# ANGLE-RESOLVED REMITTANCE

The transmission and reflection at optical interfaces varies with angle, which is an important practical consideration in optical engineering. It also depends on the refractive index, so measuring remittances is a useful way to determine refractive index, which is a fundamental optical property of a material. The alignment principles used in this lab are applicable to other beam instruments (e.g. x-ray diffraction).

### Task objectives

- Setup angle-resolved flux meter  
- Measure (pseudo)-Brewster angle & remittance profile  
- Estimate refractive index

Learning objectives  
- observe remittance as a function of incidence angle  
- apply Fresnel’s equations for flux

## Measurement strategies

At every interface between optical materials, some fraction of the incident flux is reflected (*R)* and the rest is transmitted (*T)*. The fraction of incident flux split into each of these paths depends on the angle of incidence *θi* & the material properties (e.g. refractive index *n*). It also depends on the polarization, which can be expressed in terms of the electric field orientation relative to the plane of incidence, labelled “*p*”=parallel and “*s*”=perpendicular. Unpolarized flux “*u*” is given by the average of *p* & *s*. The refractive index of unknown samples can be determined through measurements of the flux splitting together with physical models (e.g. Fresnel’s equations).



### Refraction and Reflection

A typical measurement configuration involves a flat sample of finite thickness, which has some practical implications, especially with respect to transmission.

1. The transmitted beam is bent (refracted) according to Snell’s law:



e.g. if incident @ 45° from air, the beam is refracted into glass (n=1.5) @ *θt*=arcsin(1.sin(45°)/1.5)=28°

Measurement of the angle of refraction could be used for determining the refractive index, however observing the internal beam only works on special samples (e.g. liquid, large, or semi-circular).

1. Due to refraction, the transmitted beam deviates laterally (on exit). Again, this could be used to estimate refractive index, but typically it is an inconvenience. Since most real samples are thin compared to the substrate they sit on, the sample deviation that is to be measured is much smaller than the unwanted substrate deviation.
2. Reflection from additional interfaces (e.g. at exit) complicates analysis. Although this extra data is further evidence for analysis, each additional interface requires additional estimates, which reduces certainty.
3. There are many materials that block transmission (through reflection or absorption).

For these reasons, reflection data from the front interface is often preferred, by using:

1. Non transmitting sample (e.g. Si in the visible range)
2. Blackened (e.g. tape) or rouglaserd backside
3. Sample much thicker *d* than the detector aperture *w*   
   Note that this implies that  cannot be too small.

Equipment cannot usually measure very close to normal incidence, but this doesn’t usually matter.

### FRESNEL’S EQUATIONS

Fresnel’s equations determine the amount of reflection and transmission *at a single interface*.









In general, the refractive index can be determined by:

1. collecting the reflected:incident ratios (e.g. *Rp*) at different incidence angles
2. fitting the data to the equations

However, fitting always requires a good starting guess, which can be determined from special features.

#### CRITICAL ANGLE (TOTAL REFLECTION)

Beyond the critical angle, , all light is reflected (*R*=1), and none is transmitted (*T*=0).  
Since the incident medium is typically air, and samples usually have greater refractive index, the critical angle does not feature in this experiment, however it is important in some structures.

e.g. the critical angle from air into glass is: arcsin(1.5/1)=undefined

e.g. . the critical angle from glass into air is: arcsin(1/1.5)=42°

#### BREWSTER’S ANGLE (Zero REflection)

Reflection of p-polarized light is zero (*Rp*=0), and is completed transmitted (*Tp*=1), at .

This is a very rapid way to find the refractive index of a material. However, absorbing materials (e.g. metals), do not allow reflection to fall completely to zero, and instead have a pseudo-Brewster angle which is more complicated to work out. Multilayer structures have a more complex reflection profile and do not generally have a single or well-defined Brewster’s angle. For this reason, the Brewster’s angle is not generally sufficient for determining refractive index – *the full angular data set should be tested against a model*.

e.g. the Brewster’s angle for glass in air is: arctan(1.5/1)=56°

### Procedure

1. Stabilize source power
   1. Mount Laser
   2. Insert beam block (e.g. screen)
   3. Switch on, leave on for at least 15 minutes during alignment
2. Beam align
   1. Insert turntable (TT), at lowest position on carrier for maximum stability.
   2. Insert aperture on rail carrier (54-2), set height to centre of sample (1cm above TT surface)
   3. Unblock laser, test alignment by sliding aperture along rail
   4. Adjust laser holder as necessary (can level by adjust top two screws)
   5. Adjust drag screw under TT to reduce vertical movement of arm but allow smooth turning
   6. Swing arm directly behind TT
   7. Move aperture to first hole in TT arm, center aperture on beam
   8. Insert detector to second hole in arm, center carefully (check visually and for max reading)
   9. Insert polarizer before TT
3. Get beam power for both s & p polarizations
   1. Open aperture so beam passes through
   2. Rotate polarizer to appropriate angle (s is 0°, p is 90°)
   3. Check p & s powers are similar – if not rotate polarized laser and/or insert 1/4 wave plate
   4. Record p & s power, note fluctuations over about a minute or so
   5. With beam blocked, record dark reading using the same detector scale
4. Align sample (glass slide)
   1. Rotate TT to 45° (TT sample post to back and past center along rail)
   2. Move arm to collect straight through beam, set at 45° exactly
   3. Fine rotate TT (arm fixed) to align beam with center of aperture/detector
   4. Move arm to reflection position (towards observer), set at 45° exactly
   5. Insert sample, keep the lower edge aligned exactly with the 90° line
   6. Carefully adjust tilt (top edge of sample) so beam strikes center of detector
   7. Clamp gently but firmly (adjust top screw down carefully)
   8. Check again that beam is exactly centered on detector, repeat step f as necessary
   9. Rotate TT to near 90°
   10. Check that beam is grazing sample, fine adjust beam laterally as necessary
5. Find (pseudo)Brewster’s angle and fine-adjust p
   1. Align polarizer approximately in plane of incidence (horizontal, p, 90°)
   2. Rotate TT+arm until reflection drops near minimum
   3. Fine adjust TT+arm (& polarizer) for minimum reflection
   4. Record incidence angle (and flux), with uncertainties
6. Measure *p* fluxes as a function of incidence angle (Δθ<15°, <5° near Brewster)
   1. For each incidence angle
      1. Fix arm at desired angle
      2. Rotate TT to bring beam to detector center
      3. Record reflected flux
      4. Calculate R
7. Measure *s* fluxes
   1. Rotate polarizer to 0°
   2. Measure fluxes as before
8. Determine complex refractive index using fit to Fresnel equations

## Results

### DETERMINATION of REFRACTIVE INDEX

#### BREWSTER ANGLE

Brewster angle & minimum R with uncertainty

Calculated refractive index, with uncertainty

#### ANGULAR-RESOLVED REFLECTANCE

Reflectance data

Fitted refractive index

* As a minimum overlay the Fresnel curves predicted by your Brewster estimate
* Better is fitting the refractive index (starting from Brewster) so that the Fresnel curves fit the data
* Sometimes the incident power is not measured correctly – you may need to adjust to get a good fit
* Best practice is to use a formal non-linear regression to estimate uncertainty of refractive index
* Other systematic errors may be higher than uncertainty estimated from fluctuations

#### CONCLUSION

Comparison to other data

# Reflection

* Summary of what was achieved
* Methods that worked well
* Methods that could be improved
* Summary of what was learnt
* Areas that would be interesting to investigate further