Spring 2007

PHYSICS 625

~~COUPLING AND ETENDUE~~ EXPERIMENT

~~Supplemental notes and~~ procedures

Please regard this as the primary directions.

The following 8 steps cover the essential points of this experiment.

Some questions to be answered in this experiment:

- How is the light flux handling capacity of an optical instrument determined?
- How are instruments designed and coupled to conserve light flux?

The SpectroNullOmeteR (**SNOR**) is used to investigate these questions. It looks like a real instrument, but it doesn't do anything. However, by imagining an appropriate gadget in the processing section it becomes a generic example of most optical instruments.

1. Investigate the optics of SNOR. Verify by auto collimation that the entrance and exit stops are at the focal points of the lenses in the input and output sections respectively. (To do this you need to inject light into the instrument through the stop to be investigated, and use a plane mirror after the lens to reflect the light back to the stop.)

2. Sketch roughly to scale the optical design of SNOR, including a ray diagram.

3. Measure the etendue $U = A\Omega = A_1A_2/R^2$ of the entrance section and the exit section of SNOR. The instrument is designed so these are equal. Confirm this to within 10% with your measurements.

4. Place the 9cm focal length lens about 13cm outside the exit aperture so that the processing and exit apertures can be re-imaged outside the instrument. Locate the images of the stops. The lens must be placed a distance greater than its focal length from the exit aperture (why?), but otherwise its position is not critical; you only want the pupil images to be conveniently located and large enough in diameter to be easily measured. Its diameter should be large enough to accept the entire light bundle.

Principle: The etendue of a light bundle is not changed by a lens large enough to accept the entire bundle. Etendue is conserved as long as you don't actually block the light with an opaque object.

Imagine real stops with diameters equal to those of the respective images placed at these images. From their areas and separation calculate the etendue for the externally imaged stops. This should equal the etendue value calculated for SNOR.

5. Stop down the lens so part of the light falling on it is blocked. Are the stop images of the same diameter and in the same location as before? Is A_1A_2/R^2 the same as before? But some light was blocked. What's going on?

The externally imaged stops might be coincident with the stops of another instrument (a detector system, for example) into which you want to couple the processed light. ~~However, in general the stops of the auxiliary system are fixed, and the lens coupling~~ system must be designed to couple the processed flux into the aux system. This is illustrated by trying to couple the flux from SNOR into the detector.

6. First, calculate the Etendue of the detector from the dimensions given. If it is larger than the etendue of SNOR, it should be possible to couple all the light from SNOR into the detector. Will the detector accept, in principle, all the flux from SNOR?

7. Now design a lens system for the coupling. There are numerous solutions. The easiest to understand is to place a first lens very near the exit aperture with a focal length chosen to image the processing aperture appropriately magnified (or de-magnified usually) to fit through the entrance aperture of the detector. The detector is positioned so its aperture coincides with this image, allowing the light to enter the detector. A second lens is placec near the detector entrance aperture with a focal length chosen to image the exit aperture of SNOR onto the sensitive area of the detector with appropriate demagnification so no flux is lost. The first lens is near enough to the exit aperture of SNOR that its position is nearly unchanged, and likewise the second lens is near enough the detector entrance aperture that the image of the processing aperture of SNOR is little changed.

Play around with some of the shorter focal length lenses to try to find a solution. Do som thin lens calculations to see how things work out.

If the detector is mounted on a mounting stage with x & y adjustments, the detector may be slowly positioned to maximize the signal.

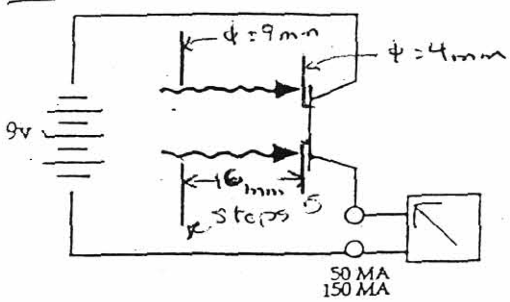
8. All this while the source should be close enough to SNOR to fill it with light. Now watch the detector reading while the source is slid away from the entrance aperture. It should be constant, approximately, for some distance, and then fall off roughly as $1/r^2$, where r is the distance from the processing aperture to the source. What's going on?

PHYSICS 625 - APPLIED OPTICS LAB EXPERIMENT → Supplemental Notes

COUPLING FLUX HANDLING DEVICES

Revised 2/26/96
2/05/04
2/21/05

EQUIPMENT PROVIDED



- Extended source with luminance:

  $L = 1.0$ bulb/cm^2 sterad

  WARNING! Lamp housing gets hot.

- Detector: NPN phototransistor with diffusers to give uniform spatial response. Sensitive area is 4.0 mm dia. A 9 mm dia. stop is permanently fixed 16 mm from the sensitive surface.

  DO NOT ALTER ALIGNMENT OF DETECTOR ASSEMBLY!

- Flux processing instrument - **SPECTRONULLOMETER** (ENTRANCE). This instrument has fixed internal alignment - do not adjust. Light normally enters through the 12 mm ~~EXIT~~ **APERTURE,** is collimated before passing through the processing element and a 25 mm aperture (we'll call it the **PROCESSOR APERTURE**). Finally, a focusing lens images the entrance aperture onto the 6mm **EXIT APERTURE.**

- Apertures: 3, 6, 9, 12, 18, 25, and 25 mm.

- Lenses: Focal lengths 25, 40, 65, 90, and 150 mm.

- Screen, assorted holders, black shroud for aperture.

This experiment explores some concepts and techniques, as well as difficulties and solutions, which are encountered in working with various flux measuring systems. Not all of the constraints found in this experiment will be relevant to a given situation in the real world, of course. In many cases things may be considerably easier; in other cases, more difficult.

You will probably find that there is more suggested to do than you can comfortably cover in one session. ~~Sections marked with a * can be skipped without impacting on later steps, particularly if you think you understand what is going on. Sections marked # are strictly optional asides, which you might try if they strike your fancy.~~

EXPERIMENTS WITH INSTRUMENT

1.* Inspect the "nullometer" carefully, making sure you thoroughly understand its optics. It will be helpful to make a ray diagram for the instrument in your notebook.

   Send light into the instrument alternately through the entrance and exit apertures, and use a small mirror between either lens and the processing stop to show by autocollimation that the apertures are in the focal planes of the lenses between the aperture and the processing stop. Are the entrance and exit aperture diameters in the ratio of the focal lengths of the lenses facing them?

2.* Calculate the etendue of the input and output sections of the instrument using careful measurements of the stop diameters, positions, and lens focal lengths and positions. The instrument has been designed so these are matched. If you have correctly analyzed the geometry your etendue measurements should agree within about ten percent.

3.* Fill the instrument with light from the source. Using a lens outside the output of the instrument, image both the final aperture and the processing aperture outside at convenient distances so you can easily measure their diameters and separations. (NOTE: Both stops must lie beyond the focal point of the reimaging lens. Why?) Calculate the entendue for the external images. The value should agree with the etendue determined from the internal measurements. The etendue is not changed by a lens that is large enough to accommodate all the rays exiting the instrument.

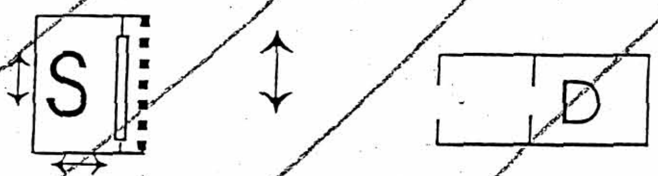
(3)* In an actual coupling problem you would try to choose a lens, or combination of lenses, so that the stop images would lie on the pupils of the instrument to be coupled to, and have the right magnifications to couple efficiently into it.

DETECTOR / SOURCE EXPERIMENTS

OMIT

O1. *Optional - Do other parts first.*
Investigate spatial uniformity of detector by forming a small (~1 mm) light spot with a lens and a pair of stops and scanning with the translating stage detector across it. Make sure the 9 mm stop of the detector does not limit the signal.

4. Investigate the source spatial uniformity by forming a small "virtual detector" across which the source may be scanned. Also check the angular dependence of the source luminance.



5. Set up the detector 5 cm from black side of a 12 mm stop. Place the diffused source 1.5 cm behind the stop and measure the signal. **AS ALWAYS, OBSTRUCT THE BEAM WITH SOMETHING BLACK** to obtain a "zero" reading and make sure there is no avoidable stray light. Now hang the black shroud over the white side of the 12 mm stop. What happens? Can you figure out why? Try moving the source back away from the stop in each case, taking care not to get off center. The signal should, of course, remain constant (up to a point). Does it? What precautions are necessary to ensure that it does? Take care to avoid this photometric problem in later steps.

6.* Place the detector assembly near the source, such that the signal is independent of distance. $S = L U \eta$. What is the etendue of U of the detector? Determine the sensitivity η of the detector in mA/bulb.

7.* Can you improve the signal by use of an appropriate external lens arrangement? What is the best you can do?

OMIT

O2. *Optional - If time permits.*
The linearity of the detector response could be measured with the help of neutral density filters. Another equally good method, however, is to use an extended source of constant luminance and vary the etendue. Two stops (one can be the detector itself) a variable distance apart will do the trick. Don't forget the zero corrections, if any.

8.* Is it going to be possible to couple the entire instrument throughput into the detector? Calculate the detector etendue from the description given in the introduction.

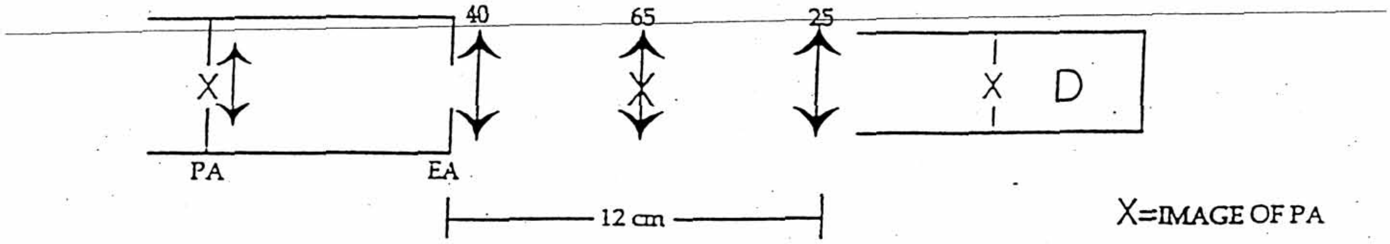
O3. *Optional.* — DO IF YOU HAVE TIME (But do 9a first)
Measure the instrument transmission τ (pretend that the source is monochromatic) by setting up a beam which does **NOT** fill the instrument and can all be put into the detector. Then measure signal with/without instrument in beam. The bright source may help, since the etendue will be low. Be sure no light spills over any stop in the instrument. The detector will have to be moved to different positions for the two measurements.

COUPLING EXPERIMENTS

9.* Now place the diffused source in front of the spectronullometer (not too close - remember number 3 above!) so as to fill the instrument. Couple the sensor to the instrument in one (or both) ways:

a.* Processor aperture imaged (approximately) on outer detector stop; exit aperture on detector. This can be done using 40 and 25 mm lenses respectively.
(TRY 65mm)

b. Processor aperture imaged onto detector surface:
OPTIONAL – come back to this if you have time



Do for 9a

Does the signal agree with predictions based on separate estimates of instrument etendue, transmission, and detector sensitivity?

$$S = U \tau \eta L$$

10.* Is the signal independent of source distance? If so, within what range? Keep source on-axis. Is it now possible to add coupling optics between the source and the instrument to increase the signal?

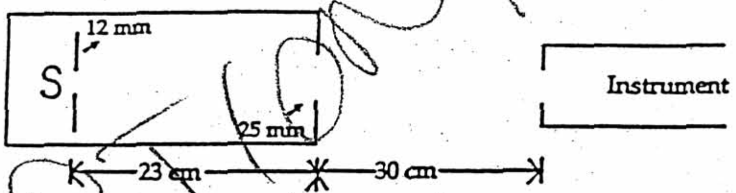
11.* Without disturbing the alignment of instrument and detector, move the source 30 cm away from the entrance aperture. Record the signal. Are you filling the instrument? Add a lens to restore the coupling (this can be done in several ways). Now what signal do you get? *Try moving the source out to 50 cm.*

12.* With the detector still in place, set up a 6mm aperture 20 cm in front of the entrance aperture. Put the source (diffused) about 8 cm behind the aperture. Checking visually, is the entrance aperture filled with light? What about the processor aperture? If system is fuilled, signal should agree with number 11 above. Does it? Wait a minute . . . what's going on here?
Plot i vs R: when does the 1/R² law start?

13. Mount a 12 mm aperture directly in front of diffused source, black side toward source. Leave this aperture in place until further notice. Now set source aperture 14 cm from instrument entrance aperture, and measure the signal. Set up a **FIELD LENS** at the entrance aperture to image the source onto the entrance aperture. Do you have available any lenses of the right focal length ? If not, a fast, short focal length lens can be improvised from two similar lenses back to back. Which way should they be oriented? Try it and compare results with the first method.

14. The source is now inaccessible, being located inside a vacuum chamber with a small window. Set system up as follows:

OPTIONAL
Do if time permits



Using a single lens, couple to the instrument as best you can. How does the signal compare with the "ideal" value of number 11 above?

15. Add a field lens to this system, locating it near the entrance aperture. The relay lens used in number 16 above may have to be readjusted slightly. What signal do you get now?

OPTIONAL