Topic >>>> Illumination and Shading

CSE5280 - Computer Graphics

Illumination and Shading

- Light/surface physics
- The Hall illumination model

- Chapter 16 (Pages 721-740) + material in notes

Discrete Illumination Models

- What occurs when light strikes a surface is quite complex.
  - ✓ Continuous process
  - ✓ Light from infinite angle reflected in infinite directions
- We are determining intensity of a pixel with…
  - ✓ Finite number of lights
  - ✓ Finite reflections into space
  - ✓ Finite illumination directions
- Hence, we must have a *discrete model* for lighting and illumination.

Illumination Models

- What should a lighting model entail?
  - ✓ Discrete
  - ✓ Lights
  - ✓ Types of reflection
- Commercial systems can be quite complex
  - ✓ Most start with a basic model and embellish to pick up details that are missing

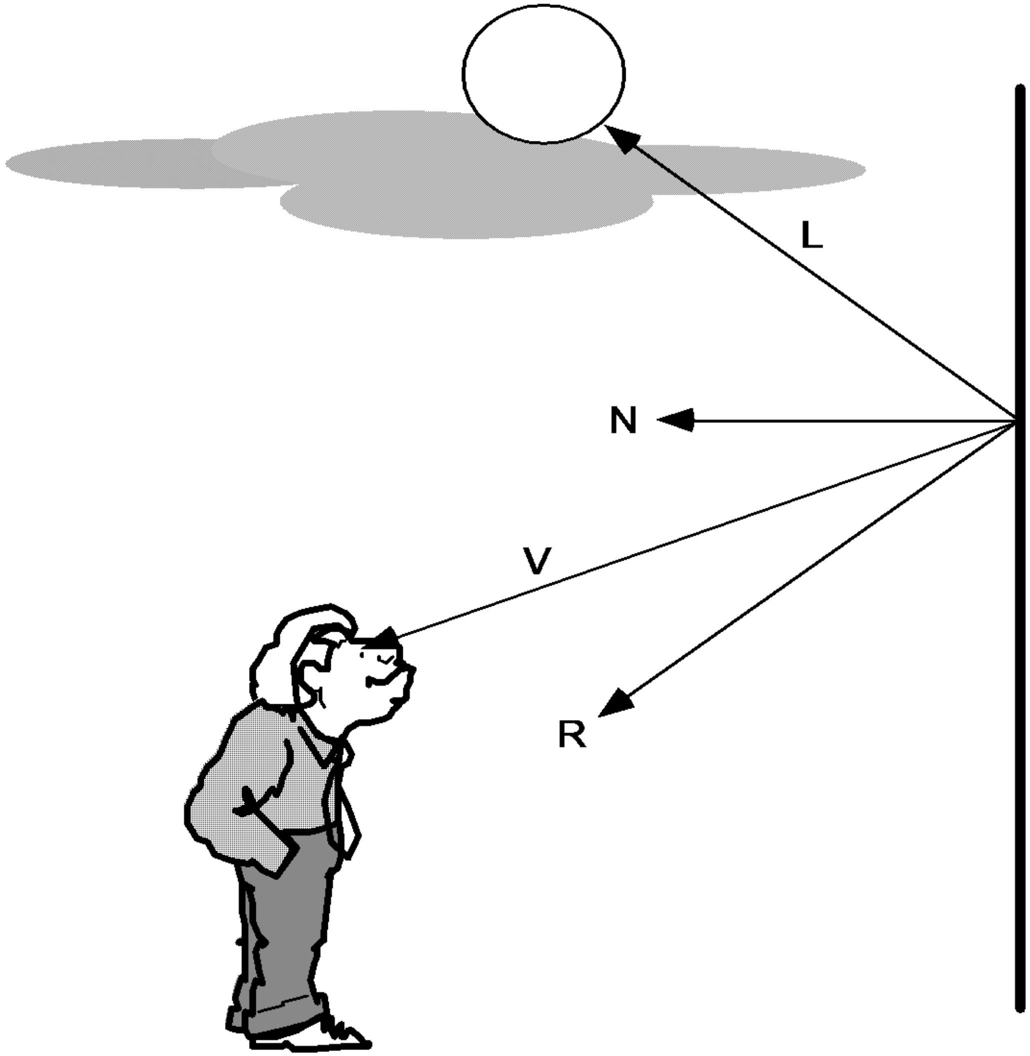
Elements of Lighting at a point

N – The surface normal

L – Vector to the light

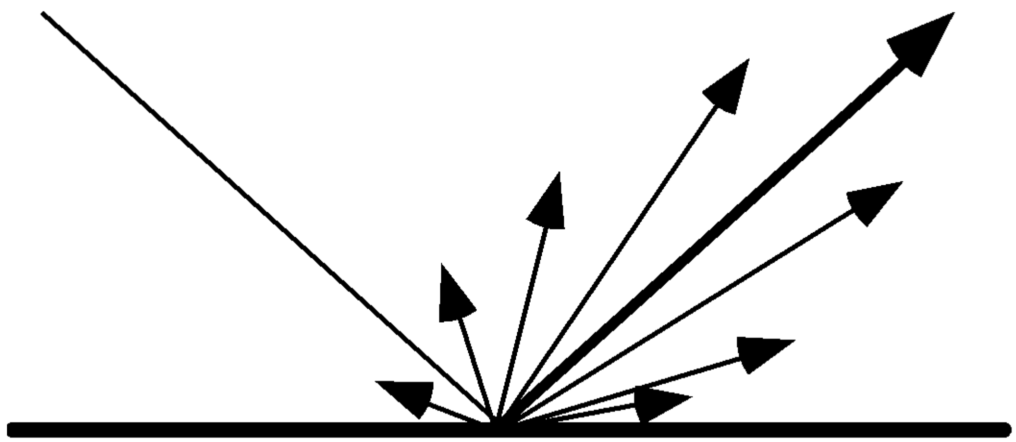
V – Vector to the eye

R – Reflection direction



Reflection

- What we need is the amount of light reflected to the eye



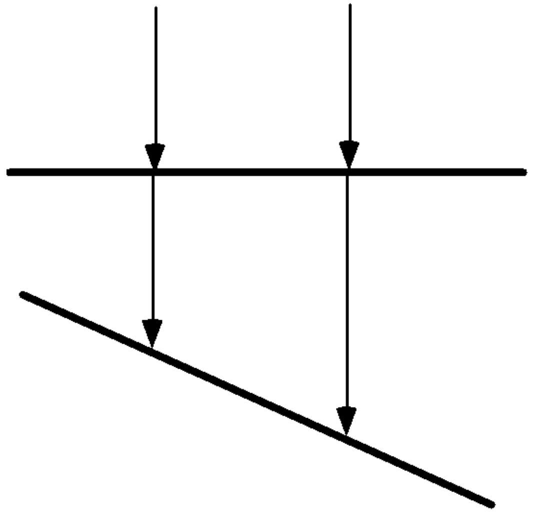
This consists of several components…

Diffuse Reflection

- *Diffuse reflection* - light reflected in all directions equally (or close to equally).
  - ✓ Most objects have a component of diffuse reflection
    - other than pure specular reflection objects like mirrors.
  - ✓ What determines the intensity of diffuse reflection?

Diffuse Reflection Characteristics

- Since the intensity is the same in every direction, the only other characteristic is the angle between the light and the surface normal. The smaller this angle, the greater the diffuse reflection:



Lambert's Law

$$\cos\theta = w / w'$$

$$w = w' \cos\theta$$

Diffuse reflection decreases intensity by the cosine of the angle between the light and surface normal.

Specular Reflection

- *Specular reflection* - If the light hits the surface and is reflected off <u>mostly</u> in a reflection direction, we have specular reflection.
  - ✓ There is usually some diffusion.
  - ✓ A perfect specular object (no diffusion at all) is a mirror.
  - ✓ Most objects have some specular characteristics

Diffuse and Specular colors

- Typically the colors reflected for diffuse and specular reflection are different
  - ✓ Diffuse – Generally the surface appearance
  - ✓ Specular – The color of bright highlights, *often more white* then the surface color

Where do these come from?

- Most surfaces tend to have:
  - ✓Deep color, the color of the paint, finish, material, etc.
    - Diffuse Color
  - ✓Surface reflection characteristics, varnish, polish, smoothness
    - Specular Color

The Hall Illumination Model

- This is the model we'll use (and you'll implement!)

$$
\begin{aligned}
I(\lambda) = {} & k_{sr} \sum_j I_{lj}(\lambda) F_{sr}(\lambda, \theta_{r,j}) (\cos\theta_{r,j})^n \\
& + k_{st} \sum_j I_{lj}(\lambda) F_{st}(\lambda, \theta_{t,j}) (\cos\theta_{t,j})^{n'} \\
& + k_{dr} \sum_j I_{lj}(\lambda) F_{dr}(\lambda) (N \cdot L_j) \\
& + k_{sr} I_{sr}(\lambda) F_{sr}(\lambda, \theta_R) T_r^{\Delta sr} \\
& + k_{st} I_{st}(\lambda) F_{st}(\lambda, \theta_T) T_t^{\Delta st} \\
& + k_{dr} I_a(\lambda) F_{dr}(\lambda)
\end{aligned}
$$

Components of the Hall Model

$$I(\lambda) = k_{sr} \sum_j I_{lj}(\lambda) F_{sr}(\lambda, \theta_{r,j})(\cos\theta_{r,j})^n$$

Specular Reflection from Light Sources

$$+ k_{st} \sum_j I_{lj}(\lambda) F_{st}(\lambda, \theta_{t,j})(\cos\theta_{t,j})^{n'}$$

Specular Transmission from Light Sources

$$+ k_{dr} \sum_j I_{lj}(\lambda) F_{dr}(\lambda)(N \cdot L_j)$$

Diffuse Reflection from Light Sources

$$+ k_{sr} I_{sr}(\lambda) F_{sr}(\lambda, \theta_R) T_r^{\Delta sr}$$

Specular Reflection from other surfaces

$$+ k_{st} I_{st}(\lambda) F_{st}(\lambda, \theta_T) T_t^{\Delta st}$$

Specular Transmission from other surfaces

$$+ k_{dr} I_a(\lambda) F_{dr}(\lambda)$$

Ambient Light

Ambient Light

- Ambient light is light with no associated direction. The term in the Hall shading model for ambient light is:

$$k_{dr} I_a(\lambda) F_{dr}(\lambda)$$

- k_{dr} is the coefficent of diffuse reflection.
  - ✓ This term determines how much diffuse reflection a surface has. It ranges from 0 to 1 (as do most of these coefficients).

Ambient Light

$$k_{dr} I_a(\lambda) F_{dr}(\lambda)$$

- $I_a(\lambda)$ is the spectrum of the ambient light.
  - It is a function of the *light wavelength* λ.
  - In nature this is a continuous range. For us it is the intensity of three values: Red, Blue, and Green, since that is how we are representing our spectrum.
  - In other words, there are only 3 possible values for λ. Simply perform this operation for each color!
- Implementation: double lightambient[3];

Ambient Light

$$k_{dr} I_a(\lambda) F_{dr}(\lambda)$$

- $F_{dr}(\lambda)$ is the Fresnell term for diffuse reflection.
  - ✓ It specifies a curve of diffuse reflections for every value of the spectrum. We don't have every possible color, we only have three. So, this term specifies how much of each color will be reflected. It is simply the color of the object.

Implementation

$$k_{dr} I_a(\lambda) F_{dr}(\lambda)$$

- It's common to combine k_{dr} and $F_{dr}(\lambda)$
  - ✓ $F_{dr}(\lambda)$ is really just a color.
  - ✓ Just call this is "ambient surface color"
  - ✓ glMaterialfv(GL_FRONT, GL_AMBIENT)
  - ✓ $I_a(\lambda)$ is the light ambient color
- Implementation
  - ✓ for(int c=0; c<3; c++)

```
for(int c=0;  c<3;  c++)
   hallcolor[c] = lightambient[c] *
                          surfaceambient[c];
```

Diffuse Reflection of Light Sources

$$k_{dr} \sum_{j} I_{lj}(\lambda) F_{dr}(\lambda)(N \cdot L_j)$$

- The iterator j takes on the index of every light in the system.

  - ✓ k_{dr} - coefficent of diffuse reflection.
  - ✓ $I_{lj}(\lambda)$ - spectrum of light source j.
    - It is simply the color of the light.

Diffuse Reflection of Light Sources

$$k_{dr} \sum_j I_{lj}(\lambda) F_{dr}(\lambda)(N \cdot L_j)$$

- $N \cdot L_j$ component.
  - ✓N is the surface normal at the point.
  - ✓Lj is a vector towards the light.
  - ✓Dot product is the cosine of the angle (and these must be normalize vectors), we have a decreasing value as the angle increases.

Doing this in code

$$k_{dr}\sum_j I_{lj}(\lambda)F_{dr}(\lambda)(N\cdot L_j)$$

```
for(int l=0;  l<lightcnt;  l++)
{
   if(light[l].loc[3] == 0)
      lightdirection = Normalize(light[l].loc);
   else
      lightdirection = Normalize(light[l].loc – surfacepoint);

   for(int c=0;  c<3;  c++)
   {
      hallcolor[c] += light[l].dcolor[c] * surfacediffuse[c] *
          DotProduct(surfacenormal, lightdirection);
   }
}
```

Specular Reflection of Light Sources

$$k_{sr}\sum_j I_{lj}(\lambda)F_{sr}(\lambda,\theta_{r,j})(\cos\theta_{r,j})^n$$

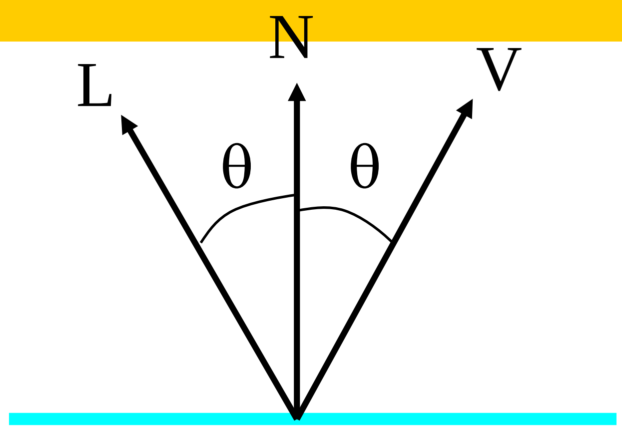
- k_{sr} and $I_{lj}(\lambda)$ are obvious.
- $F_{sr}(\lambda,\theta_{r,j})$ is the Fresnell term representing the specular reflection curve of the surface.
  - ✓ Specular reflection is due to microfacets in the surface and this curve can be complex. In real world systems which strive for accuracy, this curve will be measured for a given material. Note that the curve is dependent on not only the wavelength, but also an angle (more on that angle in a moment).
- A simplification of this is to ignore the angle, which is what we will do.
  - ✓ But, the color of spectral highlights is independent of the color of the surface and is often just white.

The Spectral Intensity Function

$$k_{sr}\sum_{j} I_{lj}(\lambda)F_{sr}(\lambda,\theta_{r,j})(\cos\theta_{r,j})^{n}$$

- $(\cos\theta_{r,j})^n$ is the spectral intensity function.
  - ✓It represents the cosine of the angle between the maximum reflection angle and the surface normal raised to a power.
  - ✓Maximum reflection is in the “mirror” direction

Reflection Angles



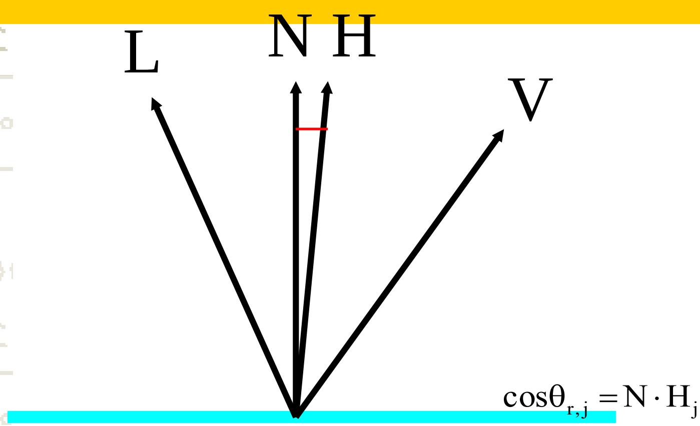
This is an example of <u>maximum reflection</u>

In this case, the “half” vector is the same as the surface normal

Cosine of angle between half and normal is 1.

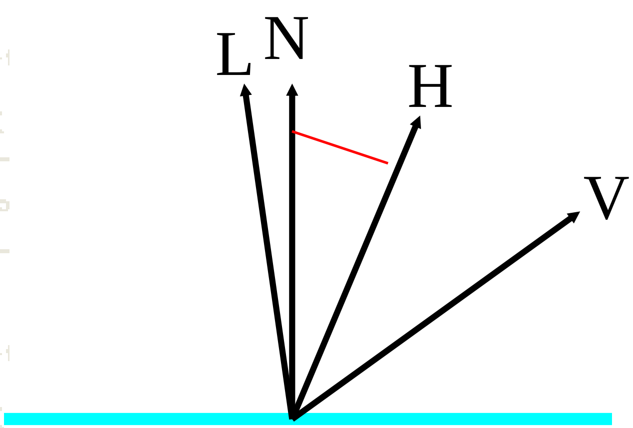
$$H = \frac{L+V}{|L+V|}$$

Cosine of Reflection Angle



$$k_{sr} \sum_j I_{lj}(\lambda) F_{sr}(\lambda, \theta_{r,j})(\cos\theta_{r,j})^n$$

$$\cos\theta_{r,j} = N \cdot H_j$$



Specular Reflection Highlight Coefficient

- The term *n* is called the specular reflection highlight coefficient.
- This effects how large the spectral highlight is. A larger value makes the highlight smaller and sharper.
  - ✓ This is the "shininess" factor in OpenGL
  - ✓ Matte surfaces has smaller n.
  - ✓ Very shiny surfaces have large n.
  - ✓ A perfect mirror would have infinite n.

Implementation

$$k_{sr}\sum_j I_{lj}(\lambda)F_{sr}(\lambda,\theta_{r,j})(\cos\theta_{r,j})^n$$

```
for(int l=0;  l<lightcnt;  l++)
{
  if(light[l].loc[3] == 0)
    lightdirection = Normalize(light[l].loc);
  else
    lightdirection = Normalize(light[l].loc – surfacepoint);

  half = Normalize(lightdirection + viewdirection);
  sif = pow(Dot(surfacenormal, half), n);
  for(int c=0;  c<3;  c++)
  {
    hallcolor[c] += light[l].scolor[c] * surfacespecular[c] *
        sif;
  }
```

Specular Reflection from Other Surfaces

$$k_{sr} I_{sr}(\lambda) F_{sr}(\lambda, \theta_R) T_r^{\Delta sr}$$

- This is reflections of other surfaces
- The only new terms are $I_{sr}(\lambda)$ and $T_r^{\Delta sr}$
  - ✓ The $T_r^{\Delta sr}$ term reflects the fact that light falls off exponentially with distance. T_r is a term which models how much light falls off per unit of travel within the medium.
  - ✓ The Δsr term represents how far the light travels. Note that for mediums such as air and a small scene T_r is close to 1, so you can sometimes ignore it.
  - ✓ This is a complaint of Roy Hall's, so think about using it, though I've not used it before. ☺

The Reflection Direction

- Given a view direction V and a normal N, the reflection direction R is:

$$R = 2(N \cdot V)N - V$$

- $I_{sr}(\lambda)$ is the color seen in the reflection direction
  - ✓ OpenGL does not do this stuff…

Transmission

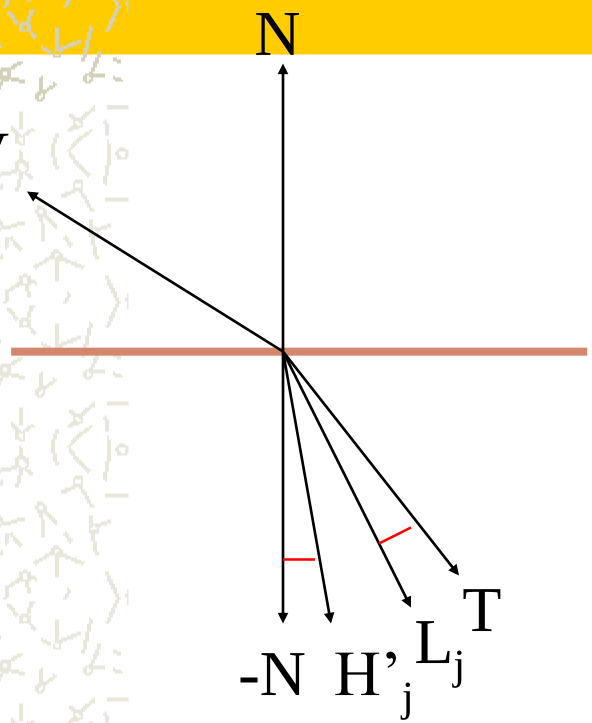
- Transmission is light that passes through materials

Specular Transmission from Lights

$$k_{st}\sum_{j} I_{lj}(\lambda)F_{st}(\lambda,\theta_{t,j})(\cos\theta_{t,j})^{n'}$$

- Bright spots from lights passing through objects. Most of the same issues apply.
- $I_{lj}(\lambda)$ is the color in the transmission direction.
- $(\cos\theta_{t,j})^{n'}$ is how the specularity falls off if looking directly down the direction of reflection.

What Transmission Looks Like



$$H_j' = \frac{V - \beta L_j}{\beta - 1}, \text{ where } \beta = \frac{\eta_2}{\eta_1}$$

$\cos\theta_{t,j}$ $(-N \cdot H'_j)$

η_1 and η_2 are the indices of refraction
for the *from* and *to* volumes respectively.

Index of Refraction

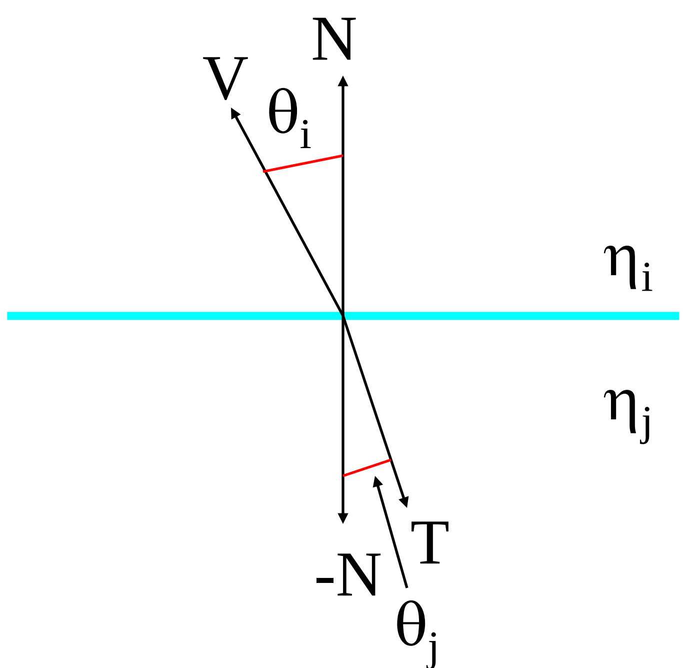
- Ratio of speed of light in a vacuum to the speed of light in a substance.

Substance	Index
Vacuum	1.0
Air	1.00029
Water	1.33
Glass	1.52
Diamond	2.417
Sapphire	1.77
Salt	1.54

Refractive Transmission

- Given indices of refraction on above and below a surface, we can compute the angle for the view and transmission vectors using Snell's law

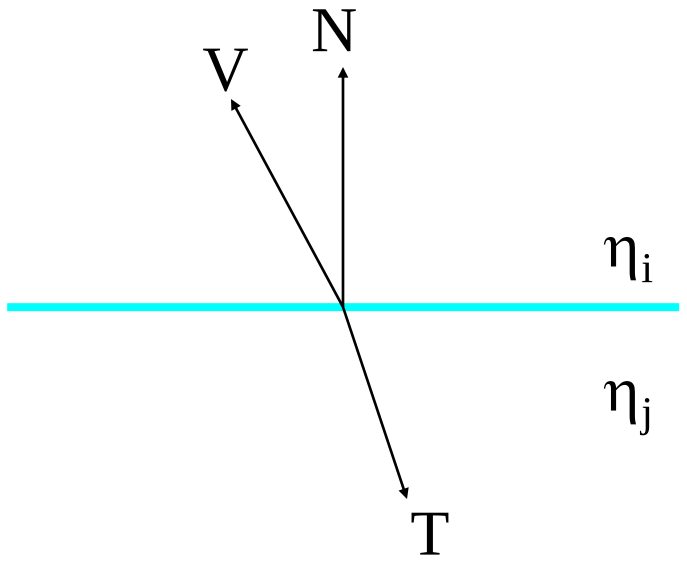
$$\frac{\sin\theta_i}{\sin\theta_j} = \frac{\eta_j}{\eta_i}$$



The Transmission Direction

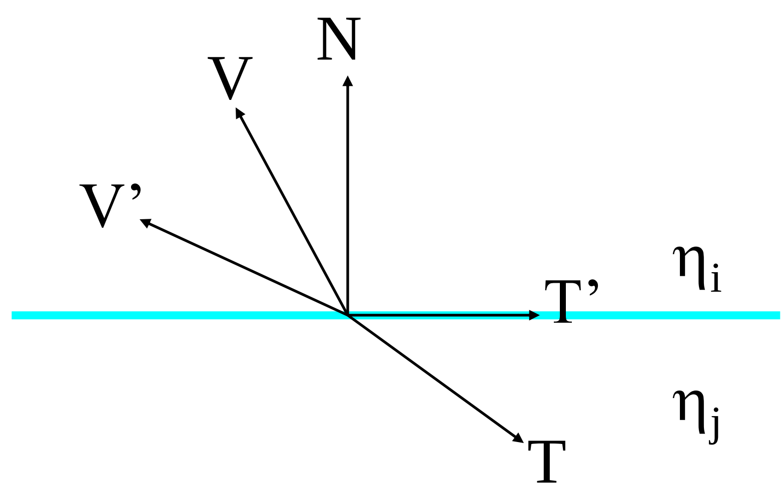
$$\eta_r = \frac{\eta_i}{\eta_j}$$

$$T = \left(\eta_r (N \cdot V) - \sqrt{1 - \eta_r^{\ 2} (1 - (N \cdot V)^2)} \right) N - \eta_r V$$



Total Internal Reflection

- If light is traveling from h_i to a smaller h_j (out of water into air for example), the angle from the normal increases:
  - This can lead to the angle for T being >=90 degrees!
  - This is called total internal reflection
  - Square root term in previous equation goes negative



Specular Transmission from Other Surfaces

$$k_{st} I_{st}(\lambda) F_{st}(\lambda, \theta_T) T_t^{\Delta st}$$

- Should be pretty obvious what these are…

What Hall Omits

- Hall is a model and is not an exact reproduction of reality.
  - ✓ As an example specular reflection from other objects is in the reflection direction only
  - ✓ No diffuse transmission
    - (What would that be and how would you model it?)

Reference

- Hall Illumination Model
  - ✓ http://www.itlabs.umn.edu/classes/Fall-2001/csci5107/handouts/Illumination.pdf
  - ✓ http://www.css.tayloru.edu/instrmat/graphics/hypgraph/illumin/illum0.htm
  - ✓ http://www.opengl.org/developers/code/sig99/shading99/course_slides/basics/index.htm