum. See e.g. figure 36-10c and 36-11. Consider two radio telescopes, each with a diameter of 100 ft, separated by 1 km.

(a) Using only 1 of these telescopes, what would be the angular resolution at a wavelength of 21 cm?

(b) Using both telescopes as an interferometer, what now would be the angular resolution? For simplicity, think of the diameter of the radio dishes as an approximate "slit-width".

Problem 11.4
Destructive interference of sound.
Giancoli 36-55.

Problem 11.5
Resolving power of the human eye.
Giancoli 36-65.

Problem 11.6
Resolving power of optical telescopes.

(a) What is the maximum possible angular resolution (diffraction limitation) of an optical telescope with a 2.4 m mirror (in blue light)?

(b) What is the actual resolution of such ground-based telescopes of which many exist on the various continents?

(c) What is the angular resolution of the Hubble Space Telescope (it has a 2.4 m mirror)?

(d) Why is there such a large difference between the resolution of 2.4 m ground-based telescopes and Hubble?

Problem 11.7
Doppler Shift of Light I.
Giancoli 37-56.

Problem 11.8
Doppler Shift of Light II.
Giancoli 37-59.