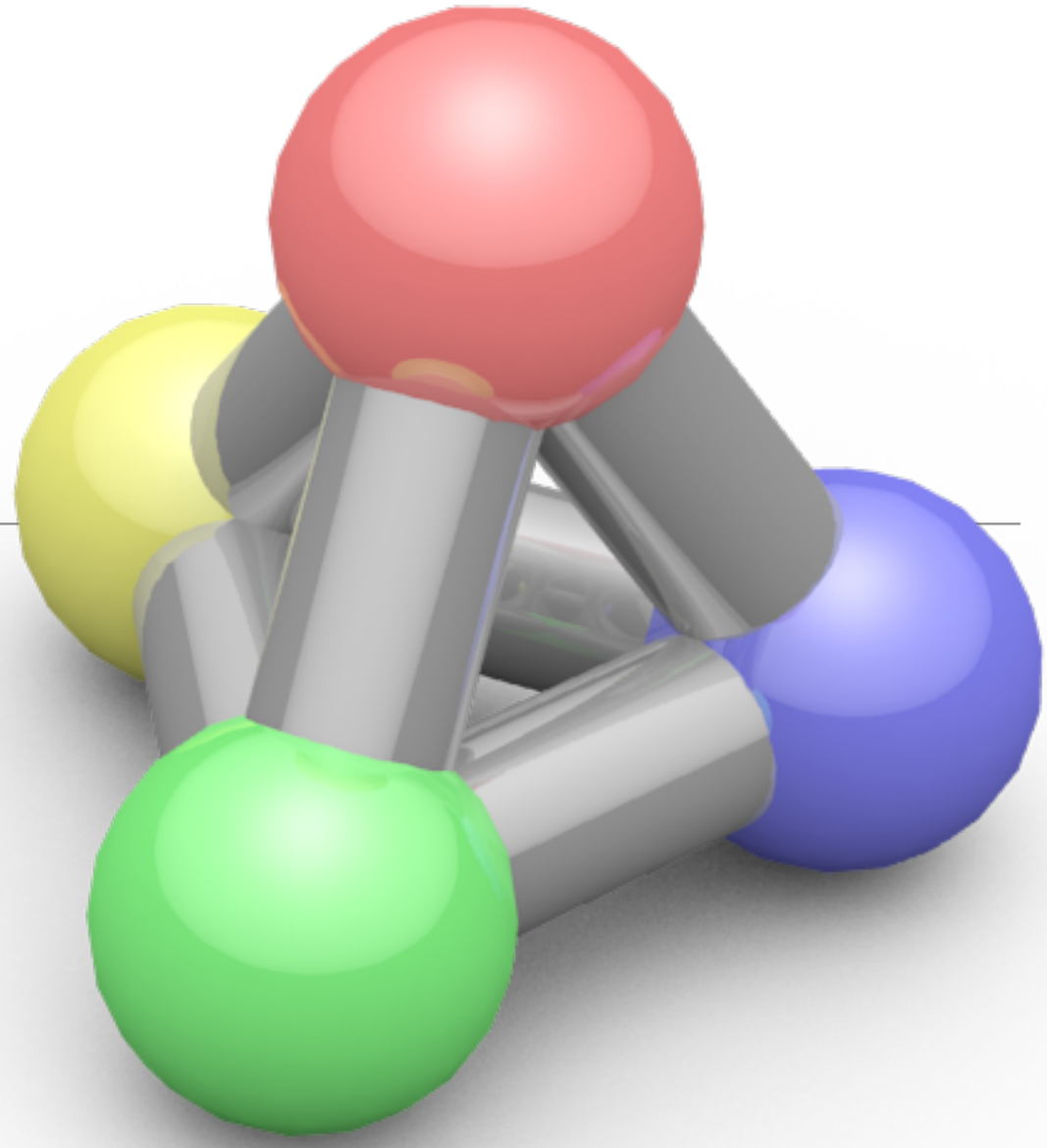
Materials & Shading



CPSC 453 – Fall 2016
Sonny Chan

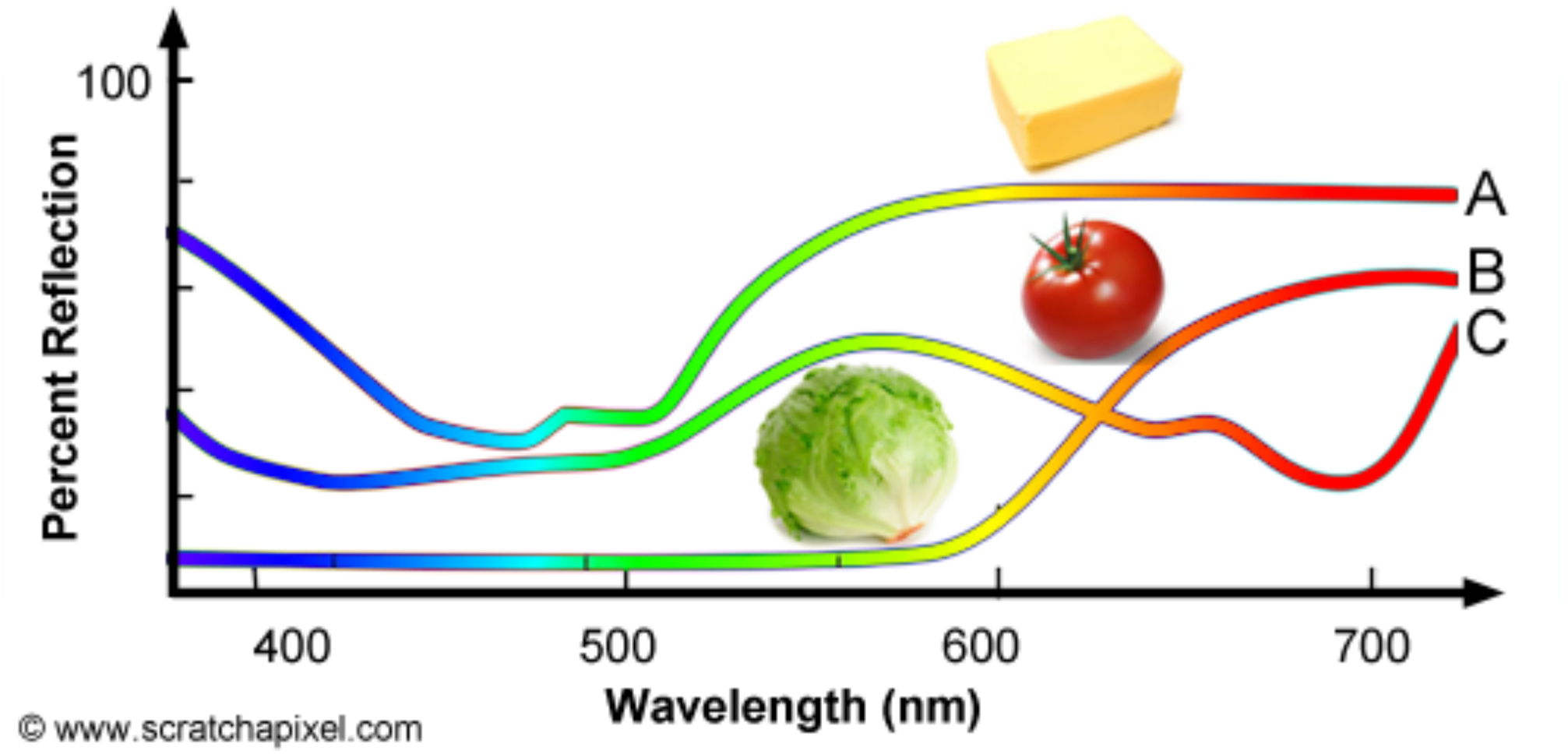
Materials

Rendered by Unreal Engine

The appearance of a material is determined by the manner in which light is reflected from it, or transmitted through it.

What is the most basic material property?

Colour: Spectral Reflectance Curves



[from scratchapixel.com]

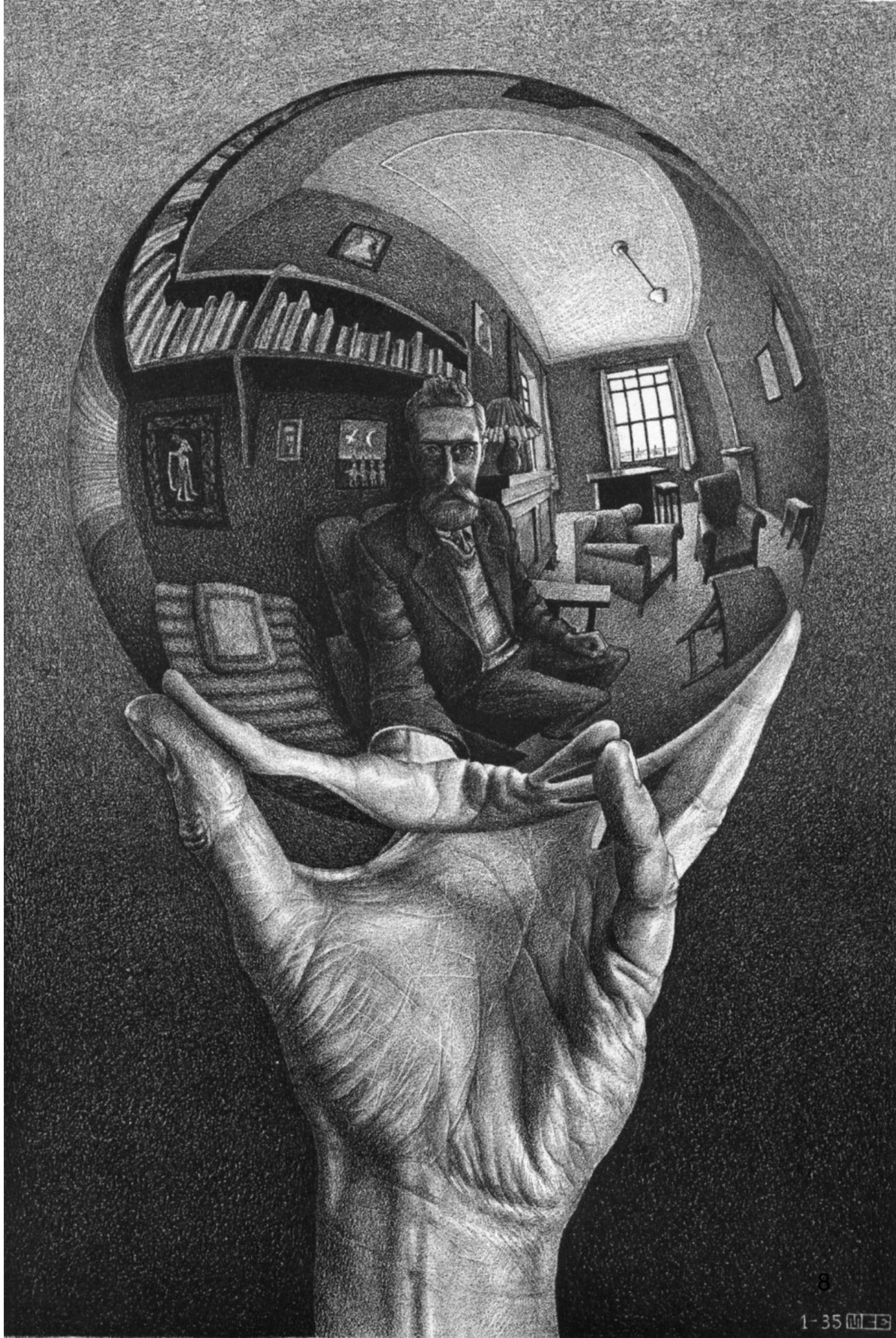
But not the only factor!

RenderMan PxrLM

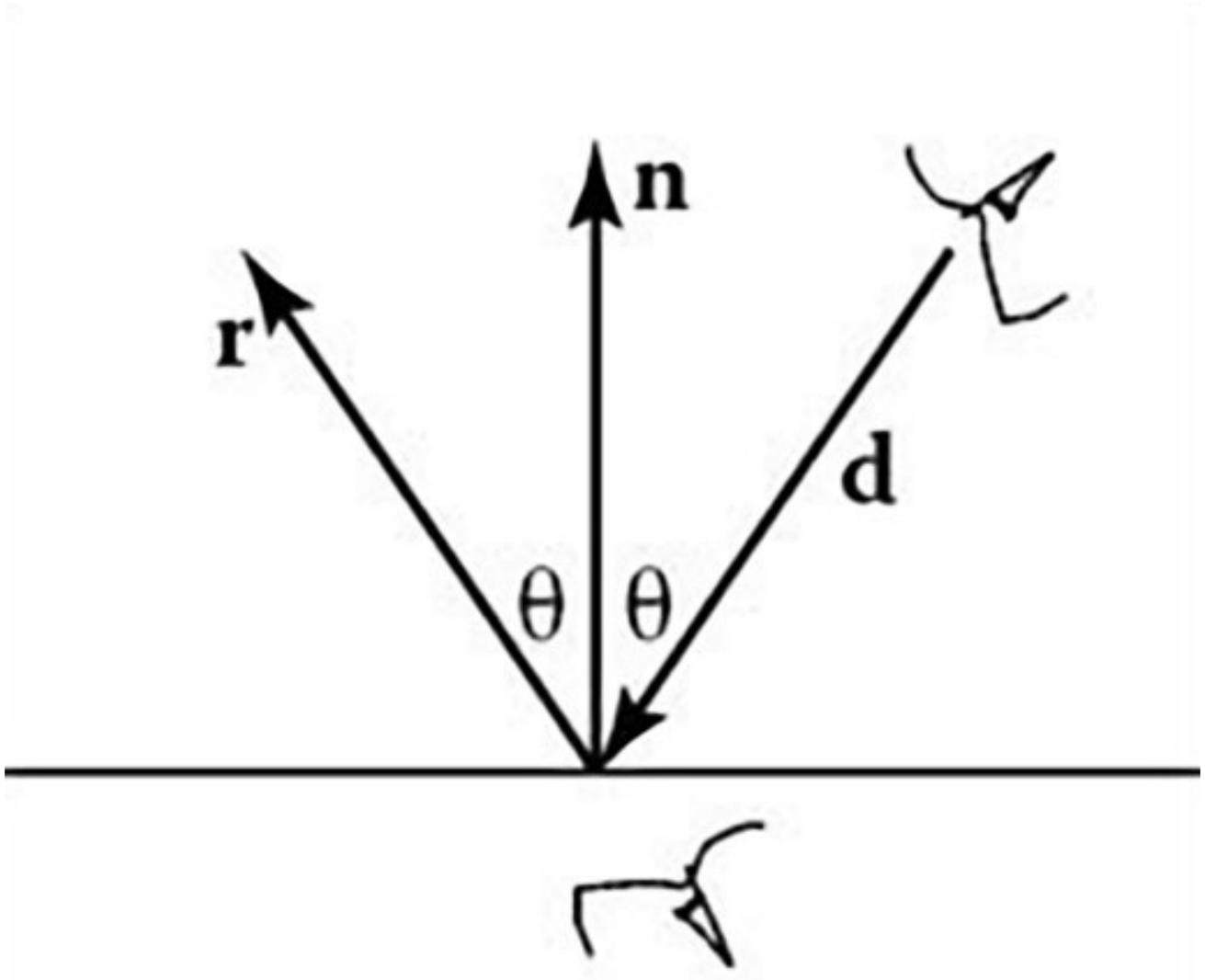
Let’s take a look at some real world materials

Hand with Reflecting Sphere (Self-Portrait)

M.C. Escher, 1935



Ideal Specular Reflections



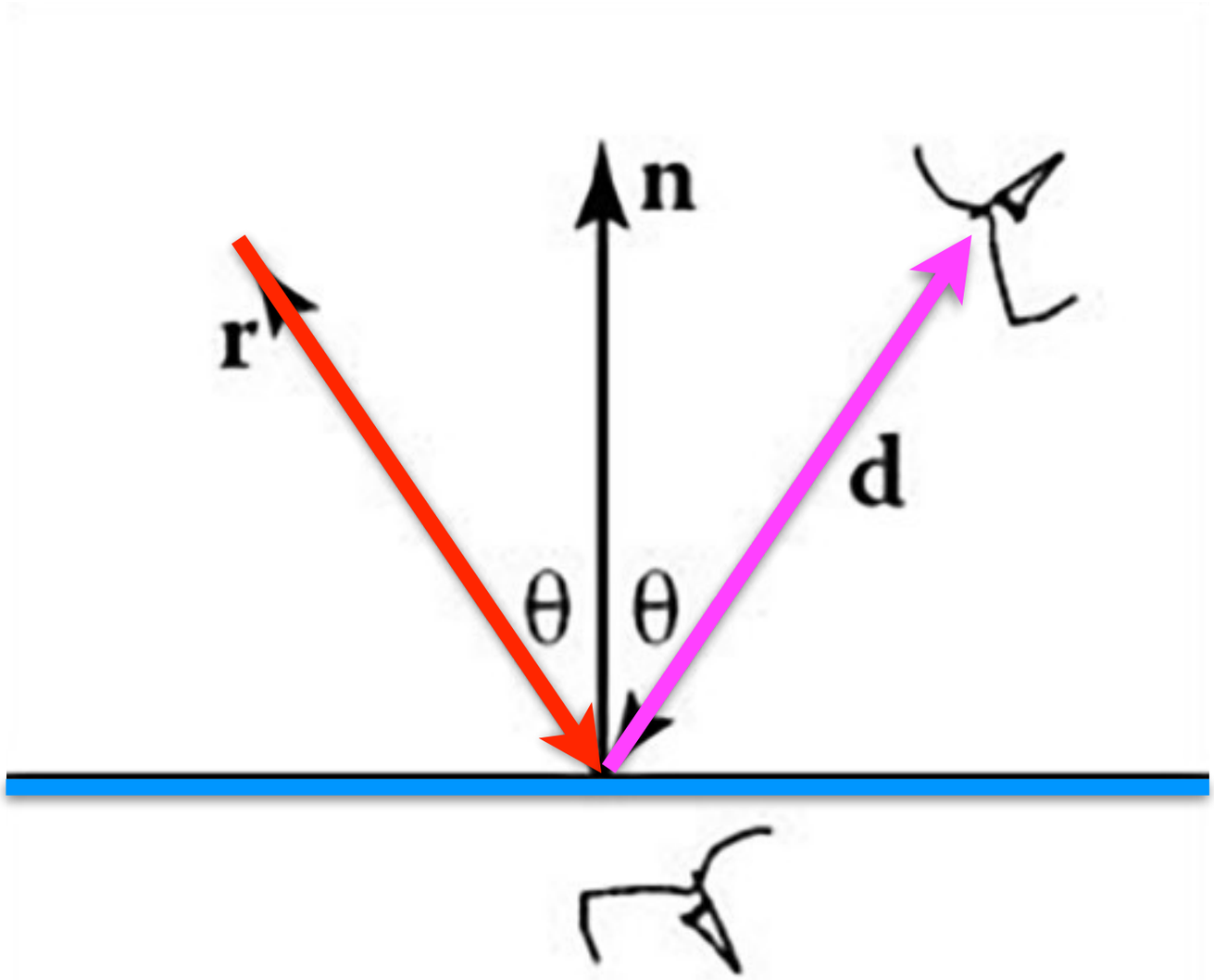
$$\mathbf{r} = \mathbf{d} - 2(\mathbf{d} \cdot \hat{\mathbf{n}})\hat{\mathbf{n}}$$

Trace another ray, as if you were looking from underneath.

Real surfaces are not perfectly specular!

Real surfaces are not perfectly specular!

Mixed Specular Reflections



$$\mathbf{r} = \mathbf{d} - 2(\mathbf{d} \cdot \hat{\mathbf{n}})\hat{\mathbf{n}}$$

Combine reflected ray's light with the surface material colour.

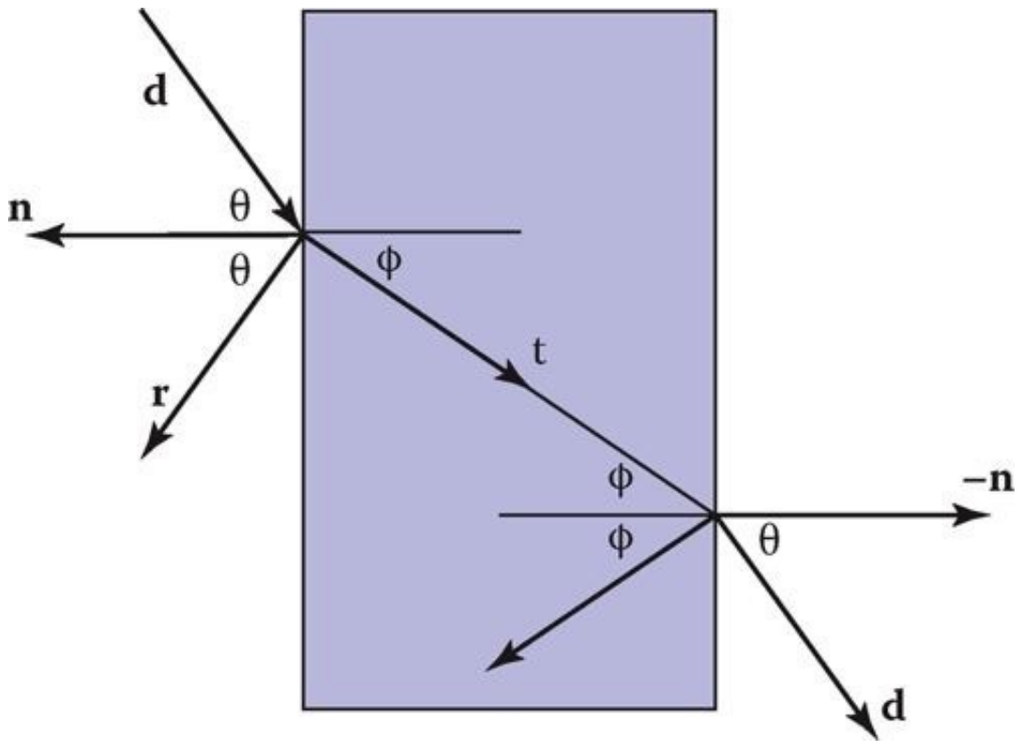
A Glass Marble

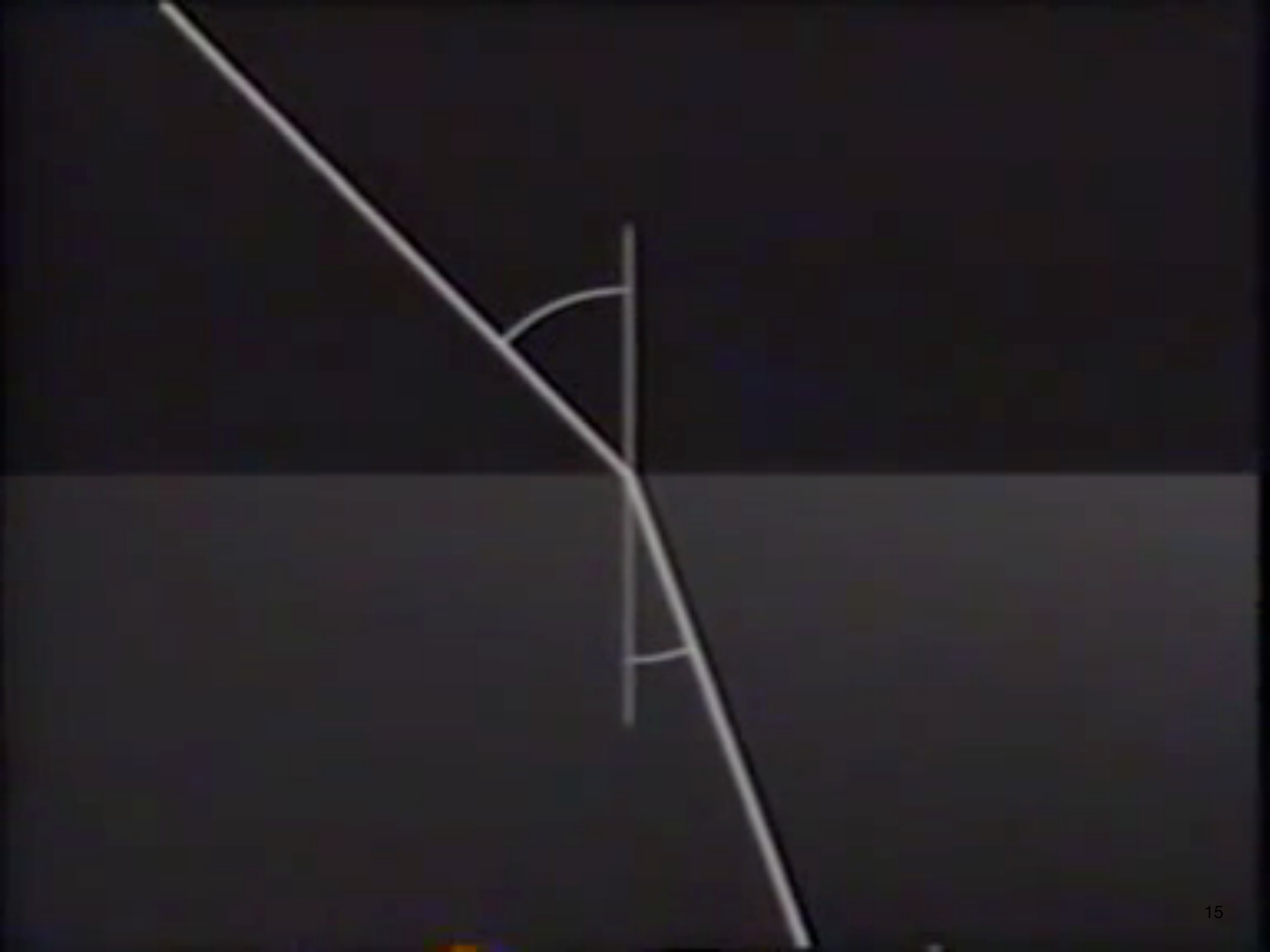
What do we do with this material?

Snell's Law

- Ratio of sines of angles is equal to ratio of velocities:

$$\frac{\sin\theta}{\sin\phi} = \frac{v}{v_t} = \frac{n_t}{n}$$



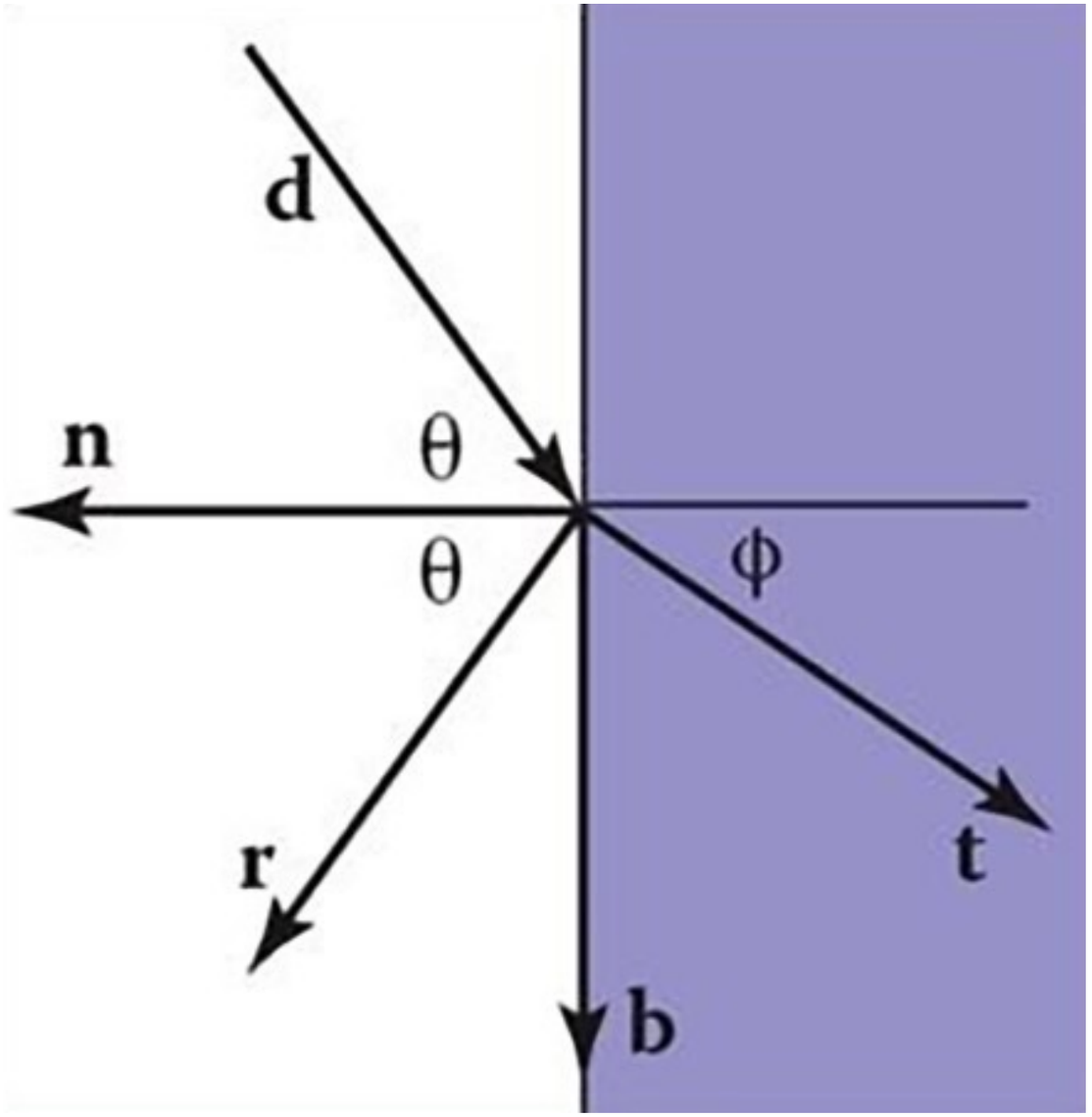


Index of Refraction

of some common materials

n	Material
1.0001	air
1.333	water
1.47	olive oil
1.52	crown glass
1.62	flint glass
2.15	cubic zirconia
2.42	diamond

Ray Tracing Refraction



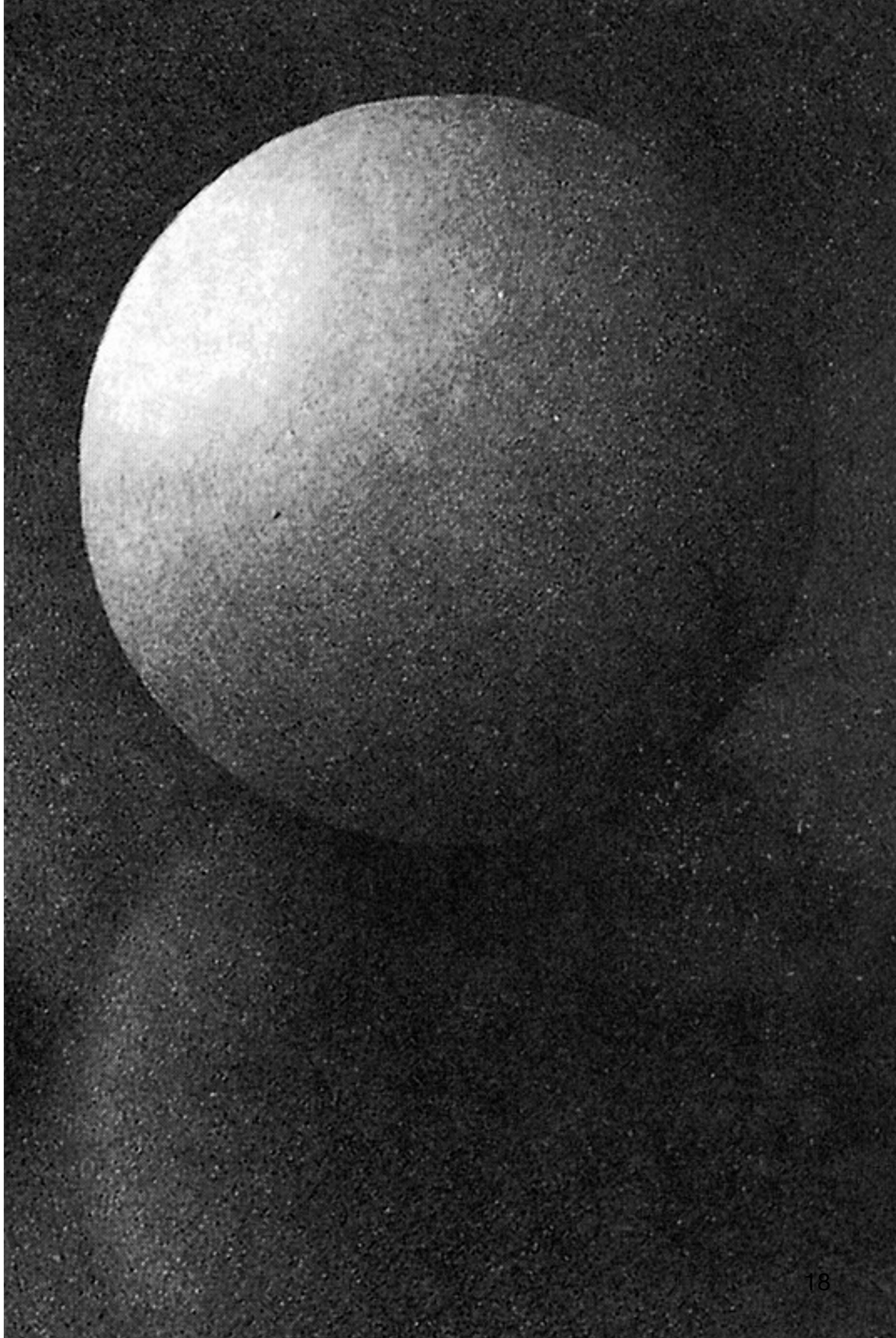
$$n \sin\theta = n_t \sin\phi$$

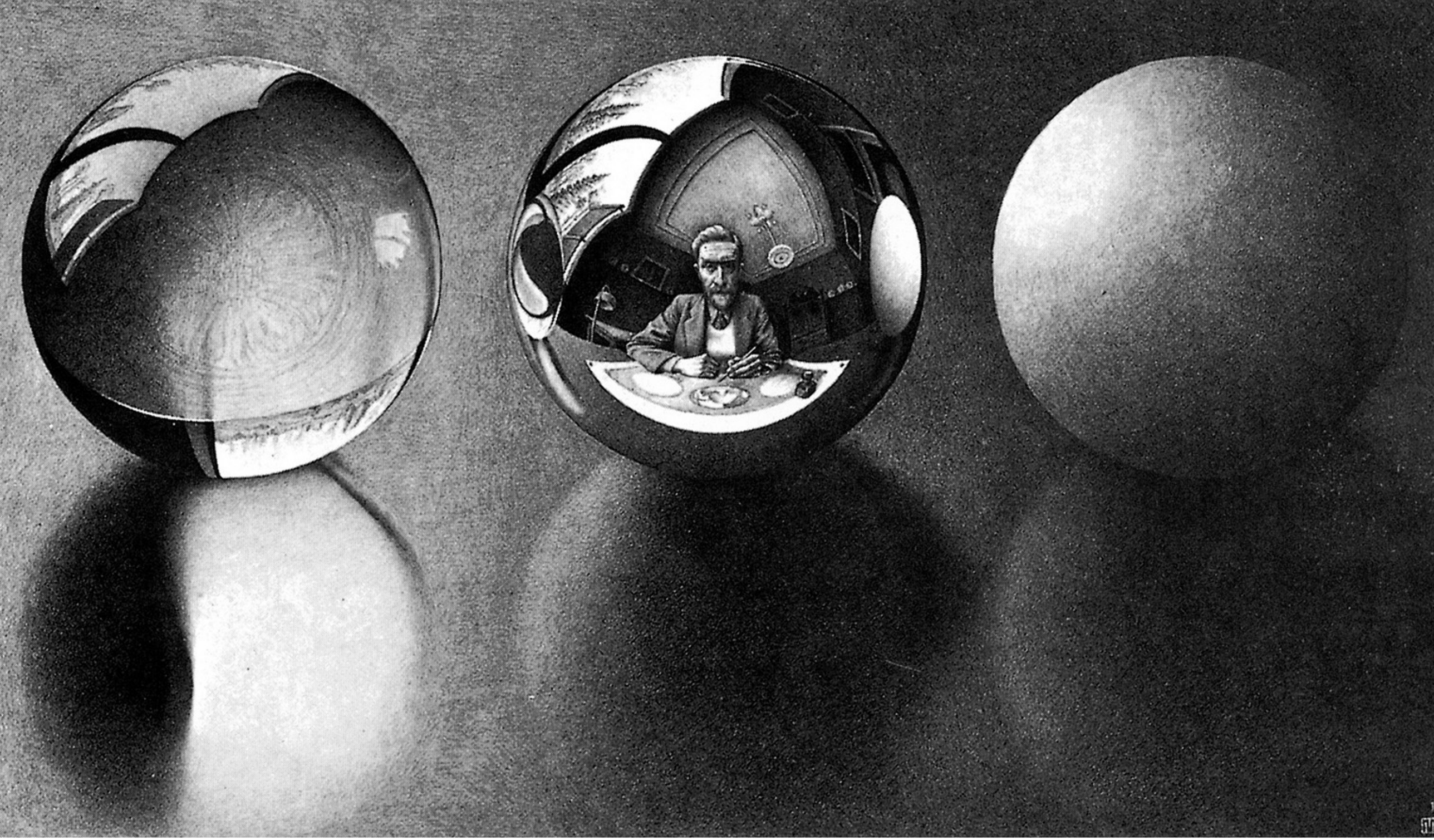
$$\cos^2\phi = 1 - \frac{n^2(1-\cos^2\theta)}{n_t^2}$$

$$\mathbf{t} = \frac{n(\mathbf{d} + \hat{\mathbf{n}}\cos\theta)}{n_t} - \hat{\mathbf{n}}\cos\phi$$

A Diffuse Reflector

M.C. Escher, 1946





Three Spheres II

M.C. Escher, 1946

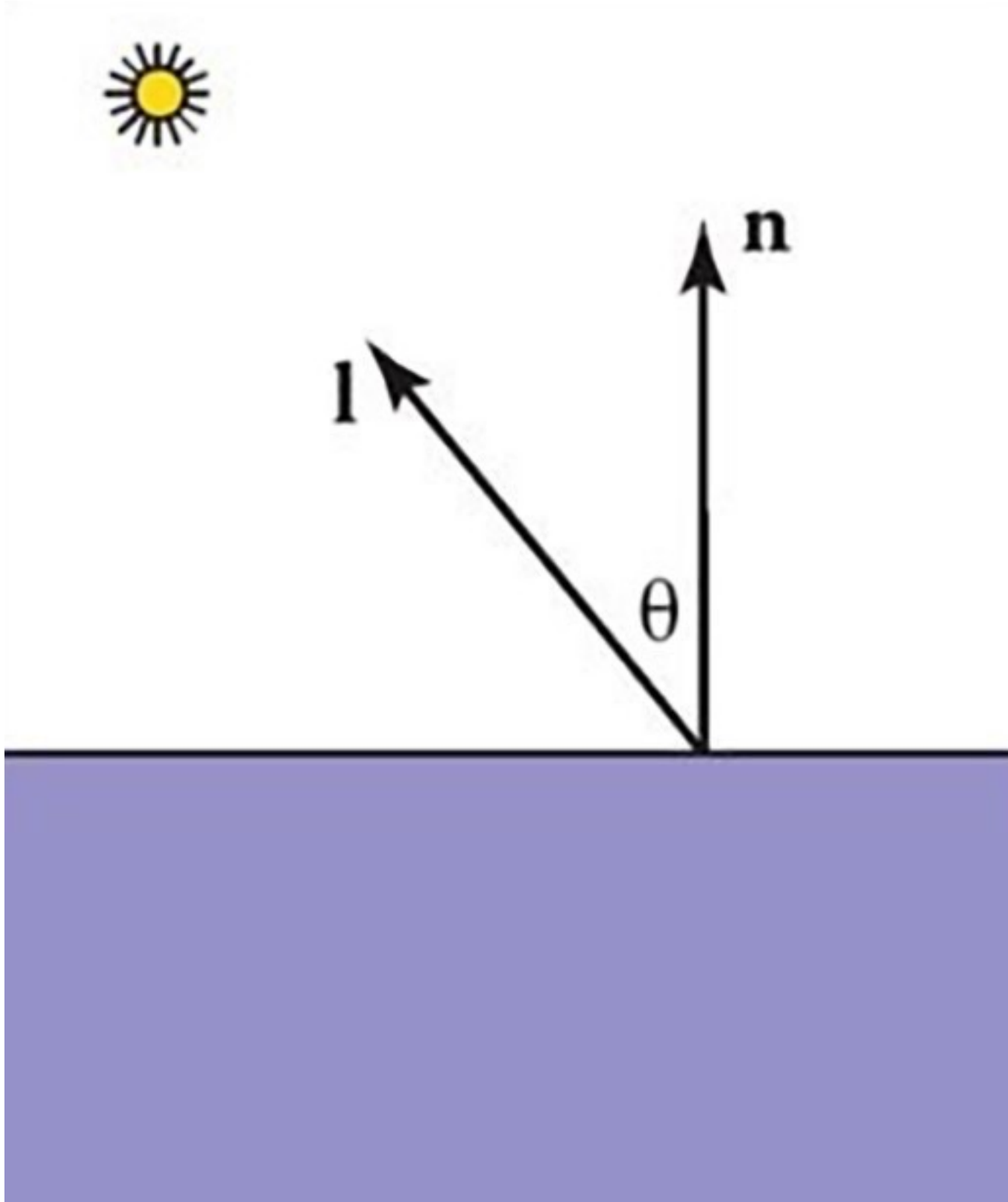
Properties of Diffuse Reflectors

Diffuse Reflection

- Brightness dependent *only* on the direction of incident light
- View direction has no effect on appearance
- Lambert's cosine law:

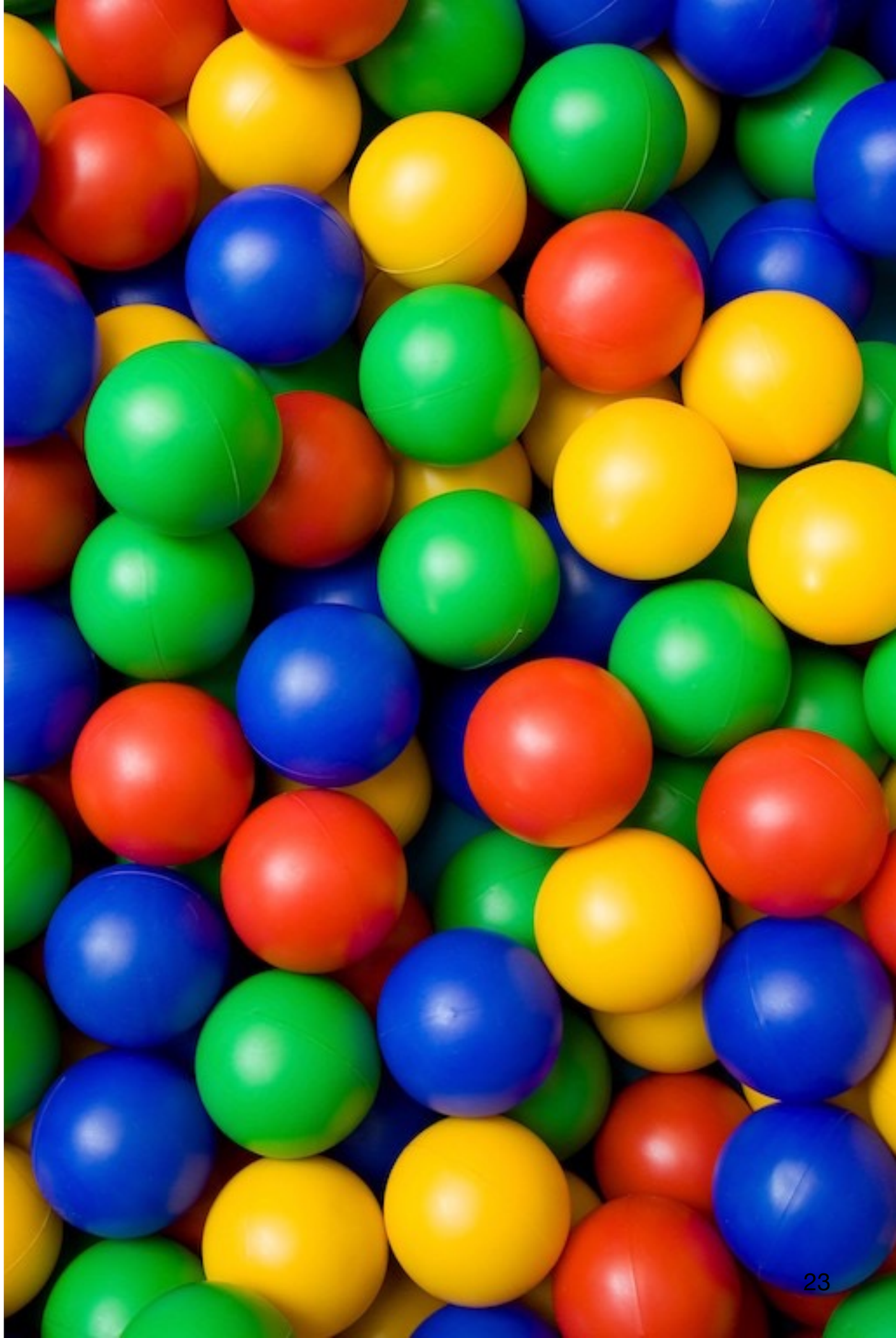
$$c \propto \hat{\mathbf{n}} \cdot \hat{\mathbf{l}}$$

$$c = c_r c_l \max(0, \hat{\mathbf{n}} \cdot \hat{\mathbf{l}})$$

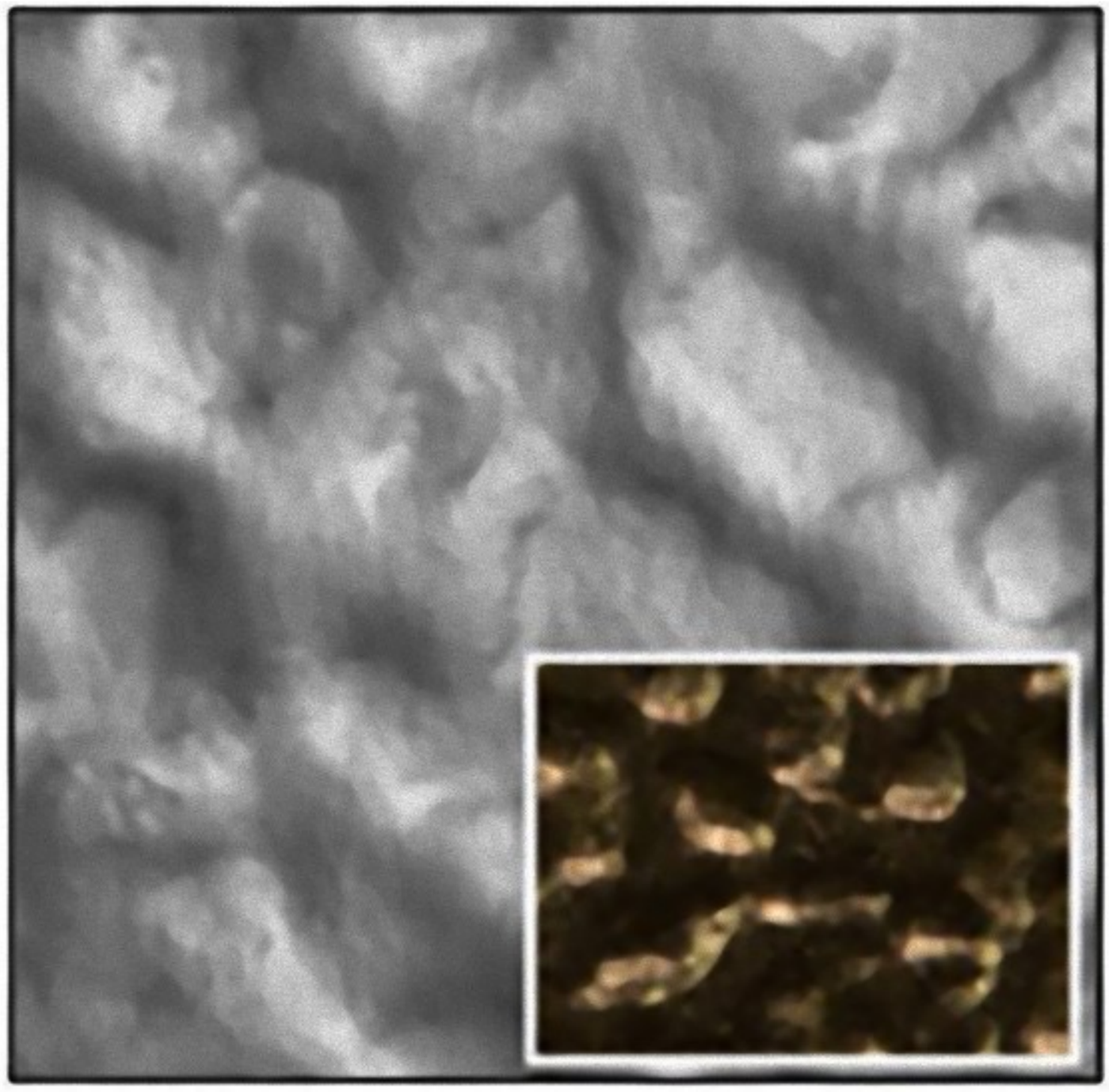


Specular Highlights

A Heuristic Approximation

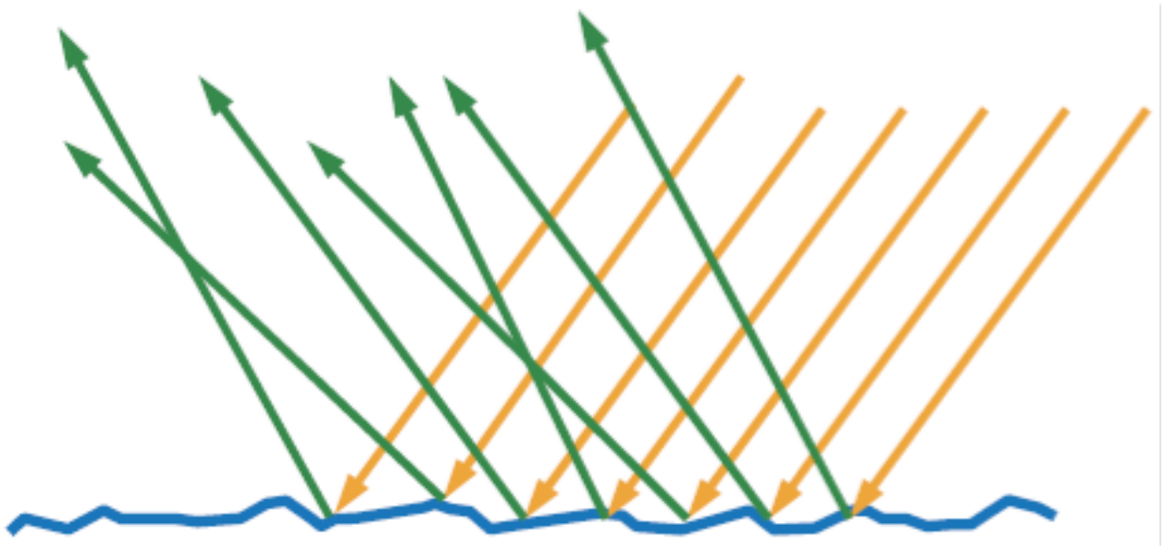


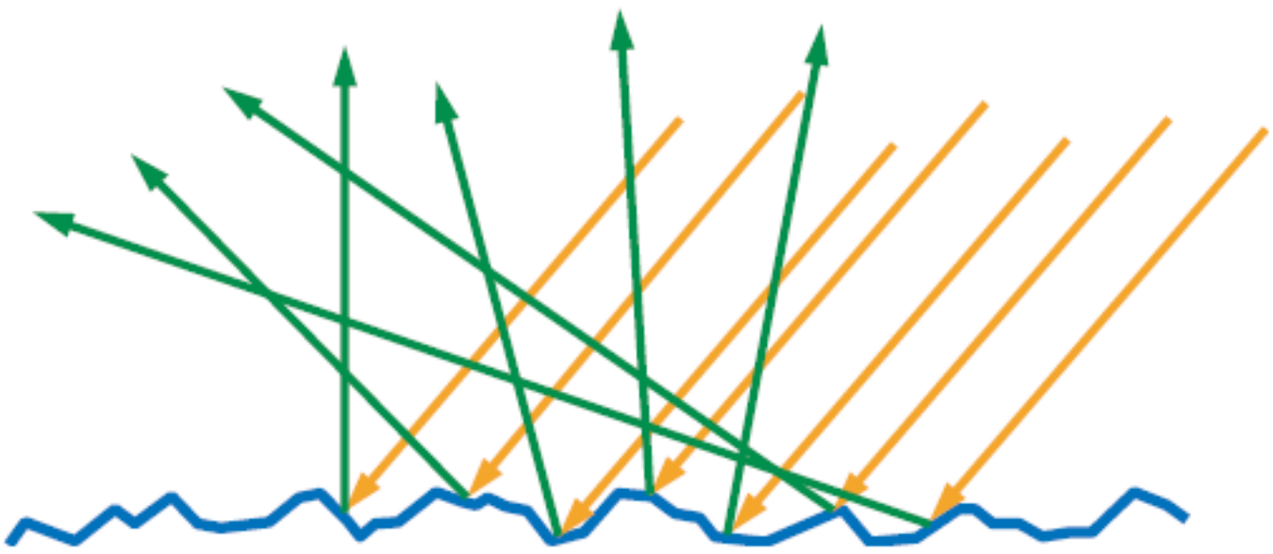
Plastic, Magnified



[image from gelsight.com]

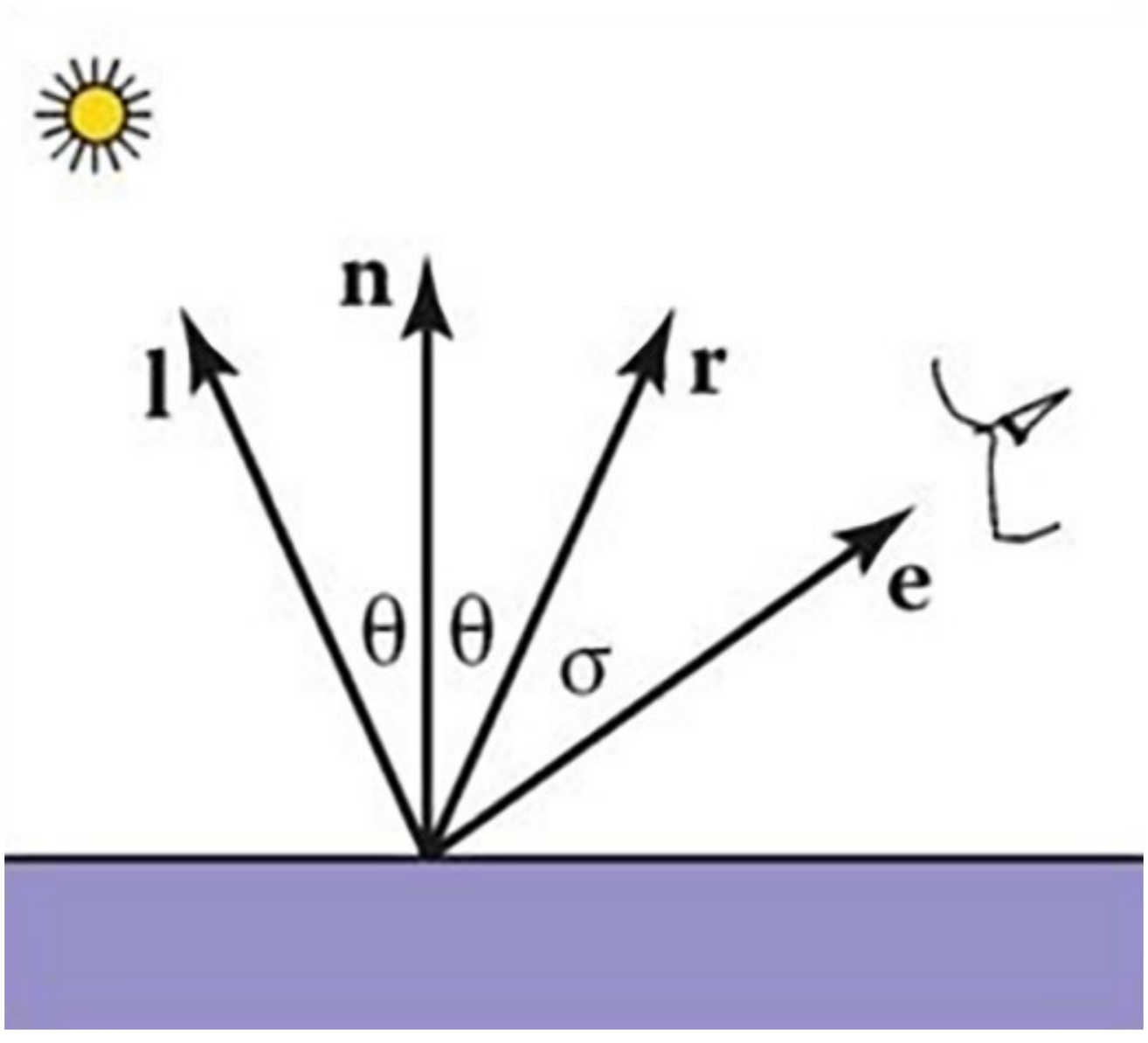
Microfacet Geometry Model





[images from *Real-Time Rendering*, A K Peters, 2008]

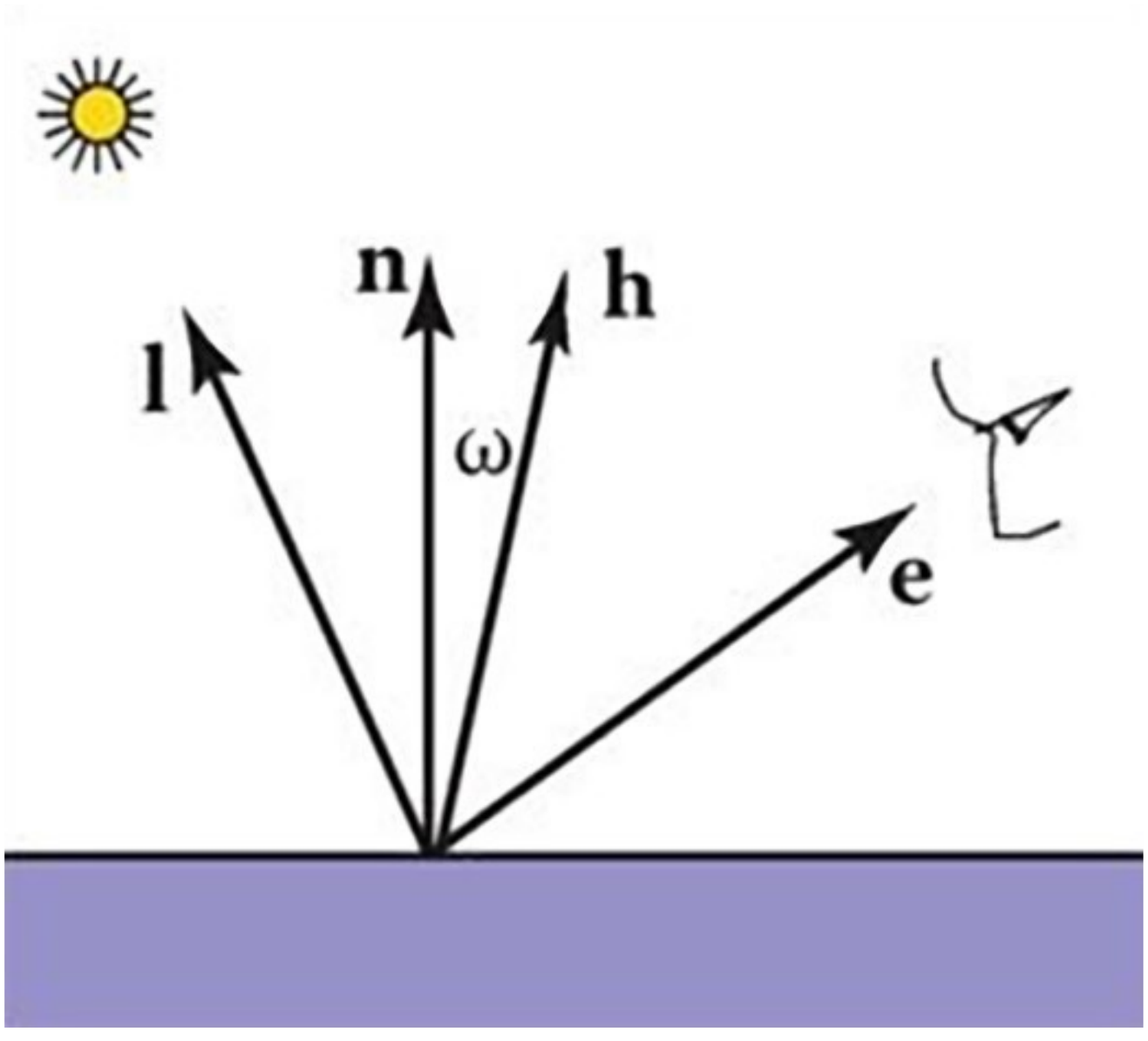
Phong Lighting Model



$$\mathbf{r} = -\mathbf{l} + 2(\mathbf{l} \cdot \hat{\mathbf{n}})\hat{\mathbf{n}}$$

$$c = c_l \max(0, \hat{\mathbf{e}} \cdot \hat{\mathbf{r}})^p$$

Blinn-Phong Lighting Model

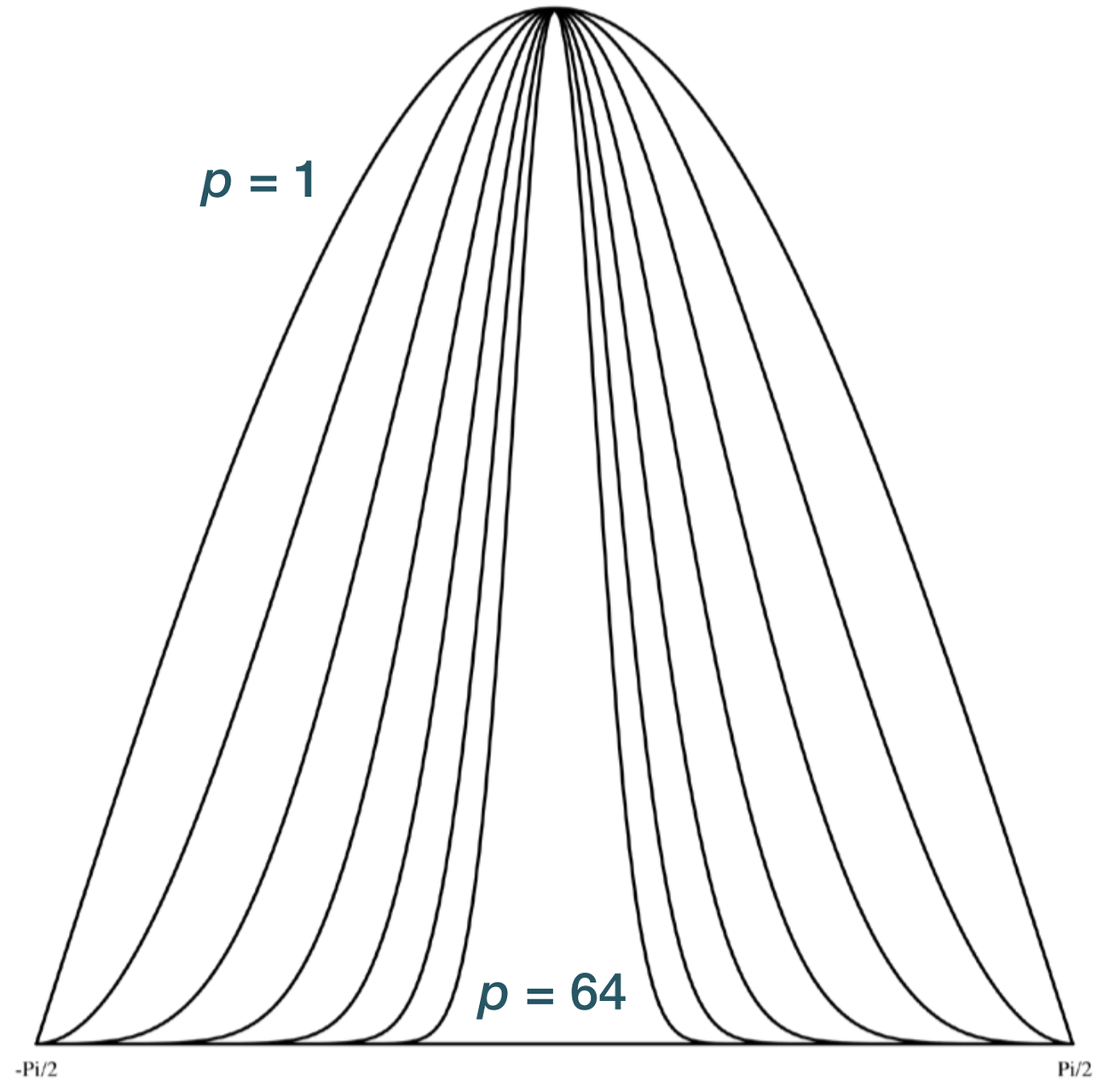


$$\hat{\mathbf{h}} = \frac{\mathbf{e} + \mathbf{l}}{||\mathbf{e} + \mathbf{l}||}$$

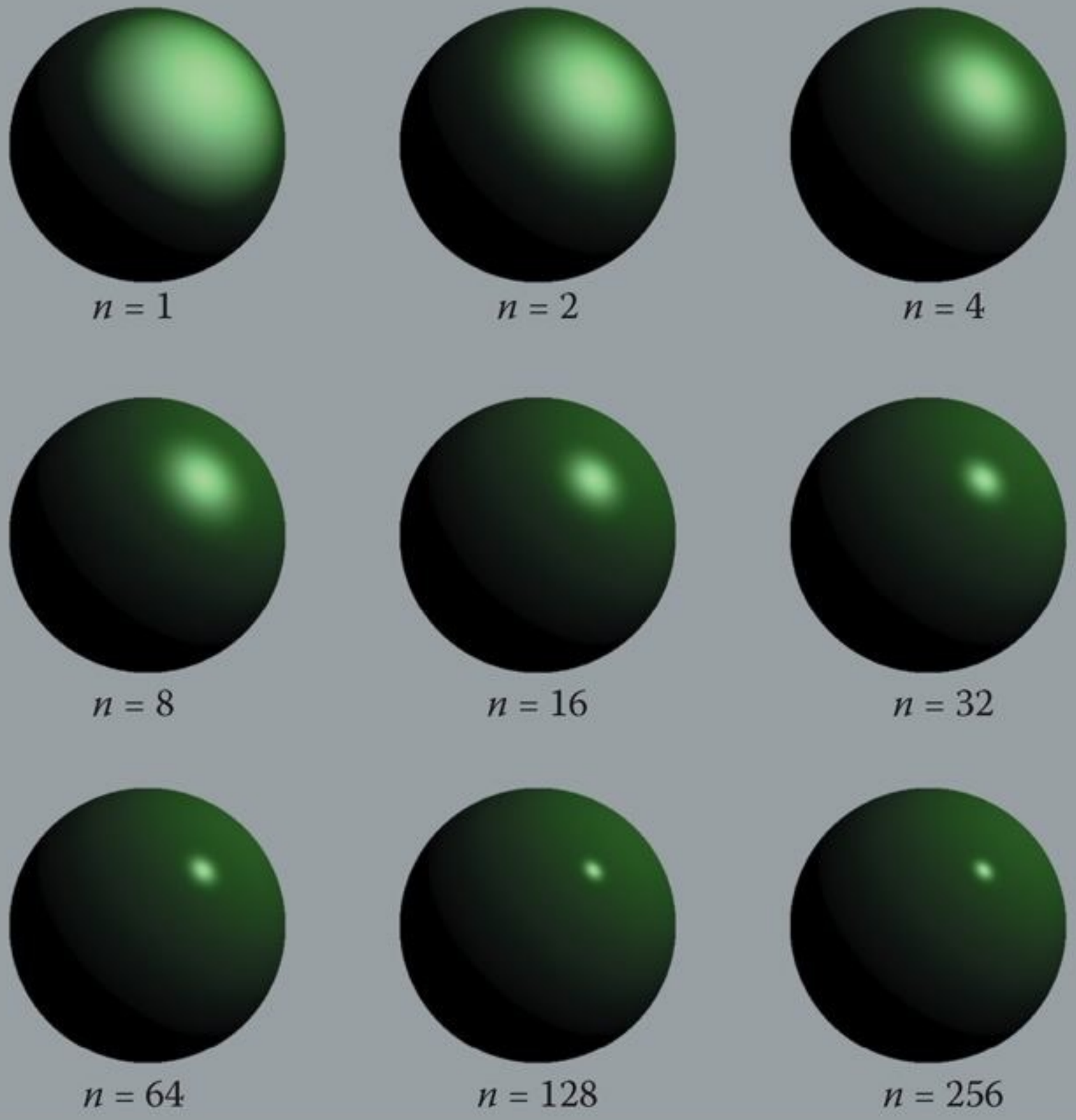
$$c = c_l \max(0, \hat{\mathbf{h}} \cdot \hat{\mathbf{n}})^p$$

The Phong Exponent

$$y = \cos^p \theta$$

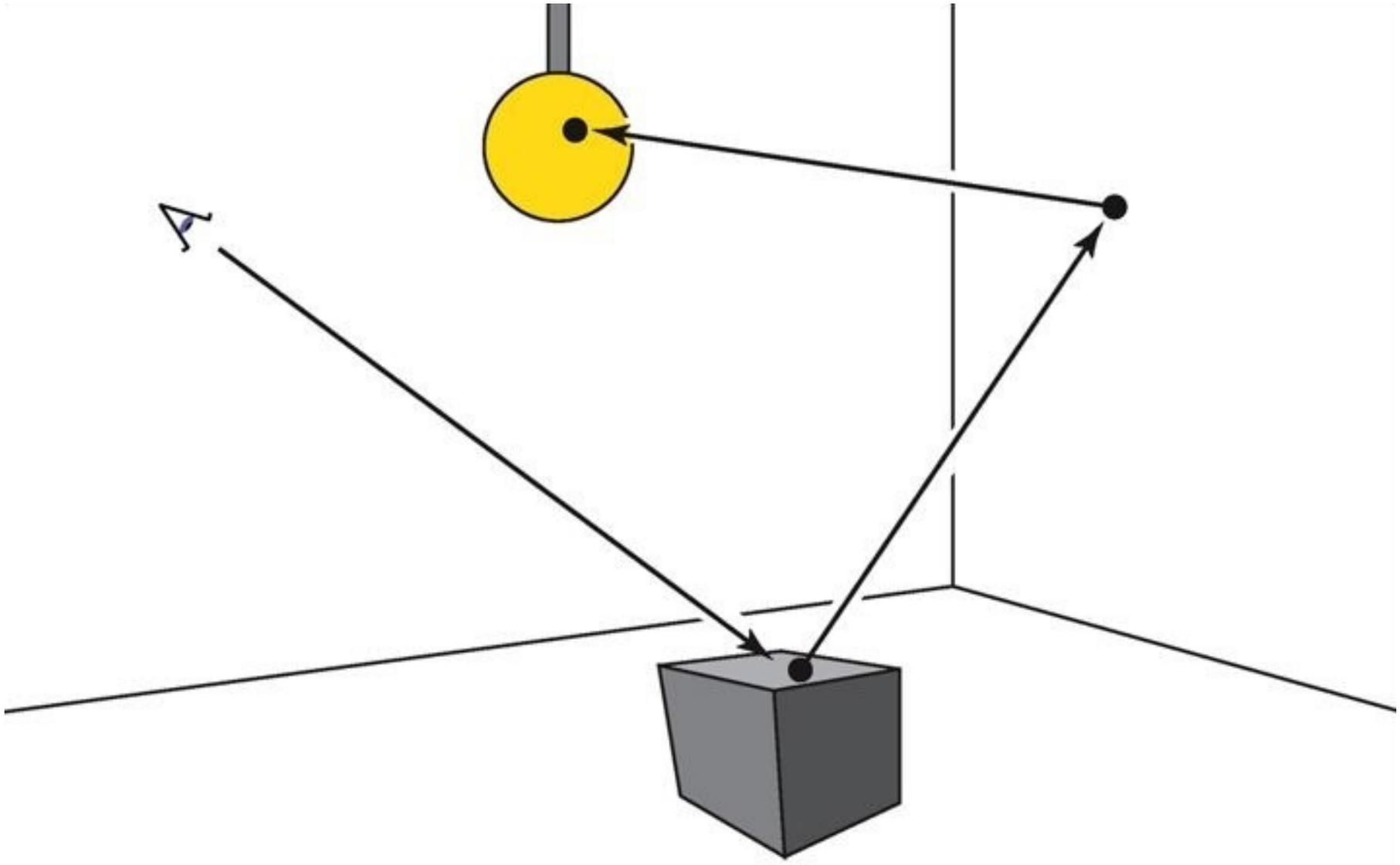


Phong Highlights



What about ambient light?

Indirect Lighting



Material reflection works both ways!

Global Illumination

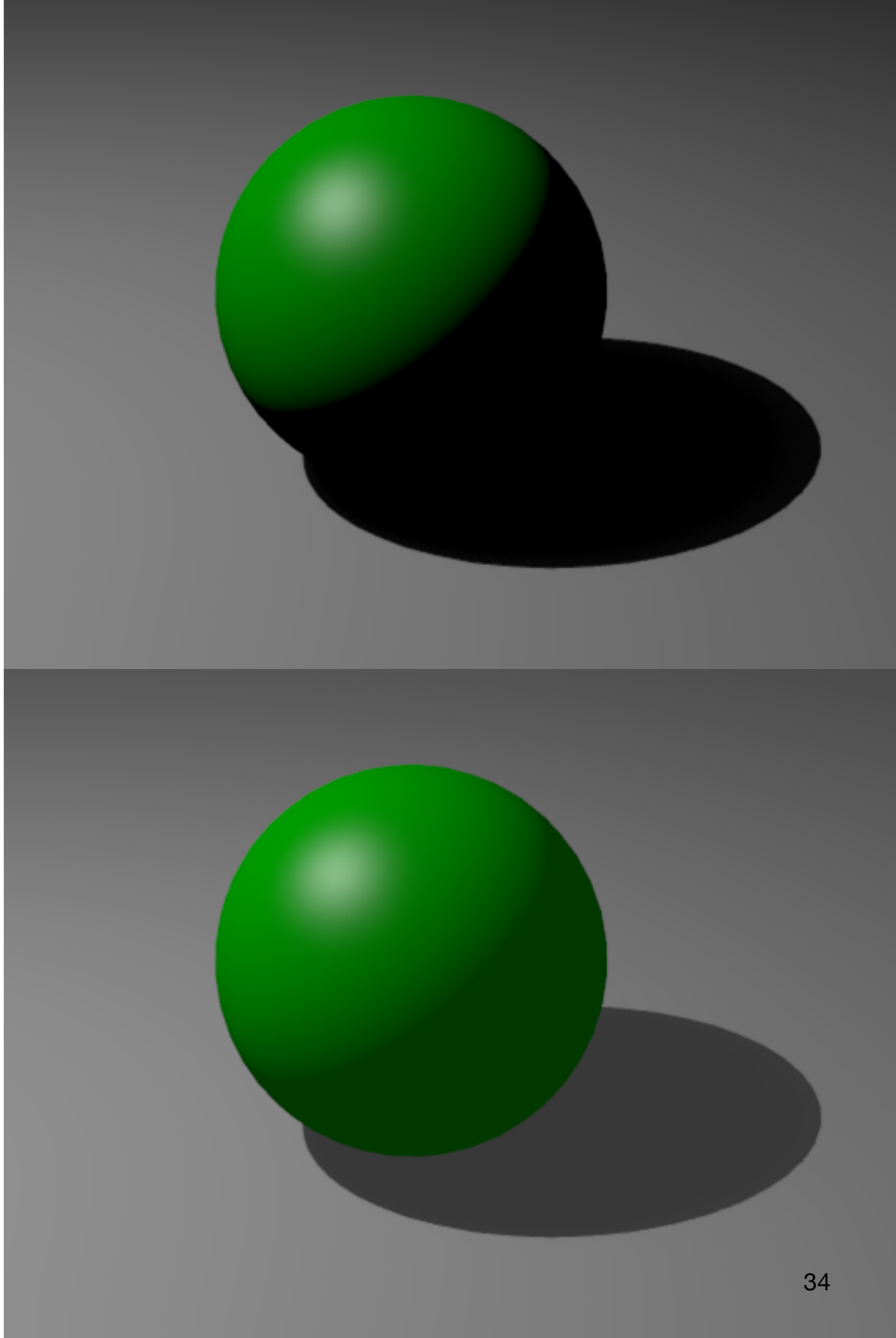
indirect direct combined

Global illumination is really hard and expensive to compute!

Ambient Light

Approximated by a constant light source that represents the average indirect light energy in the scene.

$$c = c_r c_a$$



Our final heuristic shading equation…

- with ambient, diffuse, and specular terms:

$$c = c_r \left(c_a + c_l \max(0, \hat{\mathbf{n}} \cdot \hat{\mathbf{l}}) \right) + c_l \, c_p \left(\hat{\mathbf{h}} \cdot \hat{\mathbf{n}} \right)^p$$

- c_r is reflectance (diffuse) colour of material
- c_p is specular colour of material
- p is Phong exponent, or shininess of material
- c_l is light source intensity (colour)
- c_a is ambient light intensity (colour)

What kinds of materials can’t we model?

A Glass of Milk

Would you drink it?

[image courtesy of P. Hanrahan]

Subsurface Scattering

skim milk

whole milk

diffuse “milk”?

[images courtesy of P. Hanrahan, Stanford University]

Subsurface Scattering

surface only

translucent skin

[images courtesy of P. Hanrahan, Stanford University]

Other biological materials?

real hair

shaded “hair”?

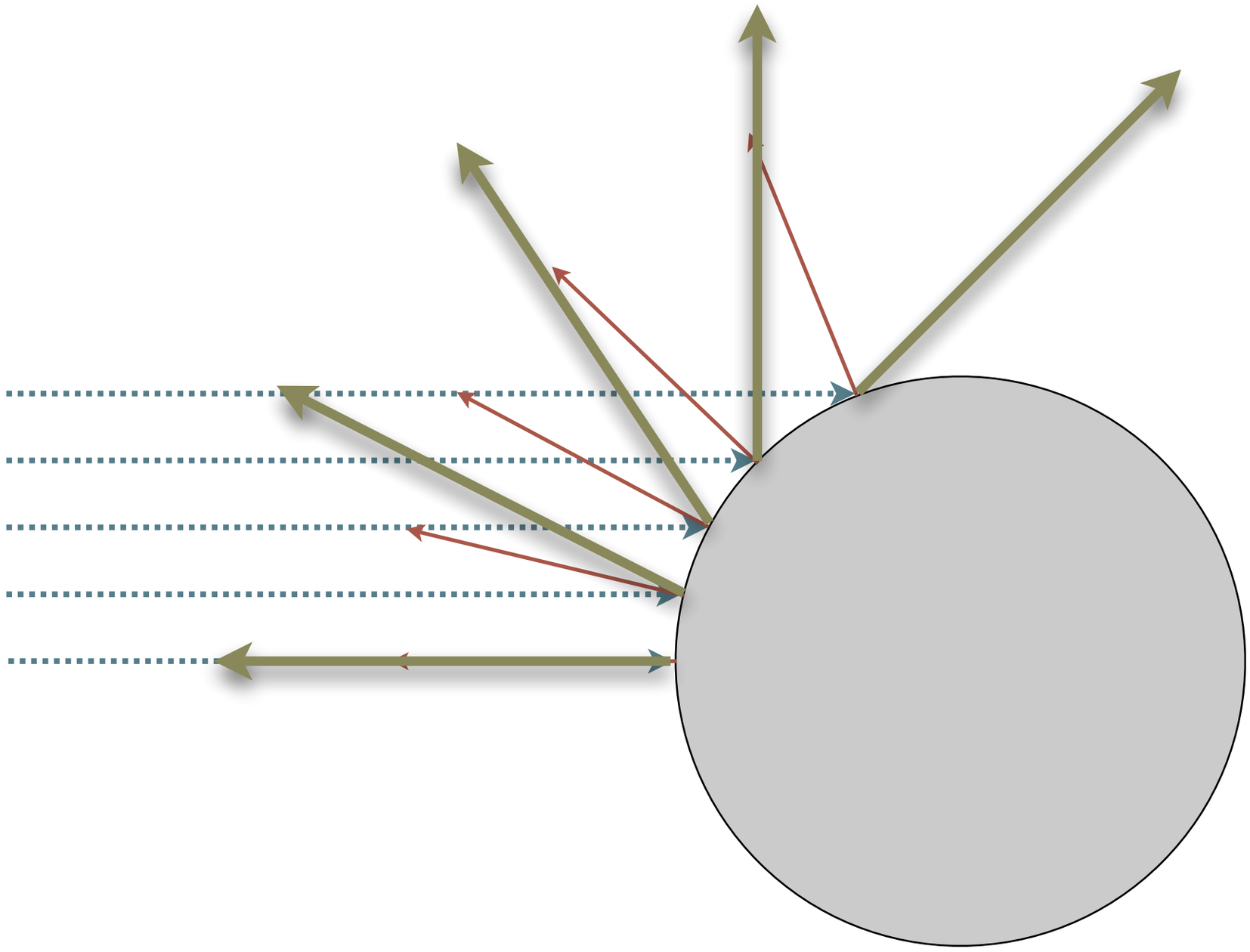
[from blendernation.com]

Environment Maps

A bonus topic…

How much can you see on this mirrored sphere?

Side View



Indexing the Image

If you need a reflection over normal

$$\hat{\mathbf{n}} = (x_n, y_n, z_n),$$

read the image at

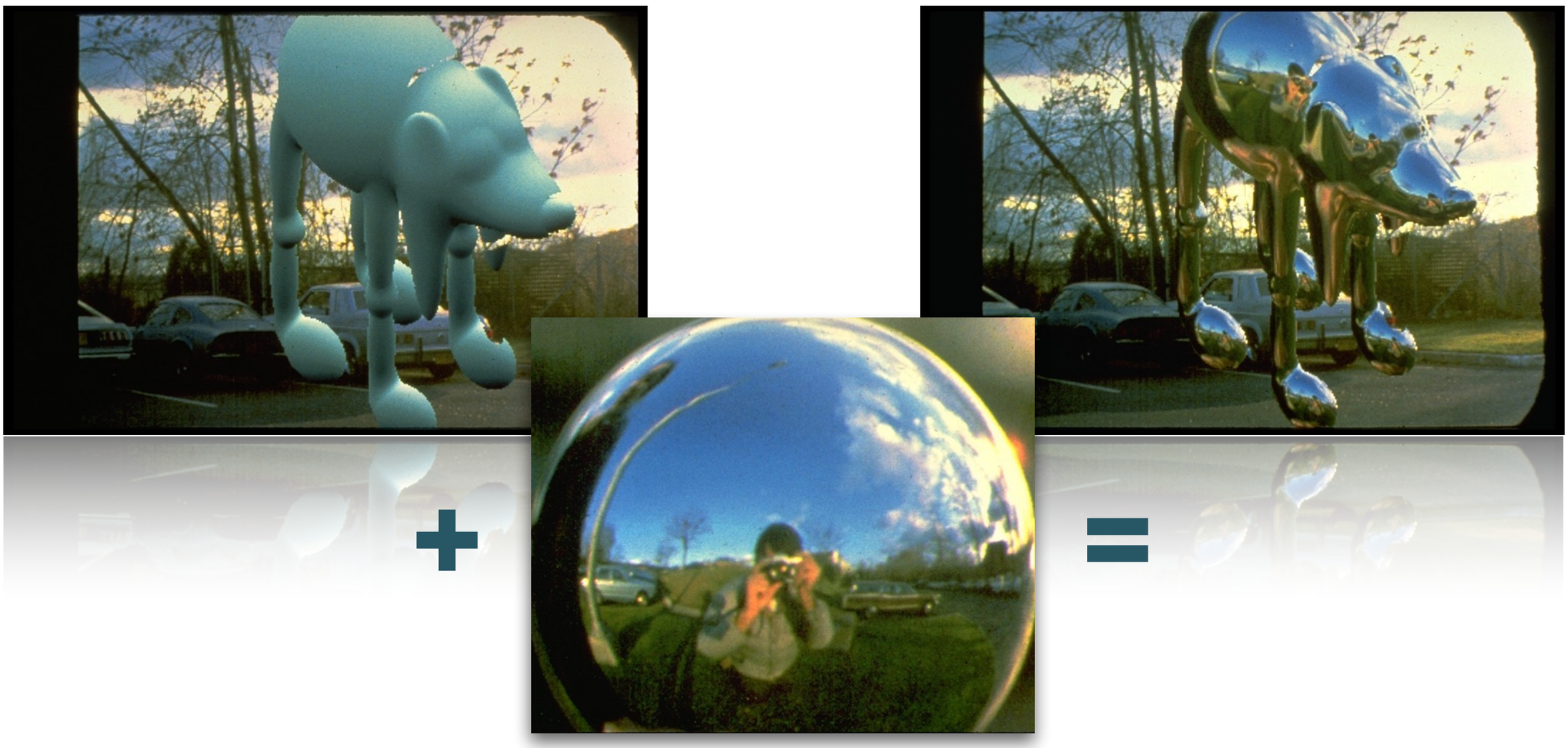
$$(x_n, y_n).$$

Early Reflectance Map Rendering

Gene Miller, MAGI SynthaVision, 1982

[images from pauldebevec.com]

Early Reflectance Map Rendering



[images from pauldebevec.com]

Terminator 2: Judgement Day

TriStar Pictures, 1991

M.C. Escher: Hand with Reflecting Sphere

Gran Turismo 6

Sony Computer Entertainment

Things to Remember

- The appearance of a material is determined by the manner in which light is reflected from it

- The Phong lighting equation approximates material colour, diffuse and specular reflection, and ambient light

- Ideal specular reflection and refraction are relatively easy to achieve with ray tracing

- Environment mapping is a simple way to give reflective materials a realistic rendered appearance