Insurance Scam (Experimental)

An Introduction to Optics

This version of the problem has been adapted as an experimental introduction to Optics

Intended Learning Outcomes

By the end of this activity students should be able to solve problems involving:

- Reflection at a transition between two mediums
- Refraction
- Snell's Law
- Ray tracing and trigonometric analysis of light rays
- Dispersion
- Diffraction gratings and patterns
- Thin film interference
- Transmission/absorption spectra
- Lasers

Students will use the following skills:

- Designing of experiments to test a hypothesis
- Evaluating the errors in an experiment and their consequences
- Working as a team
- Report writing

KEYWORDS:

Absorption spectra, diffraction, dispersion, lasers, light rays, ray diagrams, reflection, refraction, Snell's Law, thin film interference, transmission spectra

Contents

The original version of 'Insurance Scam' is run as a Laboratory Group Research Project for students on the Physics degree at the University of Leicester. It is undertaken by students in small groups. There are four laboratory sessions of 3 hours each as well as two facilitated workshops. For each of the workshops there is set question for class discussion, that are marked at the workshops. These workshop questions are designed to support the practical work by providing ideas and relevant theory. Most of the required theory can be found in any undergraduate physics text book.

Reading List

The following textbooks are suggestions, other equivalent textbooks are available:

- Breithaupt, J. ***Physics.*** Palgrave Foundations.
- Tipler, P.A. ***Physics for Scientists and Engineers***. Freeman.

Problem Statement

An Insurance Scam?

At a recent auction at Sotheby's an American collector of early twentieth century stained glass has purchased a panel on the understanding that it was by Marc Chagall. The authenticity of this work has recently come into question and the auctioneer's insurers have been asked to investigate.

Genuine samples of glass and gold leaf from the workshop of the artist are available, but the owners will not allow them to leave this country, nor can the panel be transported. These need to be characterised in order that the glass used in the panel can be compared.

Your task is to investigate the refractive index, colour, thickness and flatness of the glass and thickness of the gold leaf decoration and prepare a report that will be sent to the US, where a comparison with the disputed panel can be carried out.

Suggested Deliverables

Individual or group reports to the director of research.

Laboratory Equipment Provided

Experiment 1: Refractive index of the glass sample

- Travelling microscope with z-axis
- Micrometer
- Glass samples
- Marker pen

Experiment 2: Thickness of gold leaf sample.

- Energy Saver Mercury Light Bulb 9W - Bayonet fitting
- Green Diffusion Filter (#122) Roscolux
- Blue Diffusion Filter (#121) Roscolux
- Red Diffusion Filter (#120) Roscolux

Or

- Desktop lamp with built in green filter

And

- 2 x Inch diameter optical flats
- Gold Leaf
- Craft knife
- Small paint brush
- Cleaning fluid - methanol
- Lint free cloth
- Small Clamp Stand

Experiment 3:

- Optical bench, (1 long (~2m), 1 short (~0.5m))
- Optical bench laser stand
- Optical bench lens mount
- Optical bench mounted screen
- Small clamps
- Meter rule
- Glass sample
- HeNe laser

Experiment 4:

- 2 × optical bench (1 long (~2m), 1 short (~0.5m)) + tooth track and scale on small bench
- Pen torch - white light source
- Black cardboard tube and collimator
- Diffraction grating (600 lines/mm) / Prism
- Photodiode
- Oscilloscope or multimeter
- Ruler (1m)
- Coloured Glass samples

Laboratory Sessions

Session 1

Session Aims

In this lab session you are asked to find out the first listed property of the glass: its refractive index. This is a relatively straight forward experiment both theoretically and practically, although care should be taken when performing measurements.

Suggested Experimental Method

By the use of the 'apparent depth' it is possible to relate the refractive index of the medium to that medium's thickness.

Note: Some micrometers feature pointed ends (spindle and anvil) in order to measure a specific point on the glass surface. With these it is especially important (although this should be done for all micrometers) to use the ratchet when moving the spindle. This means that when the micrometer is closed on the object fully, no excessive force is applied which could otherwise break the rather brittle spindle end.

Session 2

Session aims

You are asked to measure the thickness of the gold leaf sample. This cannot be done by simply using a micrometer, as it is too thin. You will have to devise some method by which you can measure a different quantity and relate this to the thickness of the gold leaf.

Suggested Experimental Method

It is possible to use light source provided to create a source of (roughly) monochromatic light. The optical flats provided can be used to create two surfaces which light will reflect off of. These two basic points suggest that you can observe interference effects.

Note: The 'Edmunds Optics Optical flat manual' may help with these ideas.

The light source provided will consist of either a lamp and set of 'Roscolux' diffusion filters (with their spectra given) or a pre-made white light bulb and 'Kodak Wratten No74' filter built in to a desk lamp. The dominant wavelength of this filter is at 530nm.

Cleaning the surface:

The optical flats sometimes have grease which affects how flat they seem to be. Some ethanol and lint free cloth have been provided to clean the surfaces. Care should be taken not to touch the surface with bare hands, as this will leave a mark.

The accuracy of the results varies greatly with how clean the optical flats are. Try to check this.

Session 3

Session aims

You are asked to measure the thickness, flatness or refractive index of the sample by use of the 'two spot' method. This method is a non-invasive way of measuring the sample, and can be used to find any of the unknowns listed above as long as the other two are known. Because of this, some of the properties may initially be assumed in order to find the other. This experiment will take a longer time to perform than the first two. To help you with this the equipment has been set up for you. You should, however, check the alignment of the equipment.

It is recommended that you attempt to first find the thickness of the sample, assuming that it is flat. Once this is done, you can remove this assumption and measure the flatness of the sample. It is also possible to measure the thickness of the sample without the assumption that it is flat, which you may do if time permits.

Note that this experiment and experiment 1 both relate thickness to refractive index. They could therefore be used to find these values without using the micrometer. This experiment has the advantage that it can be used to measure the flatness of the sample.

Relevant Theory

The following diagram (figure 1) contains the same information that has been given to you in the introductory lecture, and depicts the experimental set-up for the first experiment.

Laser Hazard:

As with all laboratory projects, an analysis should be made of the potential safety hazards. Using a laser, especially one where the beam is being reflected, can be hazardous.

Suggested Experimental Method

To realise what method you must use for this experiment, you must consider what measurements you can make: you can only measure the incident and reflected angles. The refractive index of the glass can be assumed from previous measurements.

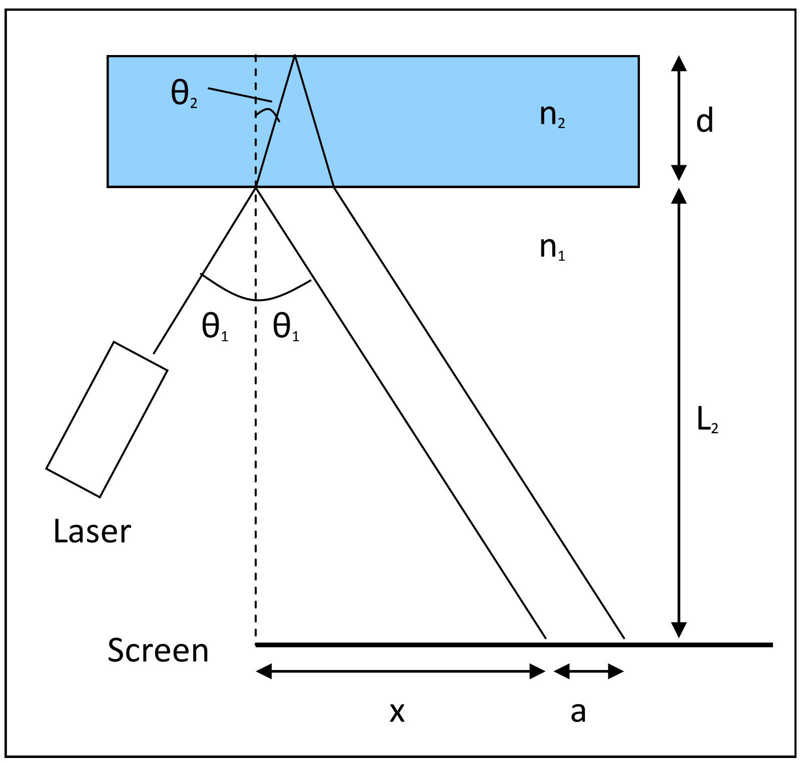


Figure 1: Two-spot experiment assuming perfectly flat sample

From this it should be clear that you must relate the angles to the refractive index (Snell's Law).

Note: If implausible results are reached, it is always worth checking the experimental set-up and alignment. Facilitators may be able to help with this check, but only ask if you cannot find the problem yourselves.

Session 4

Session aims

In this experiment, you are asked to measure the colour of the glass sample. By colour, we mean its transmission spectrum; the intensities of each wavelength which are transmitted through the sample.

Suggested Experimental Method

The following diagram has been shown to you in the introductory lecture:

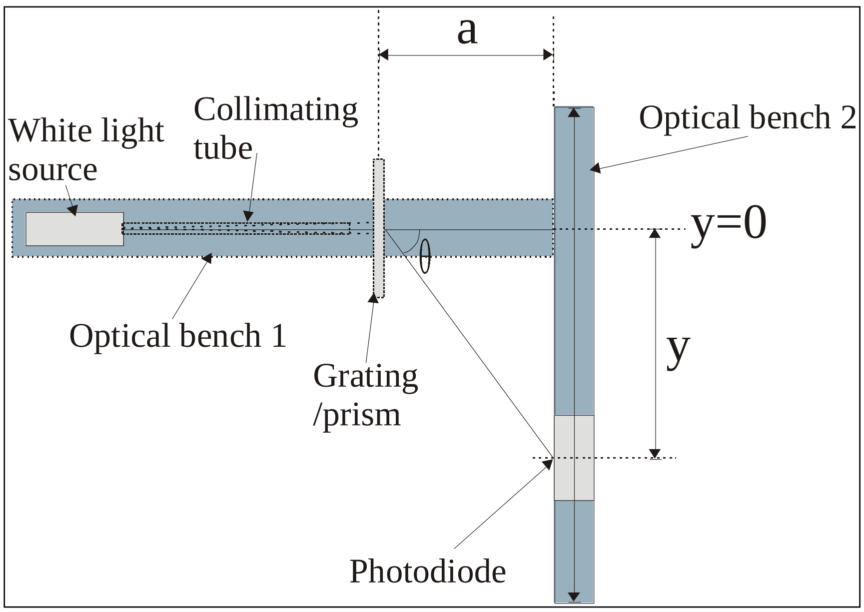


Figure 2) Glass colour experimental set-up.

This should give you a big hint as to how to measure the transmission spectra.

Note that the collimating tube must be quite long in order that the light travels 'straight' from the source. For this reason a cardboard tube should be provided, with which you can increase the length of the pre-made collimator. (This is required as the LED torch provided includes an adjustable lens, meaning the light does not propagate in the directions you may expect. The collimator allows only approximately straight paths of light to pass.)

Setting up the equipment correctly for this experiment can take some time, but if correctly done measurements can be made relatively quickly.

Supplementary Information

Correct alignment of optical bench equipment

Any results measured can only be accurate if the optical equipment used for the measurements is correctly aligned. Care should be taken at the beginning of any lab session, where it is applicable, to check the equipment is well aligned.

Key points to consider are:

- If a wall to a darkroom is being used as a screen, is the light source perpendicular to it? Otherwise measurements of angles may be incorrect.

- The laser has to be aligned to the optical bench, as well as the optical bench to other pieces of equipment being used (Especially if a sample is placed in a sample holder). One method for making sure the angle of the sample is correct would be to place the laser at a right angle to the optical bench, slightly above or below the horizontal. It could then be shone at the glass sample, and the sample rotated until the reflected dot is below or above the laser source. Of course care must be taken, as with any laser experiment.

- If a screen is being used, is it perfectly flat and orientated at the correct angle?

Questions for Class Discussion

1. An object is placed in a medium of refractive index *n* at a distance *u* from a boundary with air of radius of curvature *R* (figure 1). The lens formula for the formation of an image at distance *v* is

$$\frac{n}{u}+\frac{1}{v}=\frac{2}{R}$$

Use this to find a formula for the apparent depth of an object at the bottom of a clear tank of water viewed at normal incidence. (Begin by identifying the radius of curvature, the object and image distances.)

Check your result by direct calculation using Snell's law.

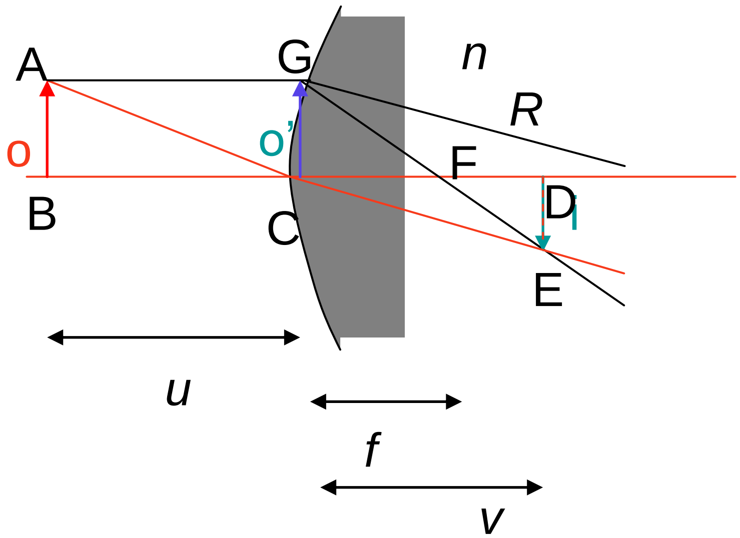


Figure 1: Question 1

2. A thin film of air is trapped between transparent parallel glass blocks. When viewed at normal incidence in monochromatic light the object appears dark. What is the minimum value for the air gap? The top block is raised at one end by an angle α and m fringes are observed within a distance *x* of the centre. Derive an expression relating the angle to the fringe separation.

3. At 5700 K the Sun radiation from the Sun peaks in blue-green light (Figure 2). Why doesn't the Sun look blue-green?

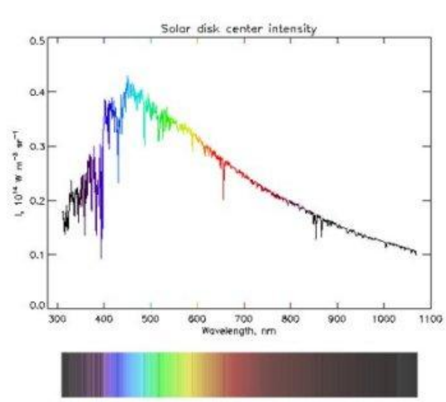
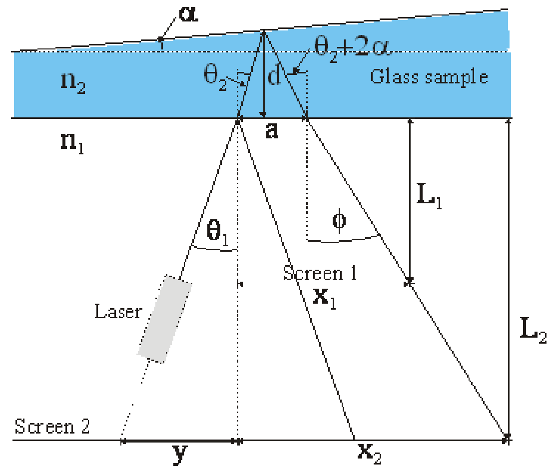


Figure 2: Question 3

4. A diffraction grating has 2000 lines per cm. What is the length of a spectrum of white light on a screen a distance *x* from the grating?

5. In the two spot experiment the beams will diverge if the glass faces are not parallel. How could you measure the divergence of the beams. (Figure 3)

Figure 3: Question 5



6. Derive a formula for the spot separation in the two spot experiment as a function of the angle of incidence and the refractive index of the medium in the case that the surfaces of the medium are parallel. Hence derive a formula for the thickness of the medium *d*.

   If instead the surfaces diverge by an angle α by what angle do the beams diverge (Figure 3). Use this to modify your formula for *d*.

   How would you measure the divergence of the beams?

7. Explain how a laser works.

   A red laser torch beam emerges from an aperture of 2mm. Estimate the divergence of the beam.

   Why do you use a laser source in the experiments?

8. For close to normal incidence on a small angle prism, show that the dispersion depends linearly on the refractive index (i.e. the angle at which a ray of a given wavelength of light emerges is proportional to the refractive index at that wavelength). Is the dispersion uniform (i.e. proportional to the wavelength)?