

# BRDF and the Microfacet Model

## As used in Physically Based Rendering

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### 0.1

Here follows a short summary of what I've learned during the HMN 2024 Learning Jam. I chose the topic of BRDF's but expanded the scope to physically based rendering, or PBR as it's often referred to in games.

<https://handmade.network/jam/learning-2024>

### 0.2

The following terms are used to represent the surface in our lighting calculations.

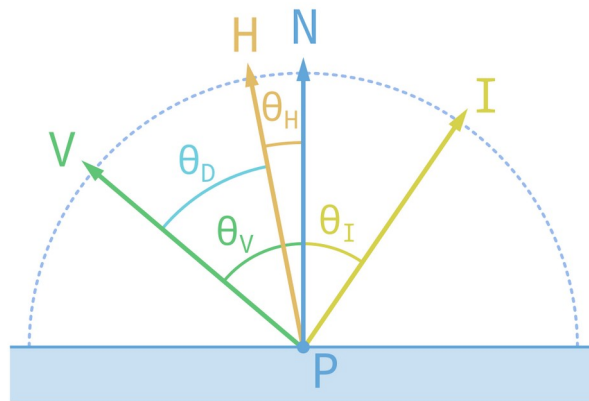


Figure 1

$P$	Surface position
$V$	View direction (outgoing light direction, pointing towards the viewer)
$I$	Incident direction (incombing light direction, pointing towards the light source)
$N$	Macro surface normal
$H$	Micro surface normal, unit vector half way between $V$ and $I$
$\theta_h$	Angle between $H$ and $N$
$\theta_d$	Angle between $H$ and $I$ or $V$
$\theta_i$	Angle between $I$ and $N$
$\theta_v$	Angle between $V$ and $N$

## 1.1 The Rendering Equation

On the topics of BRDF's and such the end goal is usually stated in the form of the "Rendering Equation", which basically summarize the shading pipeline. Usually the terms are quite similar.

$$L(P, V) = \text{diffuse}() + \int_{\Omega} \text{BRDF}(P, V, I) L_i(P, I) (I \cdot N) dI \quad (1) \text{ [CC]}$$

$L_e$	Emitted light
$L(P, V)$	Total outgoing radiance along $V$
$\text{BRDF}(P, V, I)$	Material model. Returns outgoing light along $V$
$L_i(P, I)$	Incoming light along $I$
$I \cdot N$	Outgoing light weakening factor

## 1.2 The BRDF

Short for *Bidirectional Reflectance Distribution Function* is some function which, based on  $V$  and  $I$ , returns the amount of light reflected from the surface. It models the light interacting.

For a BRDF to be considered physically correct it needs to adhere to the following criteria.

1. Return value must be  $\geq 0$
2. Obey *Helmholtz reciprocity*,  $\text{BRDF}(V, I) = \text{BRDF}(I, V)$
3. Conserve energy ie. for a perfectly white surface, the amount of reflected energy must equal the amount received.

It's not uncommon to combine multiple material models into one BRDF. Functions that model light interaction inside the material go under other abbreviations such as BTDF and BSDF. Including BRDF, they fall under the umbrella term of BSDF [W3].

BRDF's can also be based on measurements taken from real materials.

## 1.3 The Microfacet Model

Widely used in both games and films. Reflections are calculated based on some sub-pixel textured micro surface that is relative to the macro surface defined by the rendered geometry.

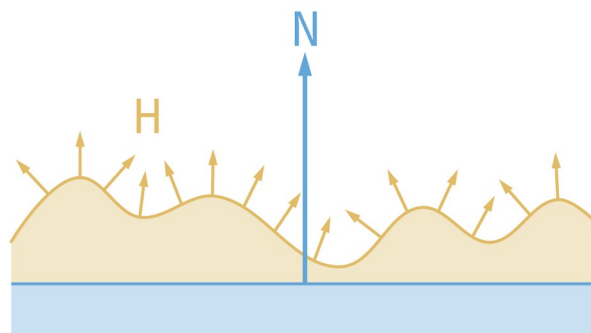


Figure 2

A BRDF based on this model could take the following form.

$$f(I, V) = f_d() + \frac{D(\theta_h) F(\theta_d) G(\theta_i, \theta_v)}{4 \cos(\theta_i) \cos(\theta_v)} \quad (2) \text{ [DS]}$$

### 1.3.1 Specular Distribution Function D

Determines what fraction of the microfacets are reflecting light along  $V$  based on  $H$ , which represents the microsurface normal.

$$D(\theta h) = \frac{c}{(\alpha^2 \cos^2(\theta h) + \sin^2(\theta h))^\gamma} \quad (3) \text{ [DS]}$$

- $c$       Some scalar constant (preferred value does not seem to be stated)
- $\alpha$       Roughness (0 – 1)
- $\gamma$       Exponent (In the case for Disney; 2 for base material, 1 for clear coat)

### 1.3.2 Specular Fresnel Term F

Models how light reflects at grazing angles. Always reaches full reflection ("unity" = 1.0) at some point.

The following is based on the Schlick approximation.

$$F(\theta_d) = F_0 + (1 - F_0)(1 - \cos(\theta_d))^5 \quad (4) \text{ [DS]}$$

- $F_0$       Base reflectance at surface normal. 0.04 common value for dielectrics.

### 1.3.3 Geometric Attenuation Term G

Since the micro surface has peaks and valleys, incoming light that would, on the macro level, be reflected could be either deflected or blocked by the microsurface. The Geometric attenuation term handles the distribution of this phenomenon and can take the following form.

$$G(I, V, H) = G1(I, H) G1(V, H) \quad (5) \text{ [GGX]}$$

$$G1(S, H) = \max\left(\frac{S \cdot H}{S \cdot N}, 0\right) \frac{2}{1 + \sqrt{1 + \alpha_g^2 \tan^2(\theta_v)}} \quad (6) \text{ [GGX]}$$

- $\alpha_g$       Distribution width parameter
- $S$       Either  $I$  or  $V$

$$\alpha_g = (0.5 + (\text{Roughness} 0.5))^2 \quad (7) \text{ [DS]}$$

It's common for  $G$  to be "bidirectional". Evaluating for both  $I$  and  $V$  models aforementioned deflection and obscuring of light coming towards the viewer.

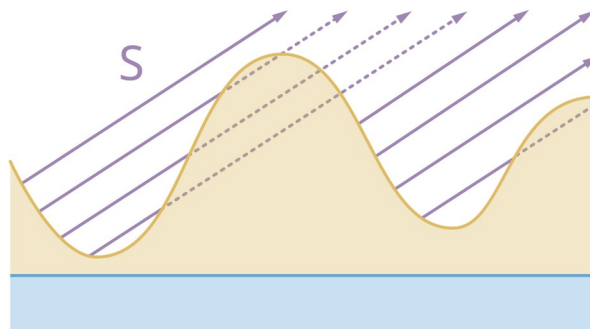


Figure 3

### 1.3.4 Diffuse Model

Diffuse reflection is essentially minor subsurface scattering, where light enters the material, scatters around and exits with most of its spectrum lost except the color of the surface.

Smooth surfaces can exhibit a shading around the silhouette while on rough surfaces the opposite occurs, what is called a "retro reflection", probably the effect of subsurface scattering at grazing angles. The following function captures this behaviour.

$$F_d = \left( \frac{BaseColor}{\pi} \right) (1 + (F_{D90} - 1)(1 - \cos \theta_i)^5) (1 + (F_{D90} - 1)(1 - \cos \theta_v)^5) \quad (8) \text{ [DS]}$$

$$F_{D90} = 0.5 + (2 Roughness \cos^2 \theta_d) \quad (9) \text{ [DS]}$$

## 2.0 Sources

[CC] Crash Course BRDF

<https://boksajak.github.io/files/CrashCourseBRDF.pdf>

[DS] Physically Based Shading at Disney

[https://media.disneyanimation.com/uploads/production/publication\\_asset/48/asset/s2012\\_pbs\\_disney\\_brdf\\_notes\\_v3.pdf](https://media.disneyanimation.com/uploads/production/publication_asset/48/asset/s2012_pbs_disney_brdf_notes_v3.pdf)

[GGX] Microfacet Models for Refraction through Rough Surfaces

<https://www.graphics.cornell.edu/~bjw/microfacetbsdf.pdf>

Wikipedia

[W1] [https://en.wikipedia.org/wiki/Rendering\\_equation](https://en.wikipedia.org/wiki/Rendering_equation)

[W2] [https://en.wikipedia.org/wiki/Bidirectional\\_reflectance\\_distribution\\_function](https://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function)

[W3] [https://en.wikipedia.org/wiki/Bidirectional\\_scattering\\_distribution\\_function](https://en.wikipedia.org/wiki/Bidirectional_scattering_distribution_function)