

# CS 130 : Computer Graphics

Lighting and Shading

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# Why we need shading

- Suppose we build a model of a red sphere
- We get something like



- But we want



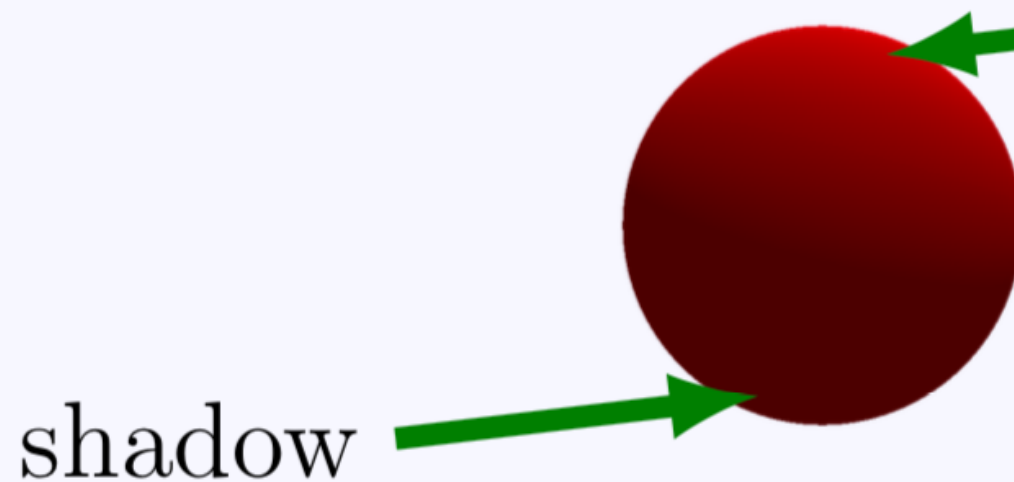
# Shading

- Why does a real sphere look like this?

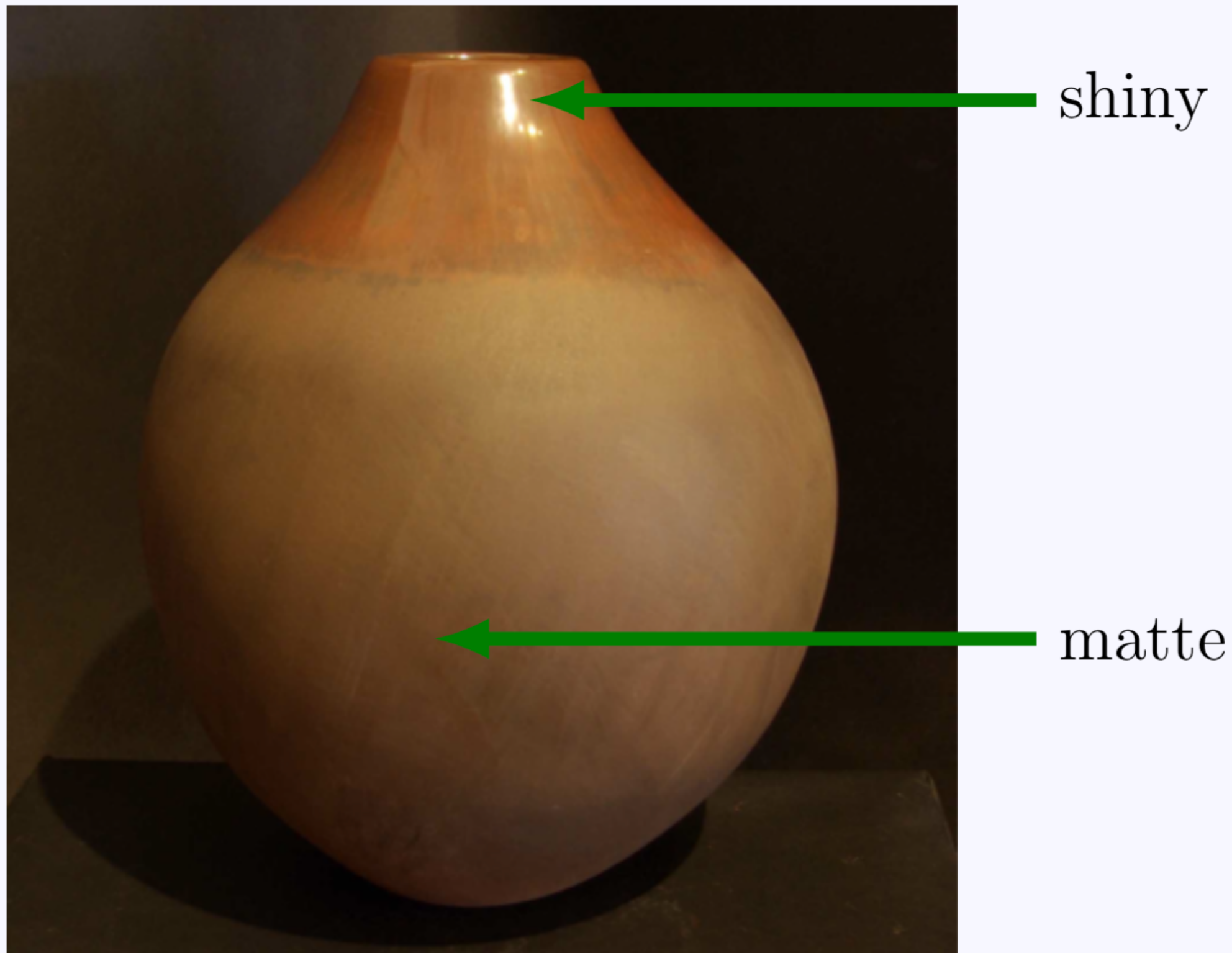


# Shading - lighting

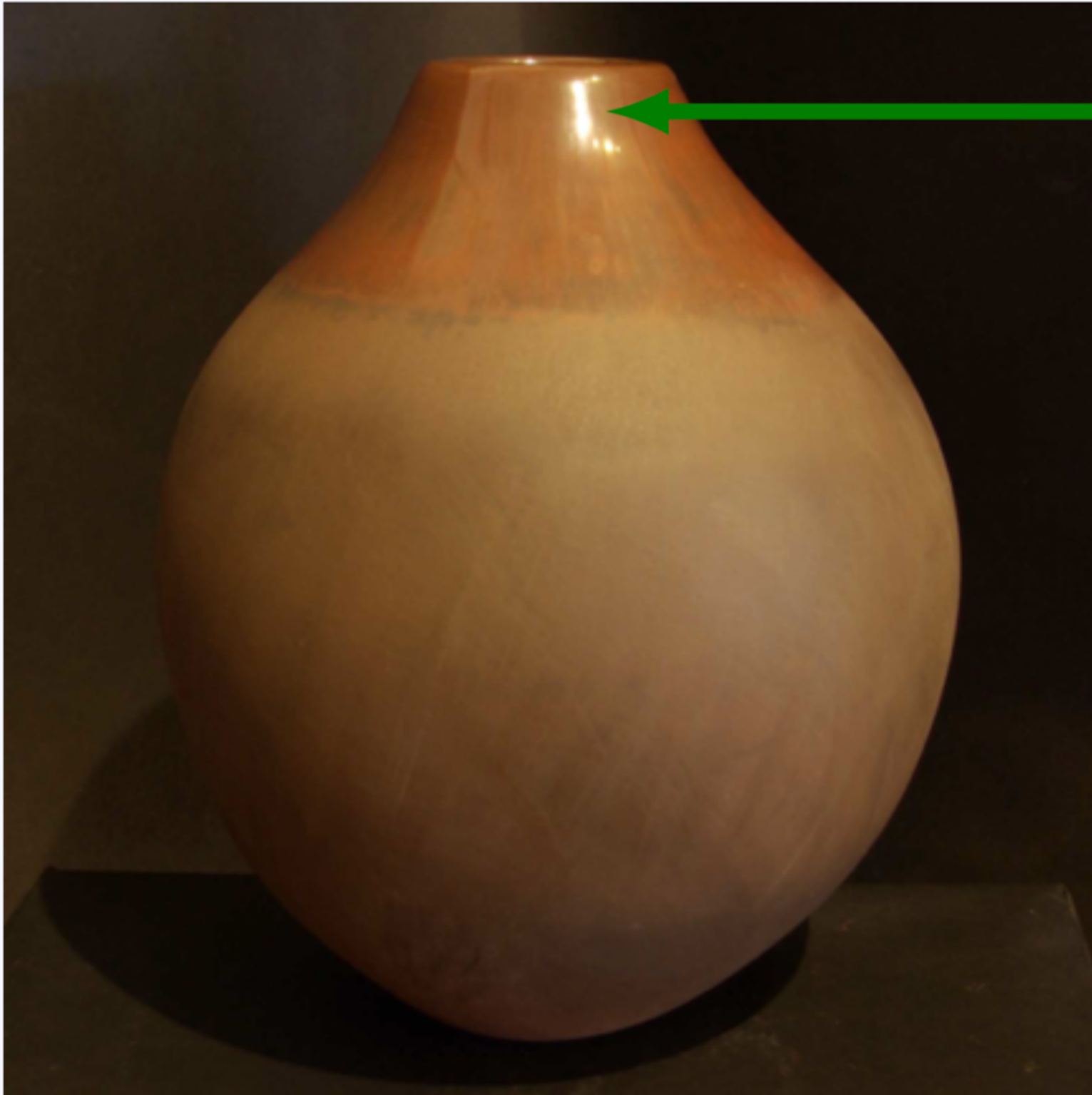
- Why does a real sphere look like this? facing light



# Shading - material properties

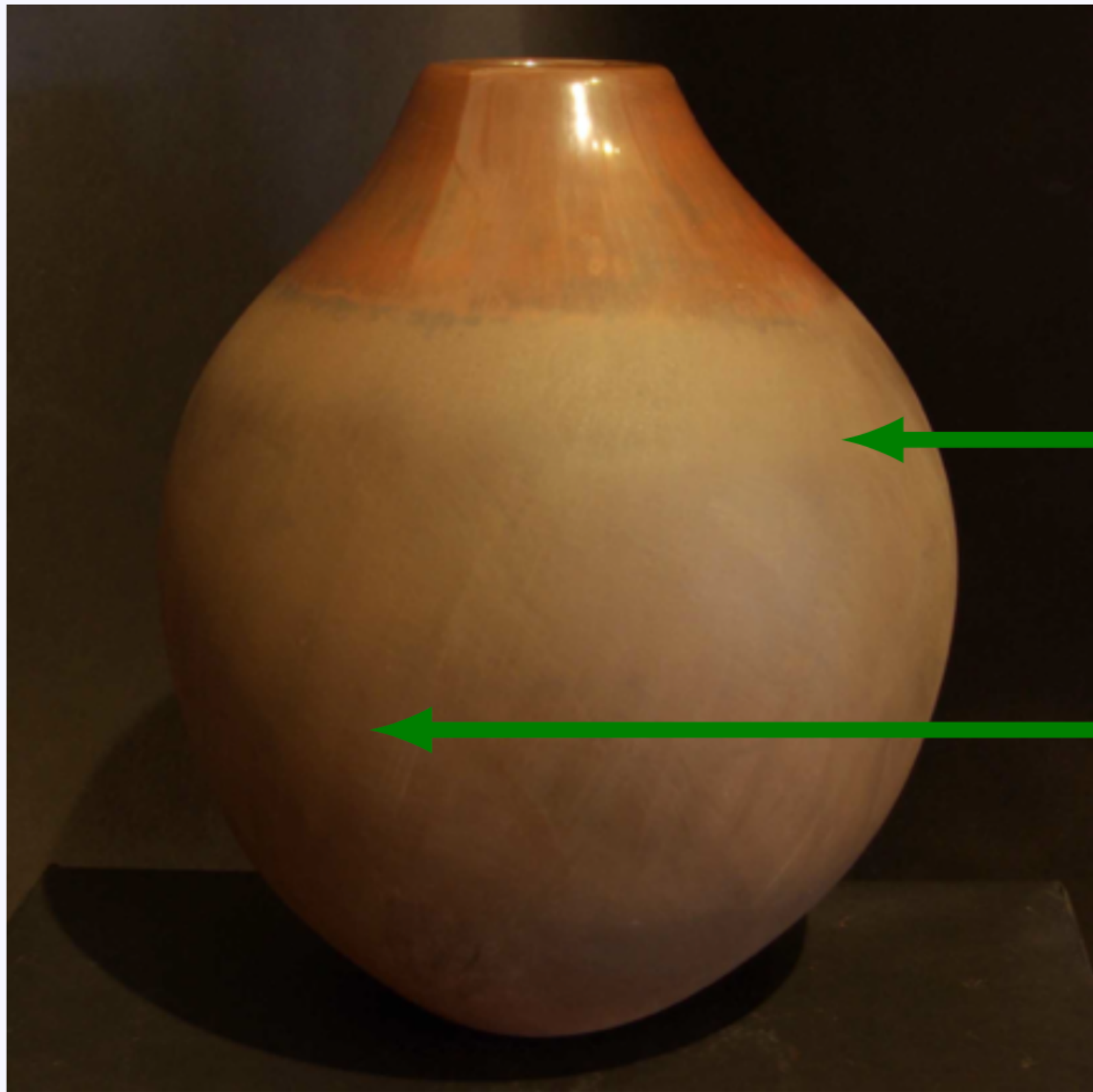


# Shading - viewing location



What if I move?

# Shading - surface orientation

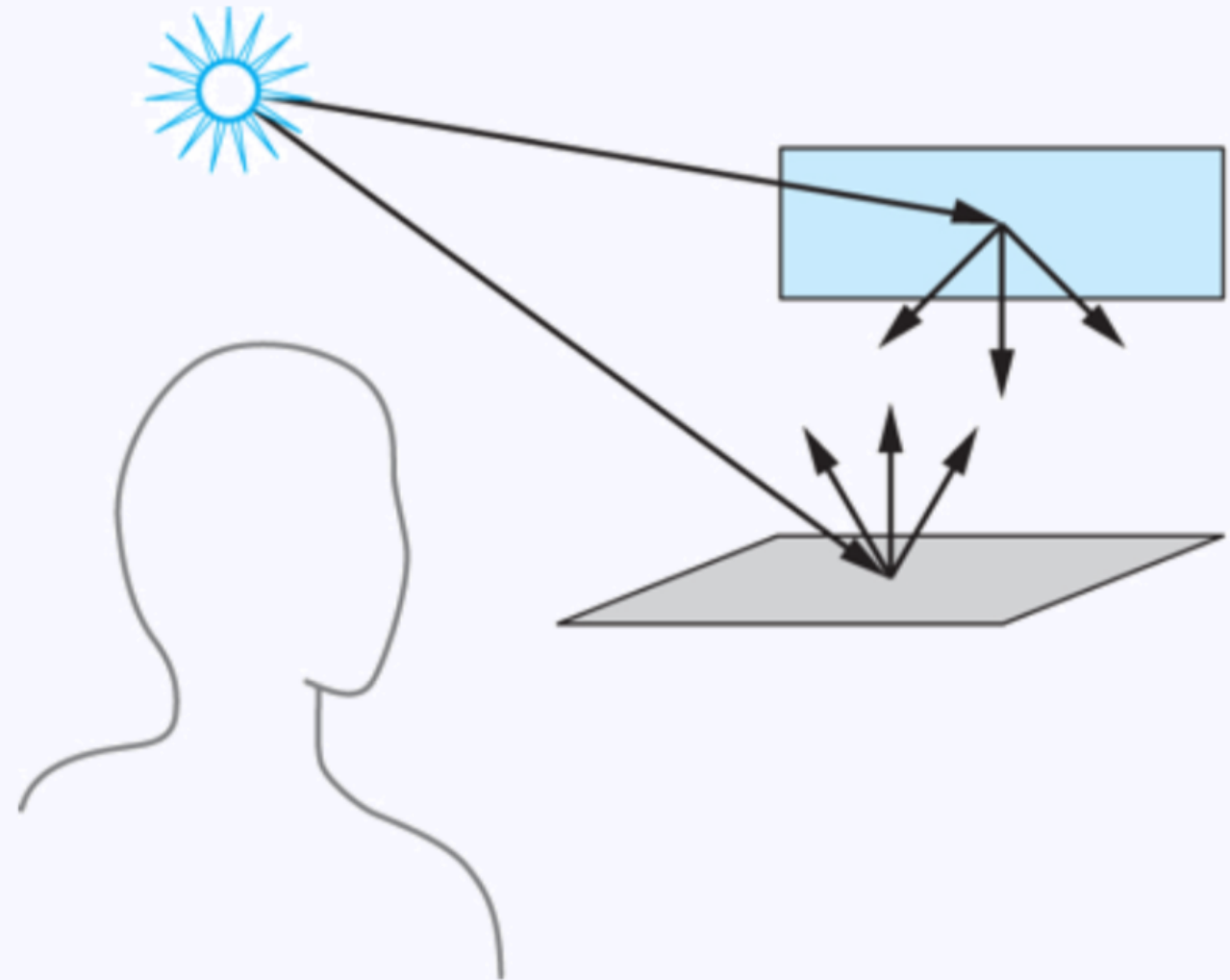


well lit

poorly lit

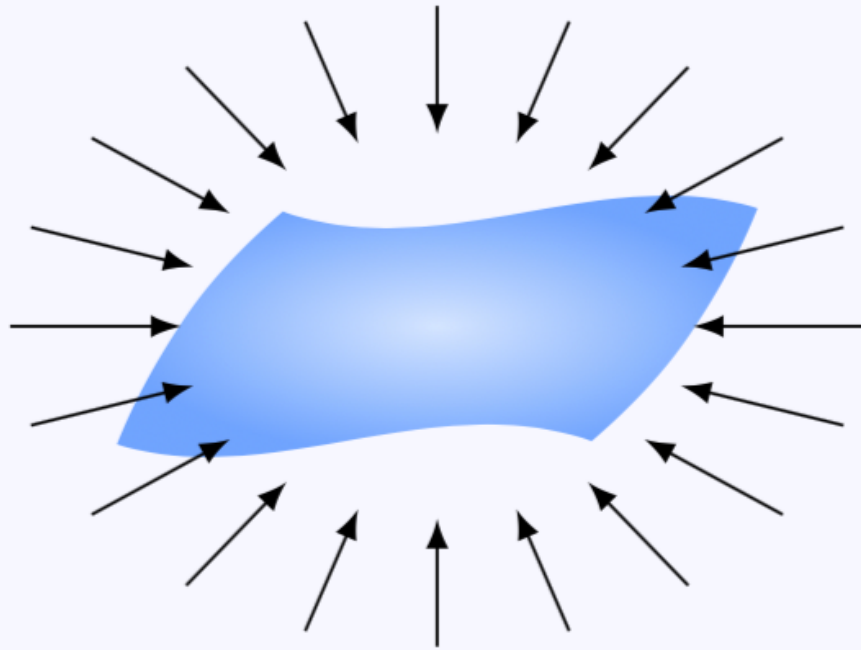
# General rendering

- Based on physics
  - conservation of energy
- Surfaces can
  - absorb light
  - emit light
  - reflect light
  - transmit light

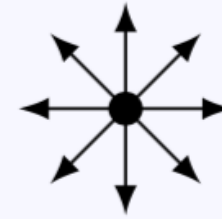


# Light Sources

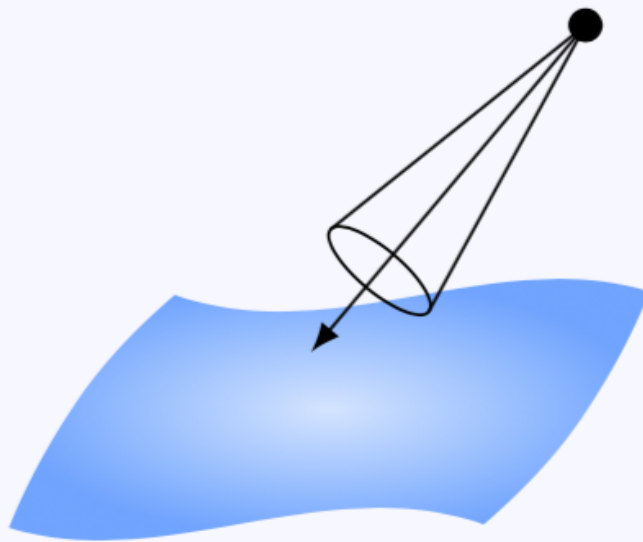
# Idealized light sources



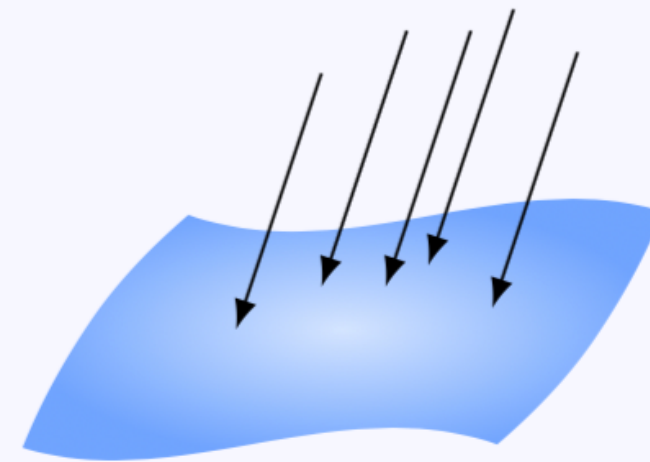
ambient



point light



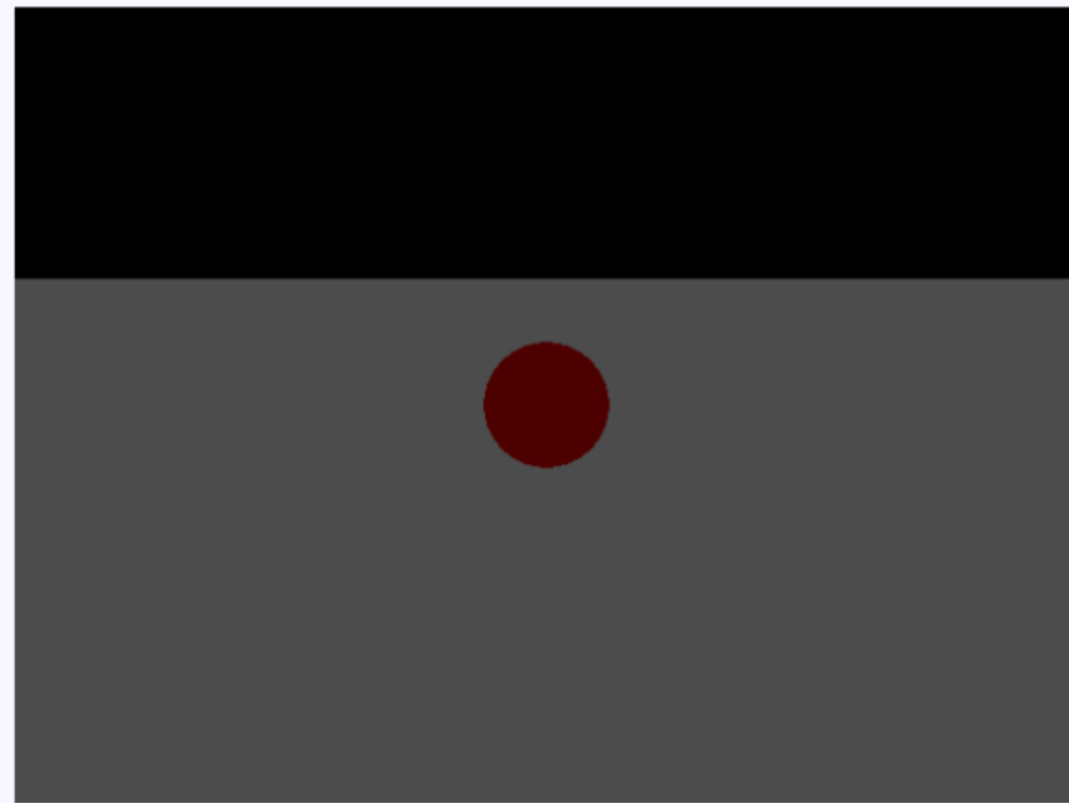
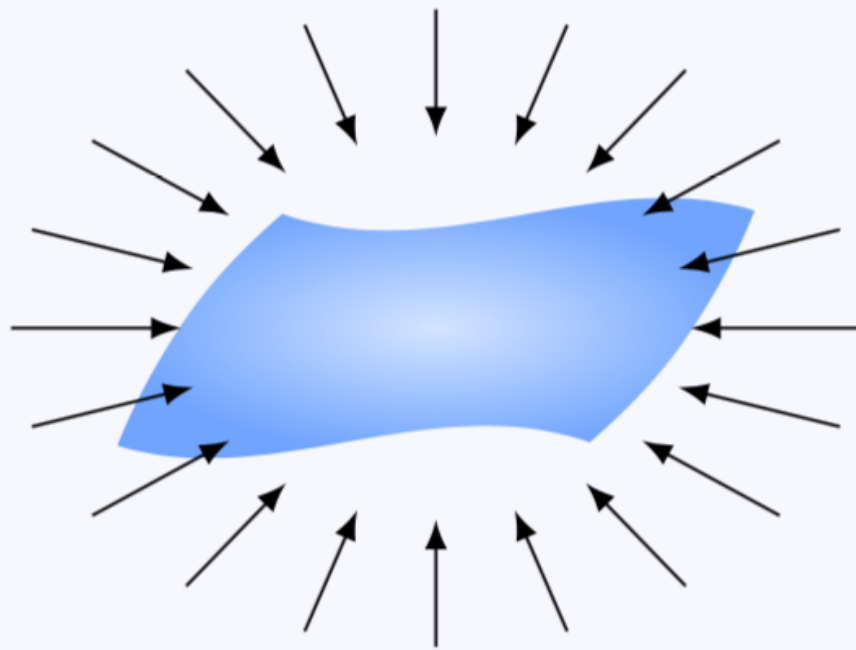
spotlight



directional light

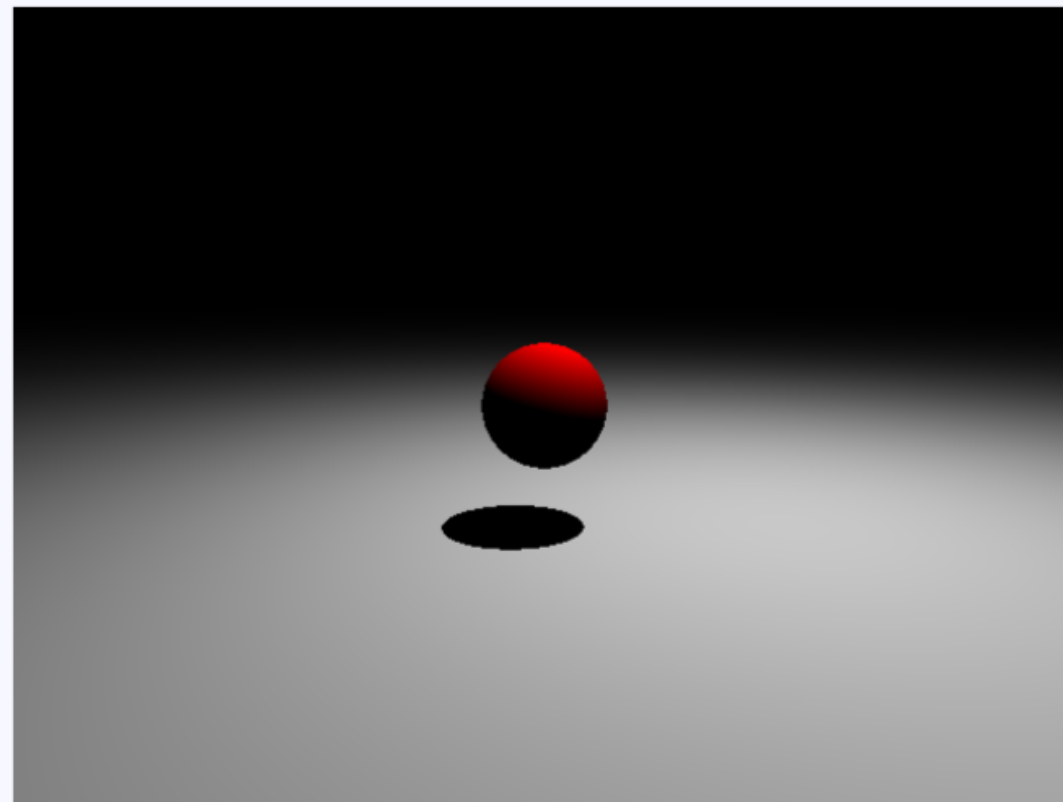
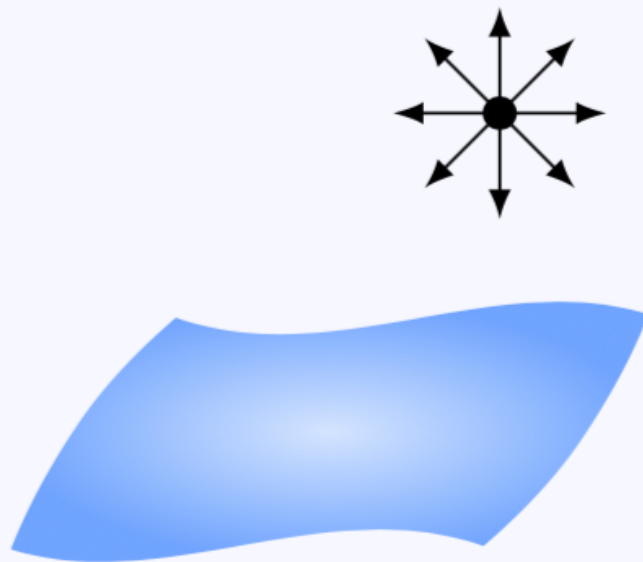
# Ambient light

- Achieve uniform light level
- No shadows
- Same light level everywhere

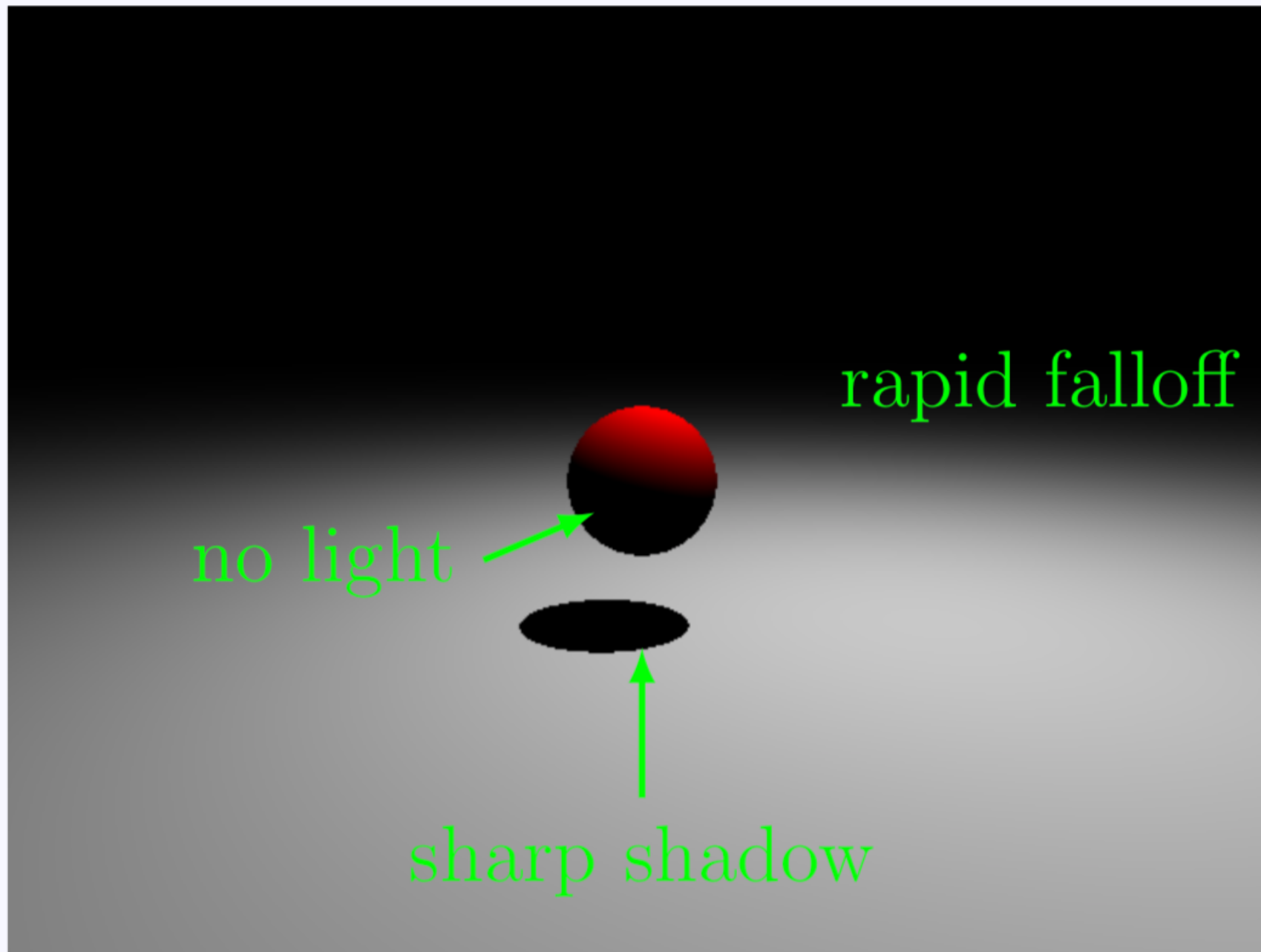


# Point light

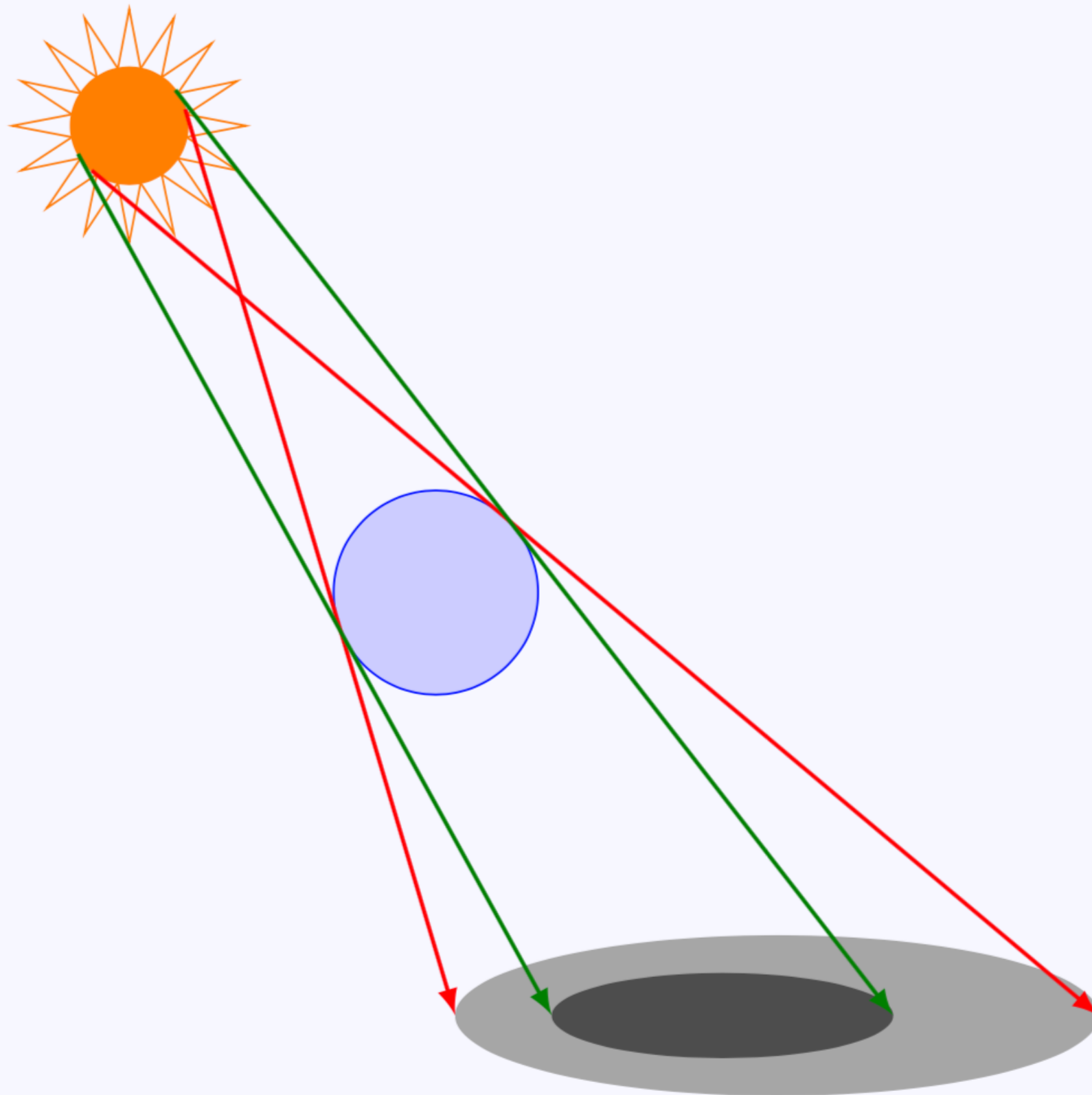
- Light emitted from a point  $\mathbf{p}$
- Uniform in all directions
- Falls off with distance:  $\ell(\mathbf{x}) = \frac{1}{\|\mathbf{x} - \mathbf{p}\|^2} L$



# Point light - limitations

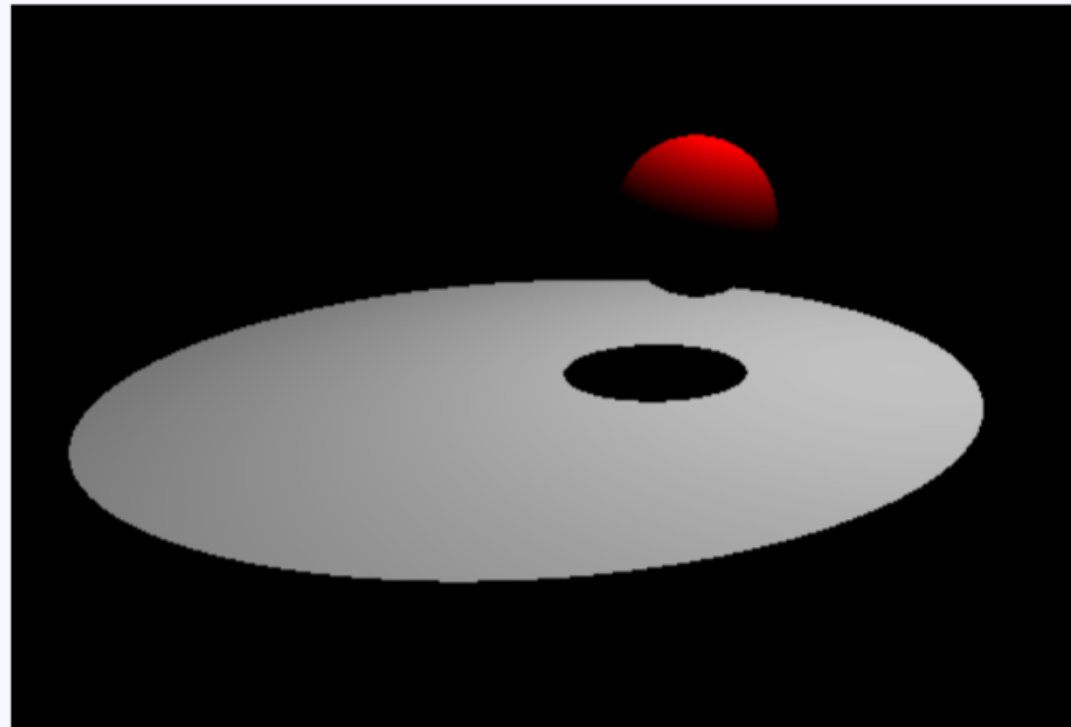
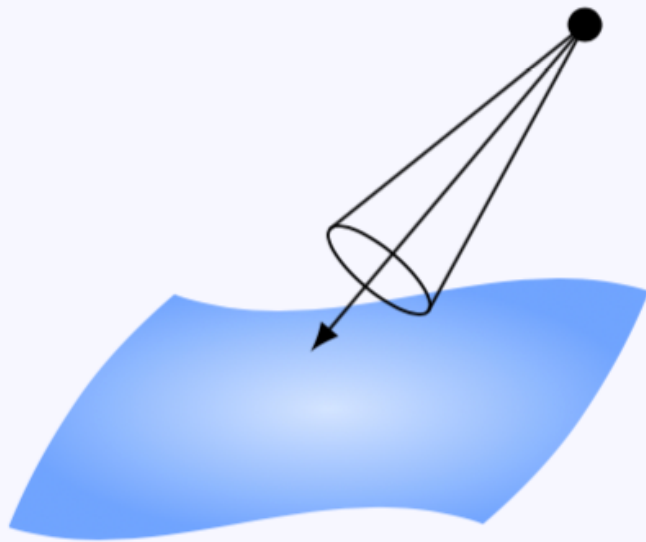


# Soft shadows



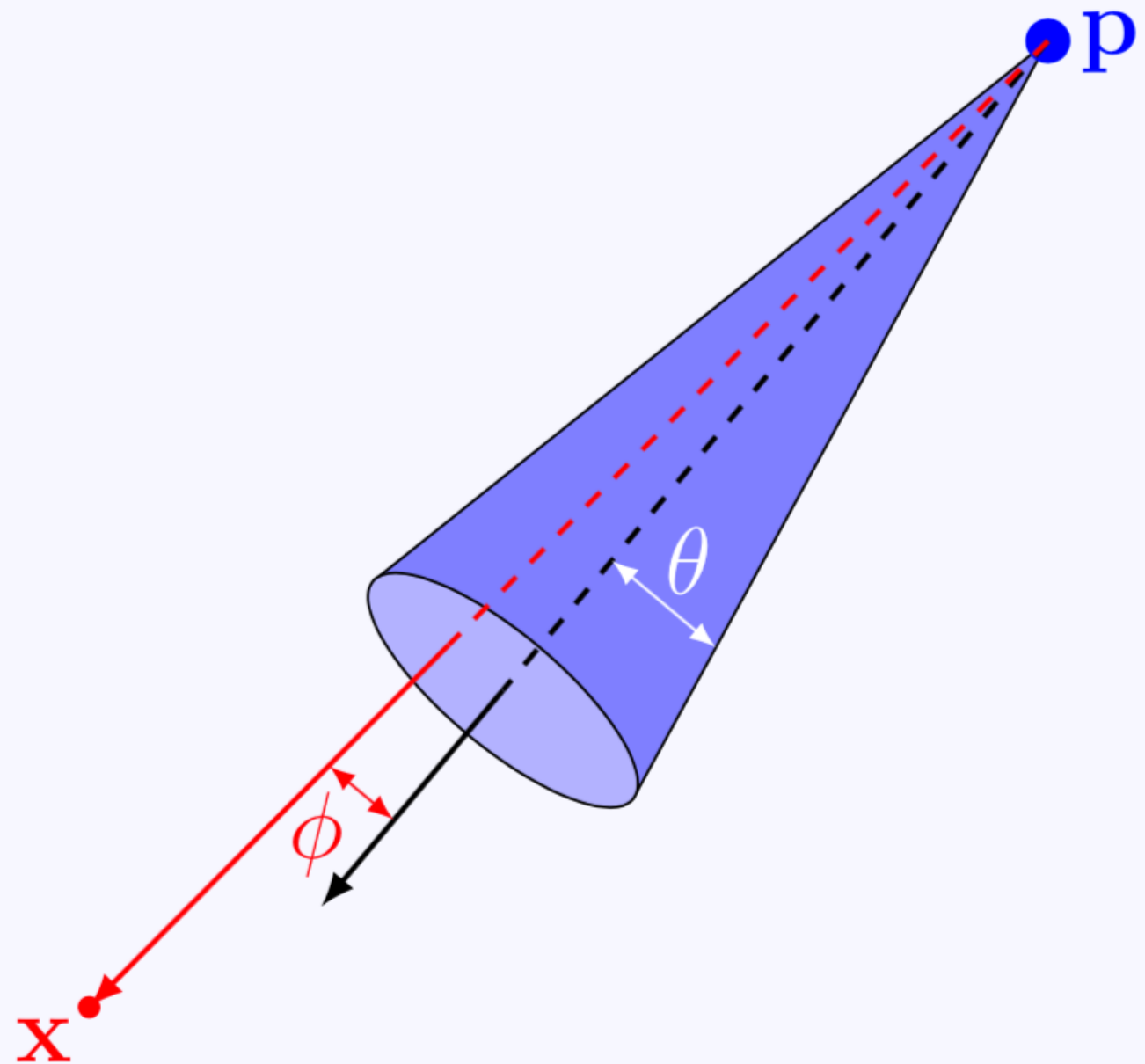
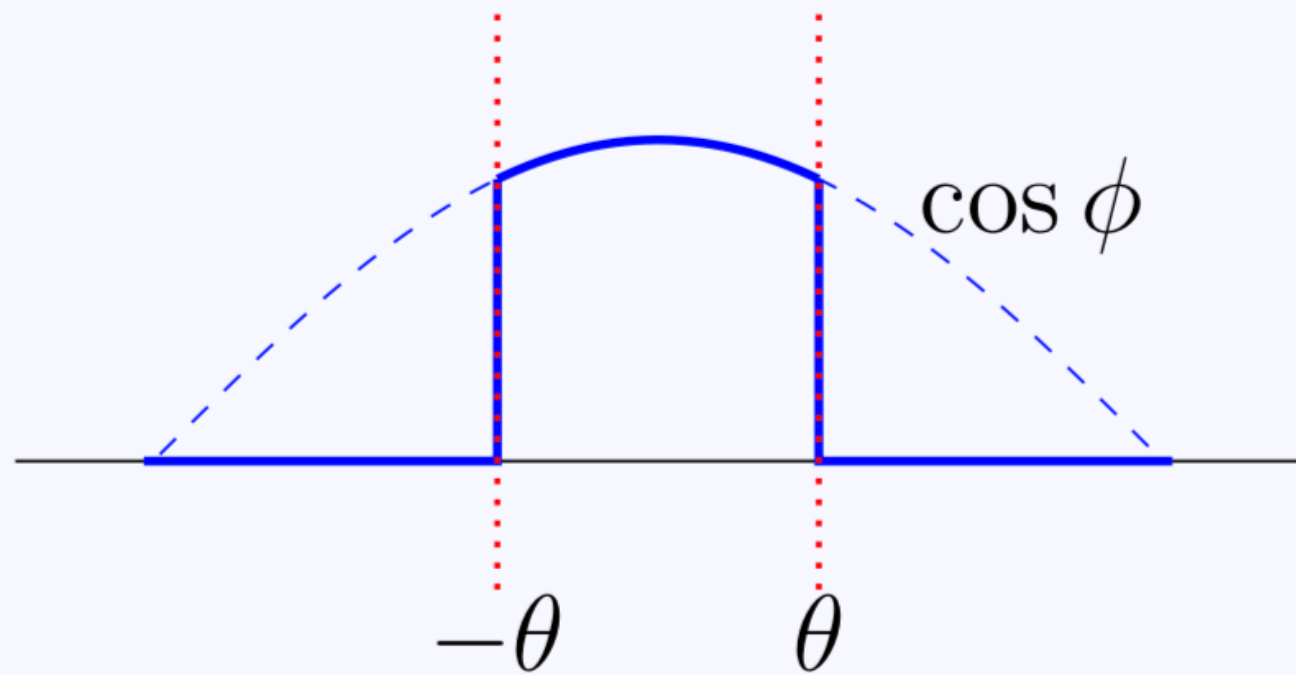
# Spotlight

- Light emitted from a point  $\mathbf{p}$
- Emitted in a cone
- Brightest in middle of cone
- Falls off with distance

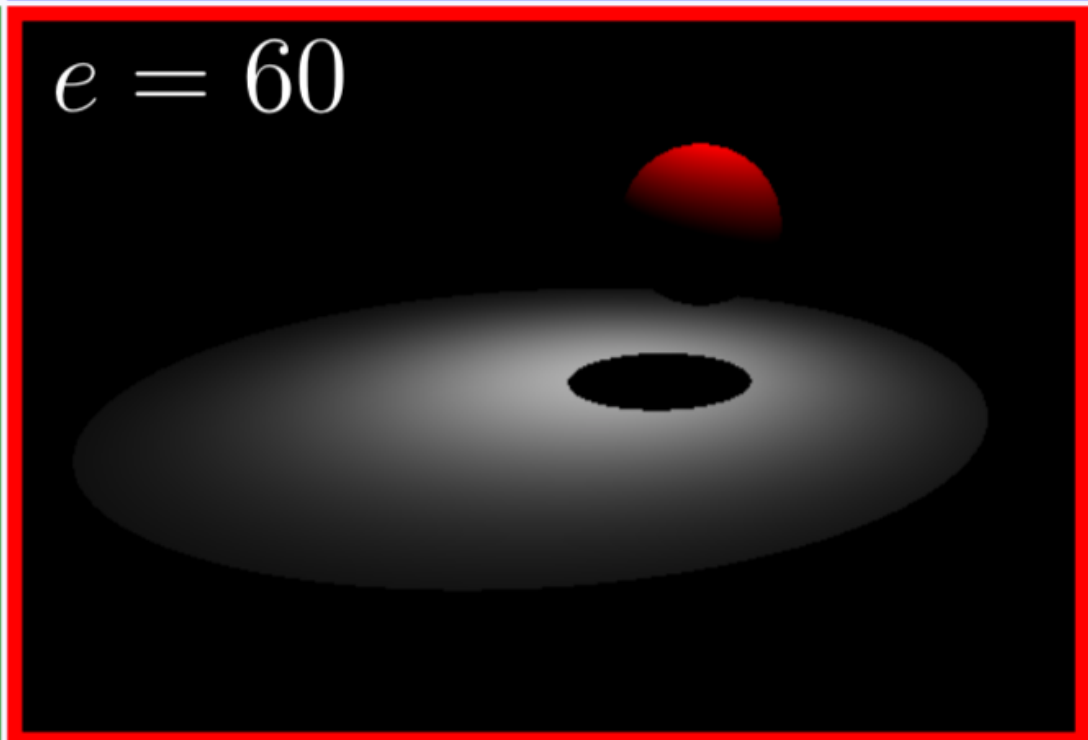
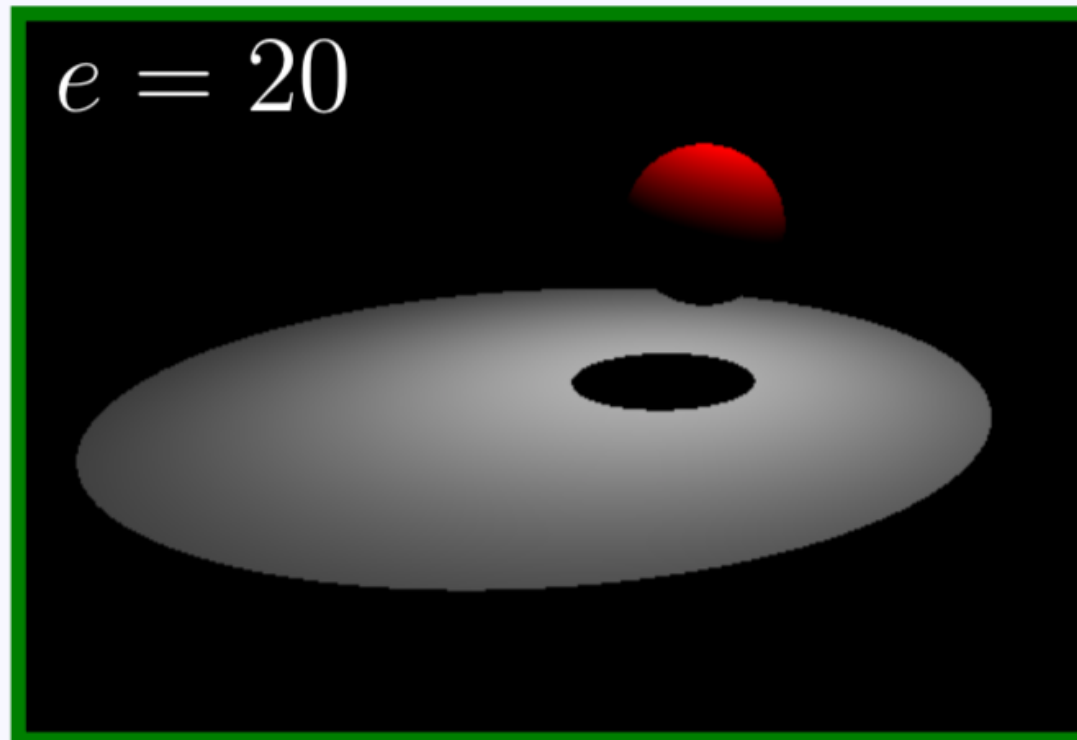
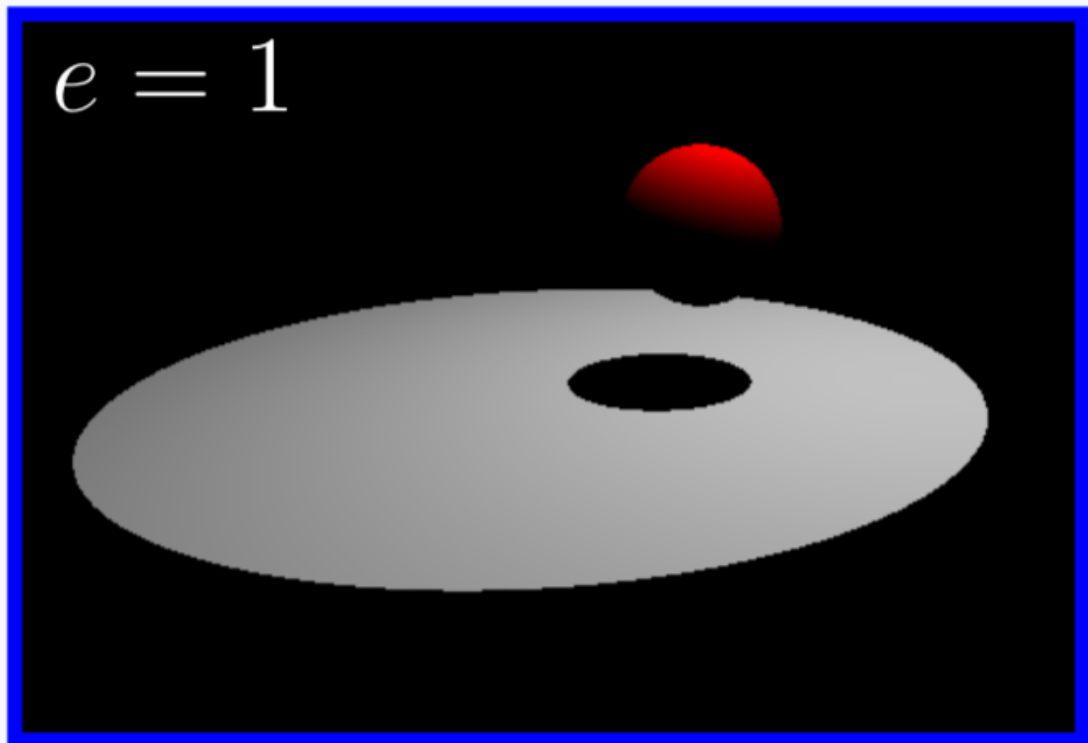
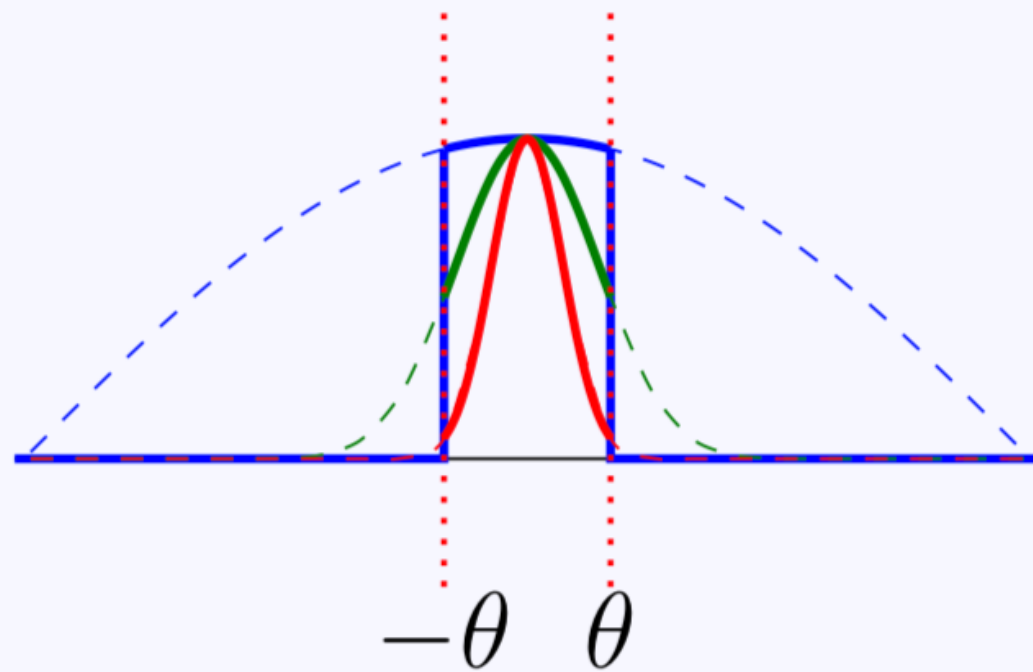


# Spotlight

$$\ell(\mathbf{x}) = \frac{\cos^e \phi}{\|\mathbf{x} - \mathbf{p}\|^2} L$$

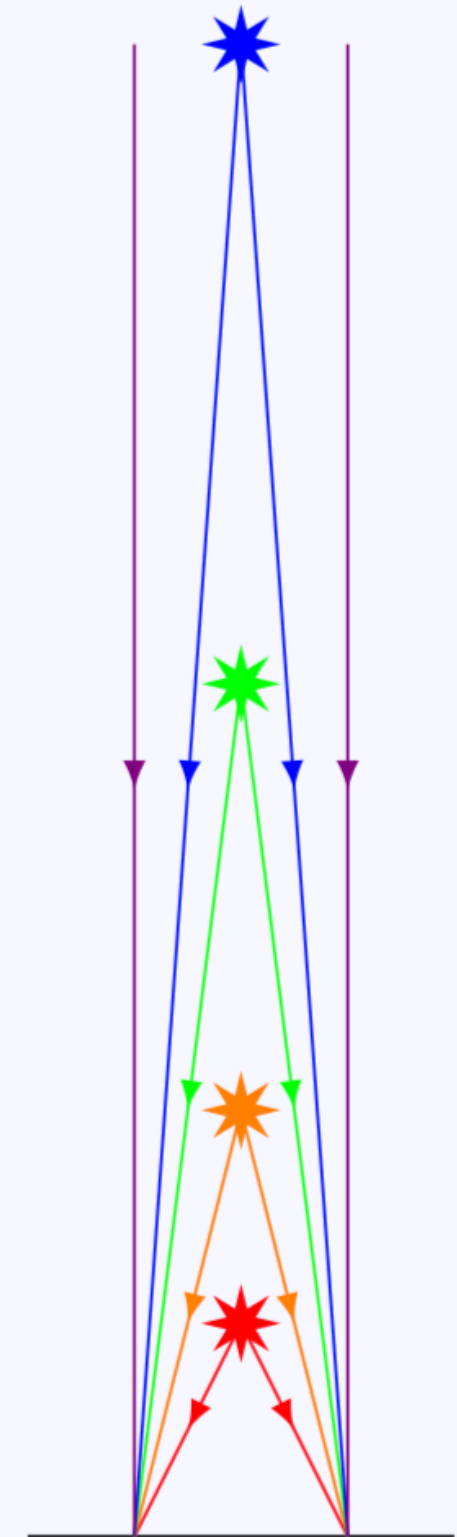
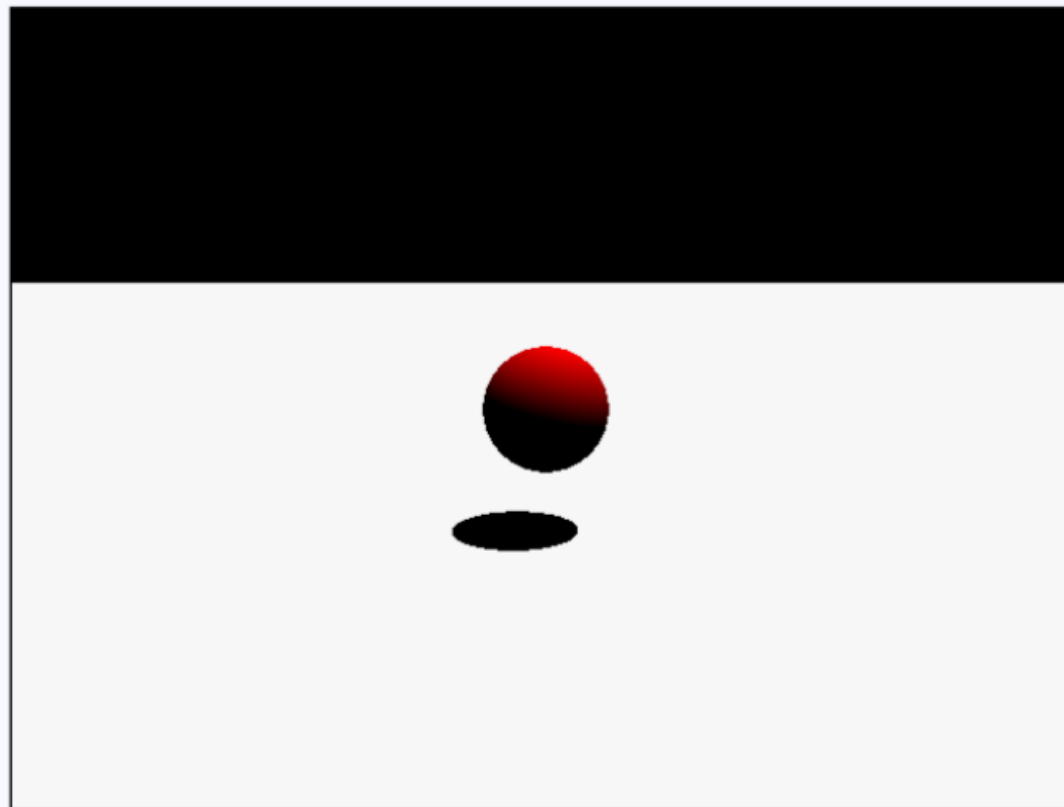
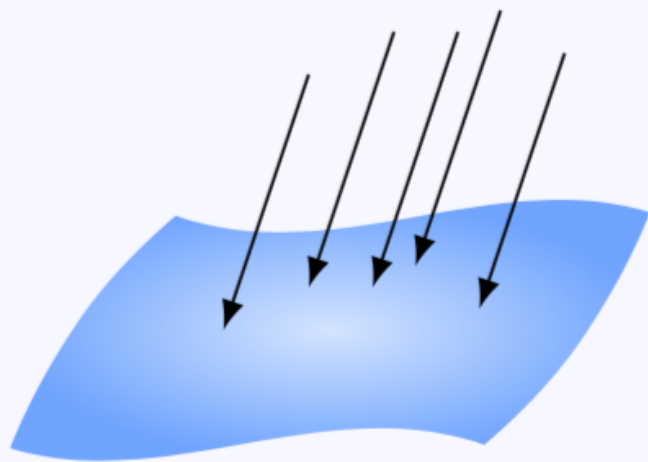


# Spotlight - exploring $e$



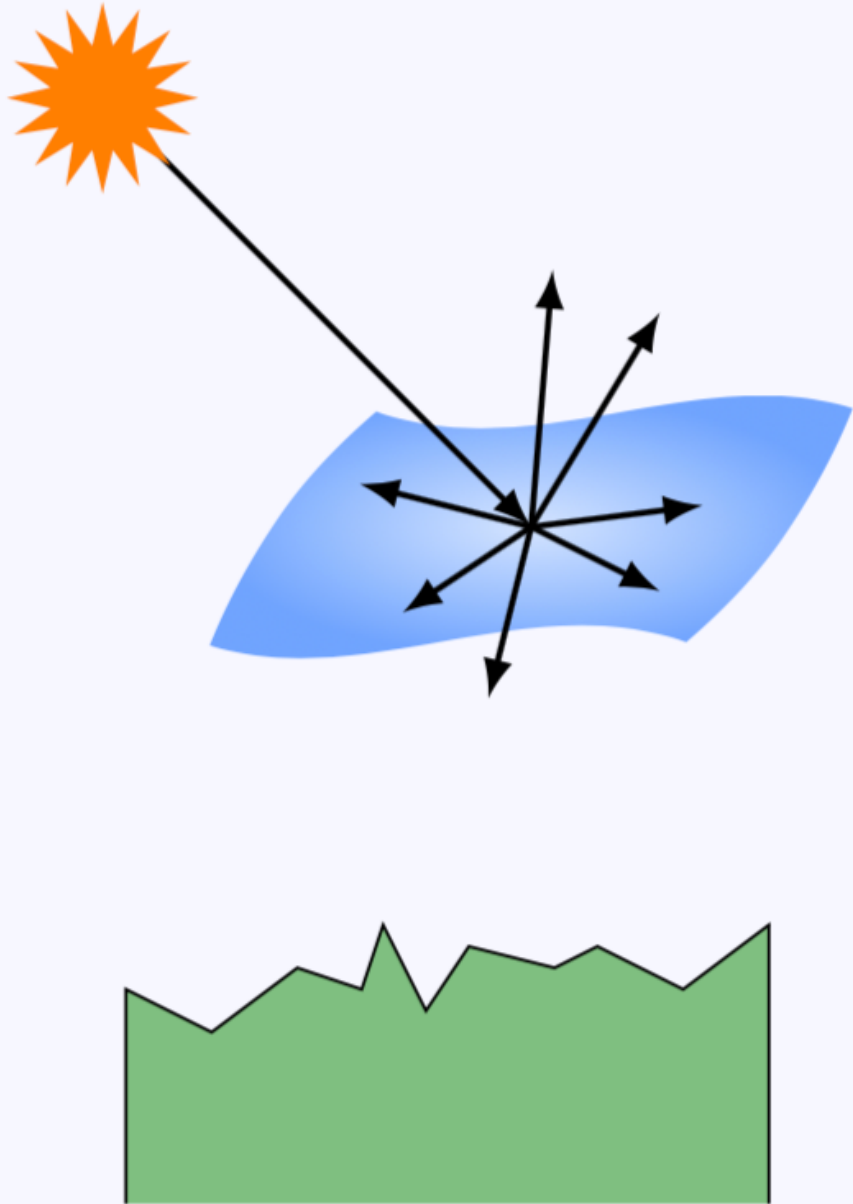
# Directional light

- Light source at infinity
- Rays come in parallel
- No falloff
- Characterized by direction

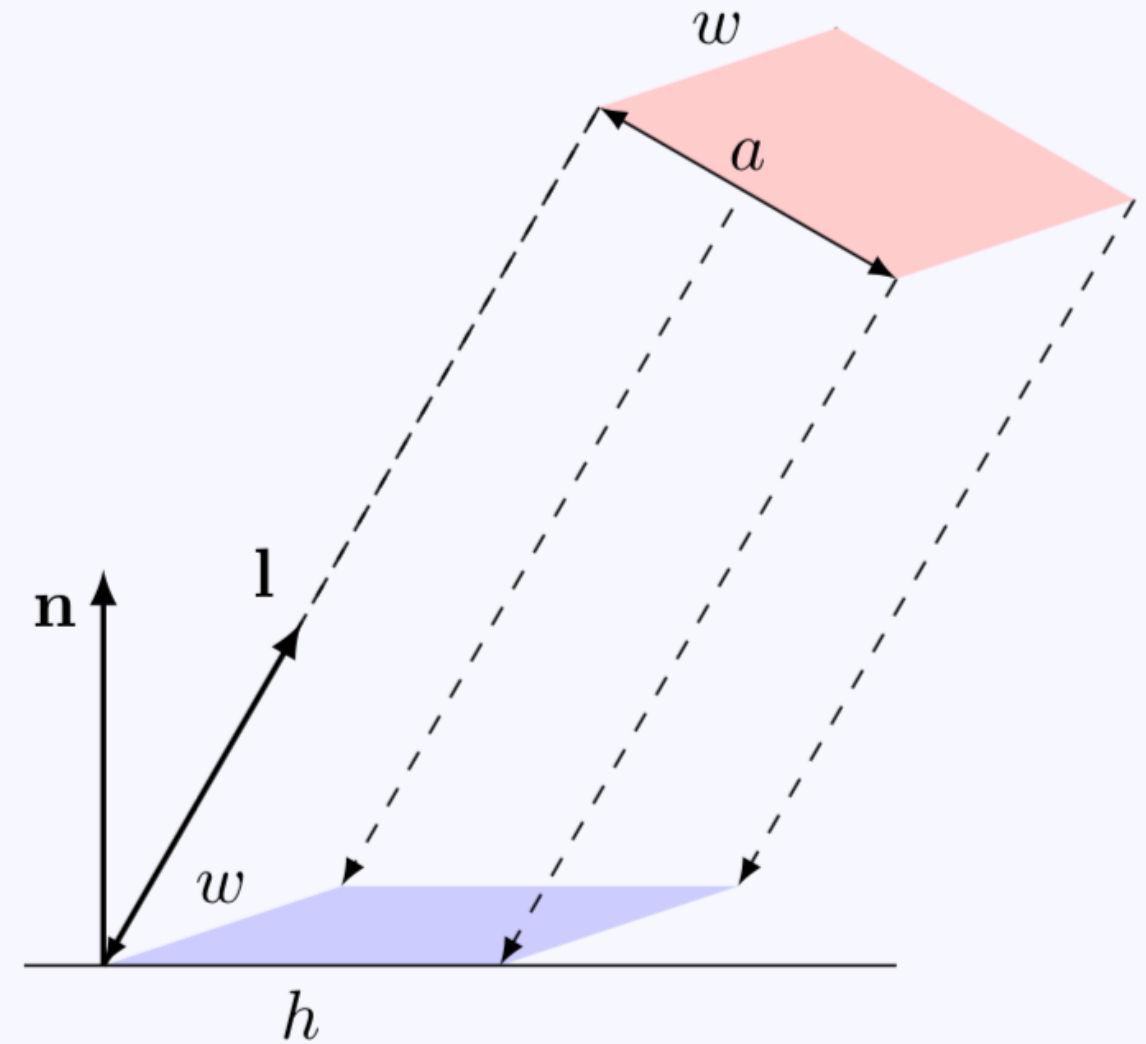
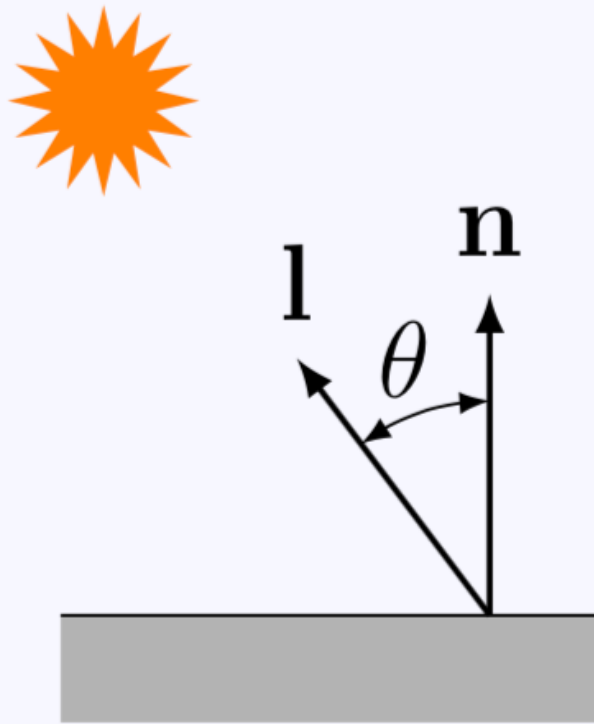


# Shading

# Lambertian reflection model

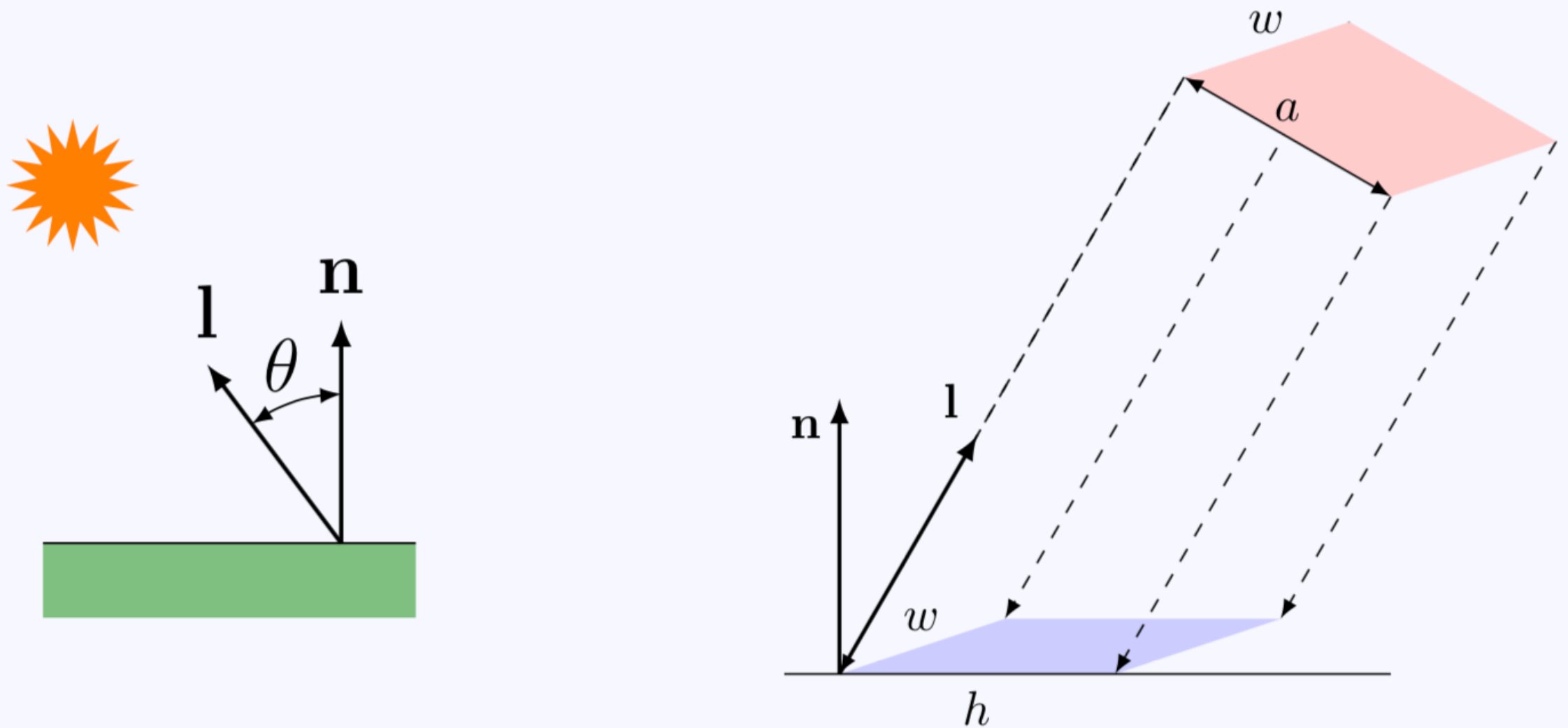


# Lambertian reflection model



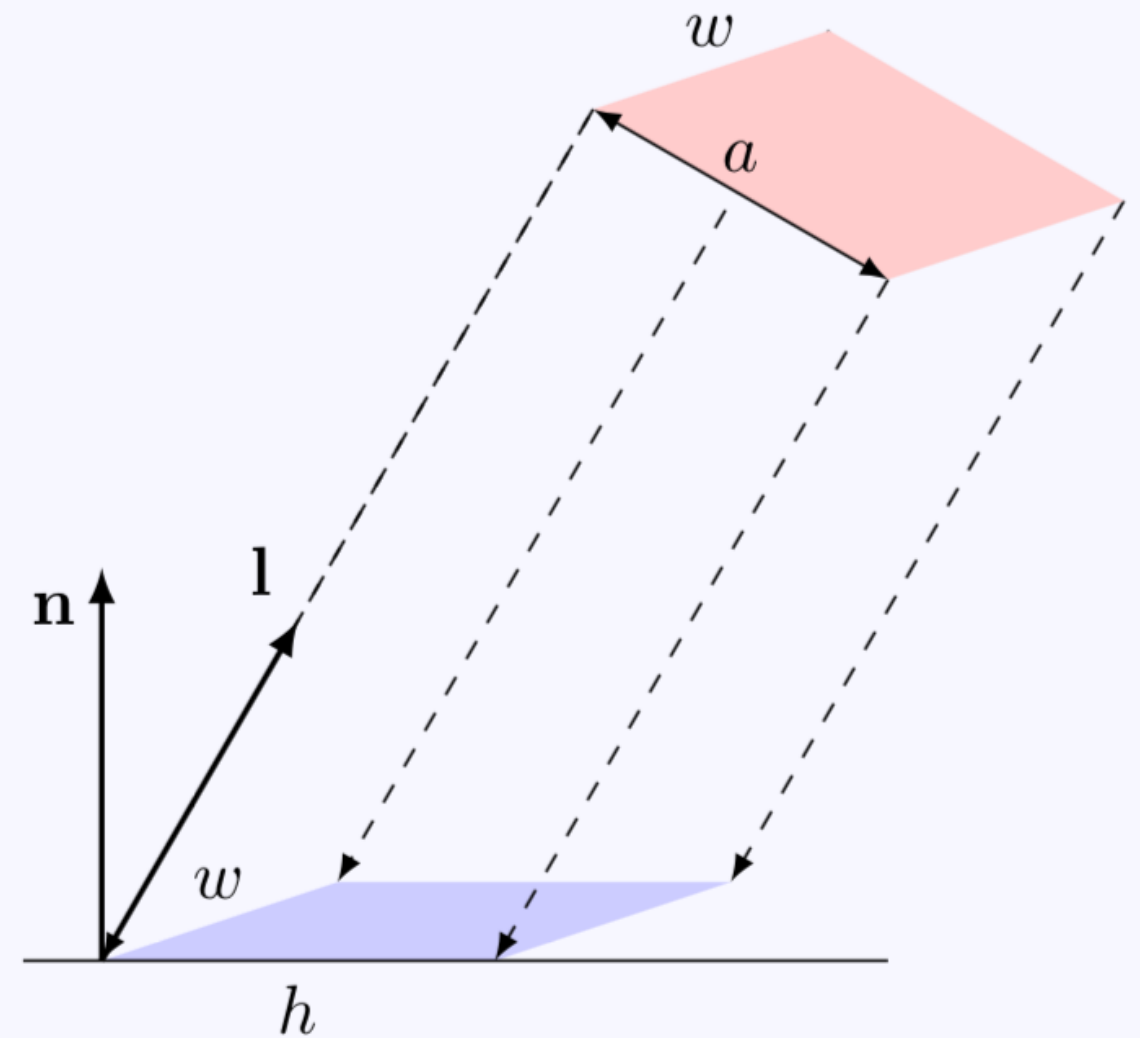
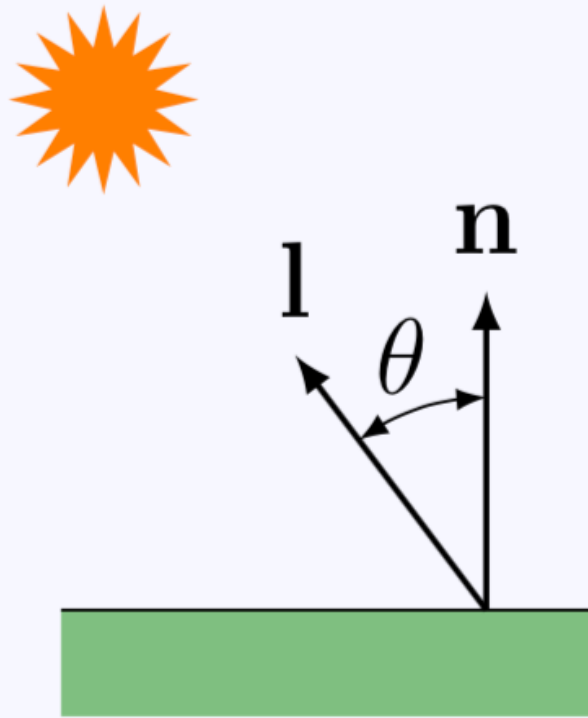
|           | Light     | Absorbed   |
|-----------|-----------|------------|
| Intensity | $L$       | $L'$       |
| Energy    | $E = Lwa$ | $E = L'wh$ |

# Lambertian reflection model



|           | Light     | Absorbed   | Emitted   |
|-----------|-----------|------------|-----------|
| Intensity | $L$       | $L'$       | $I = RL'$ |
| Energy    | $E = Lwa$ | $E = L'wh$ | $RE$      |

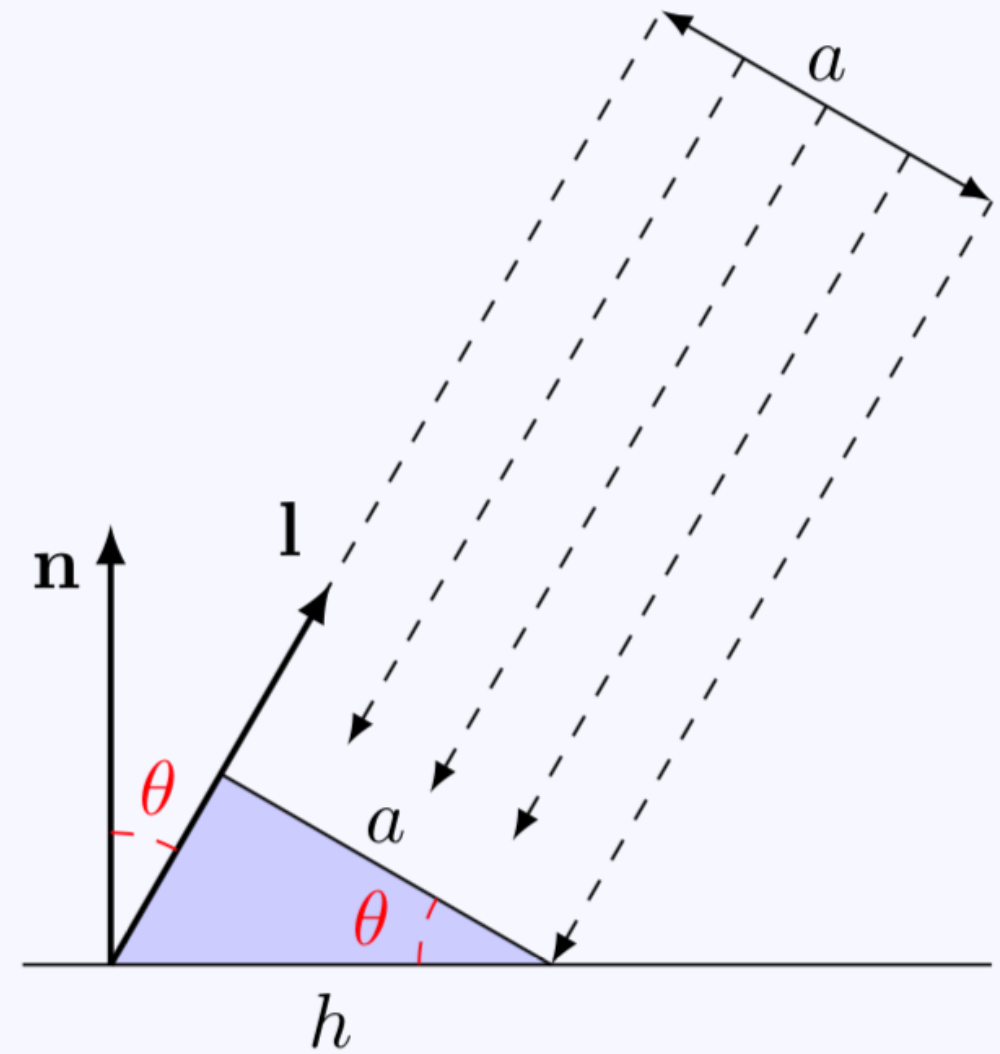
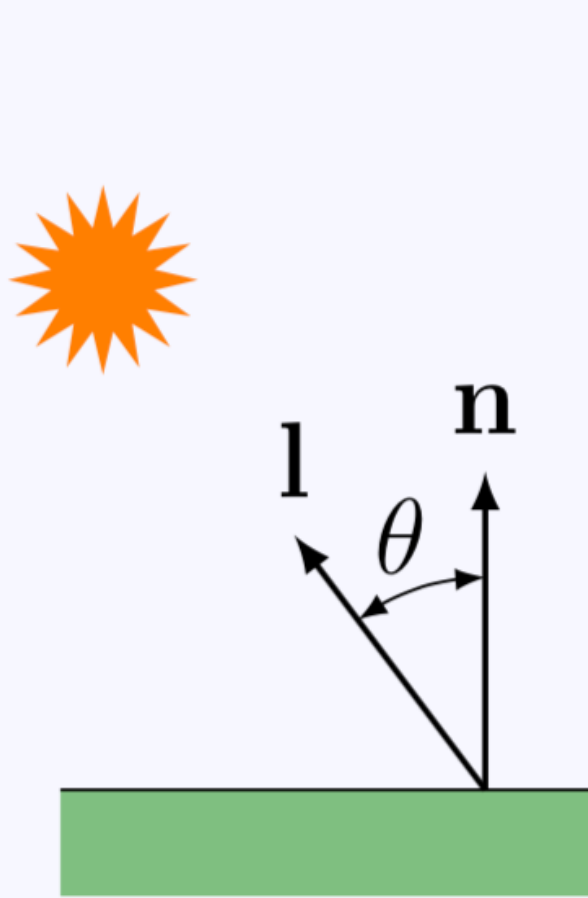
# Lambertian reflection model



|           | Light     | Absorbed   | Emitted   |
|-----------|-----------|------------|-----------|
| Intensity | $L$       | $L'$       | $I = RL'$ |
| Energy    | $E = Lwa$ | $E = L'wh$ | $RE$      |

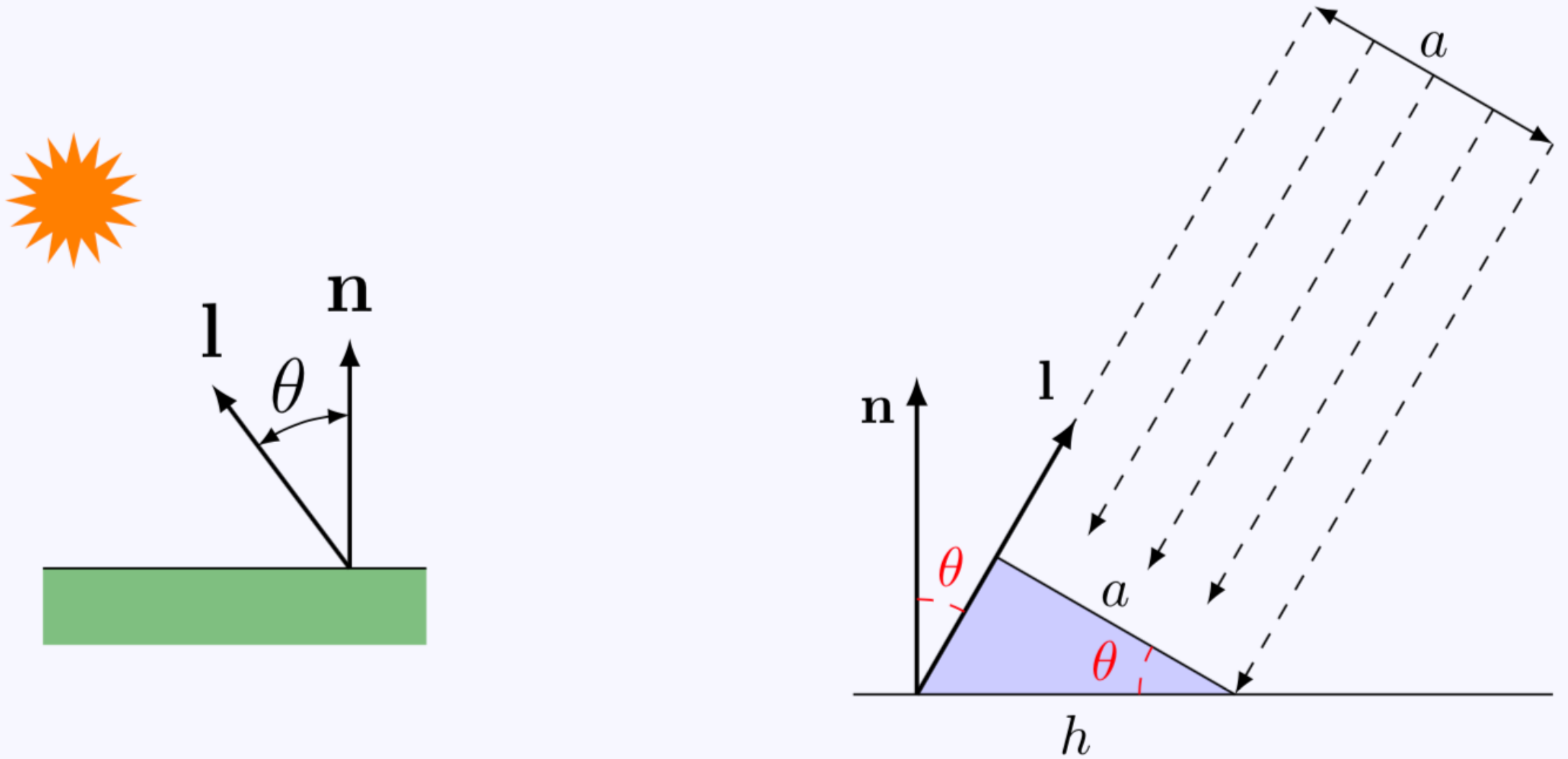
$$I = LR \frac{a}{h}$$

# Lambertian reflection model



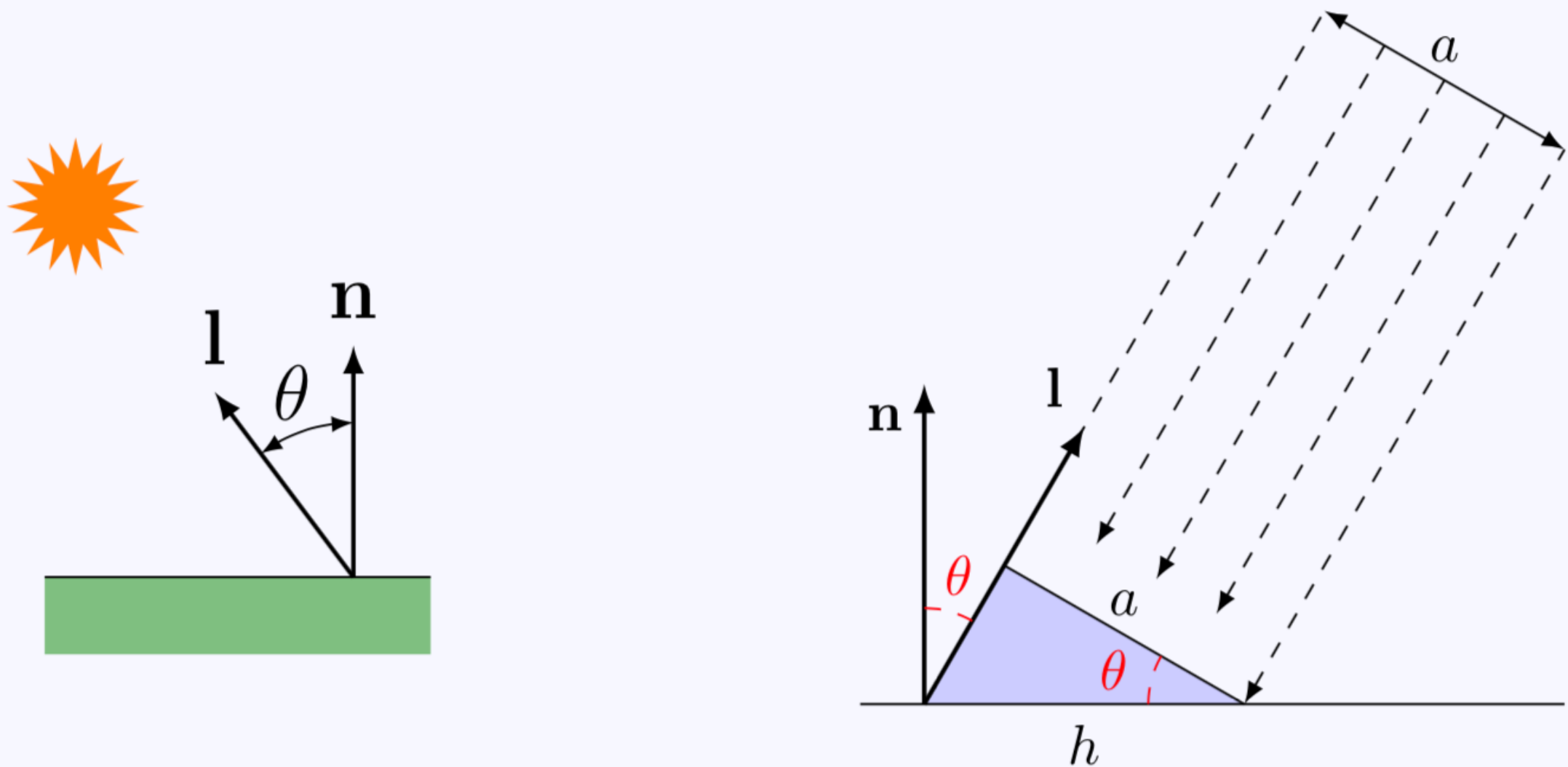
$$I = LR \frac{a}{h}$$

# Lambertian reflection model



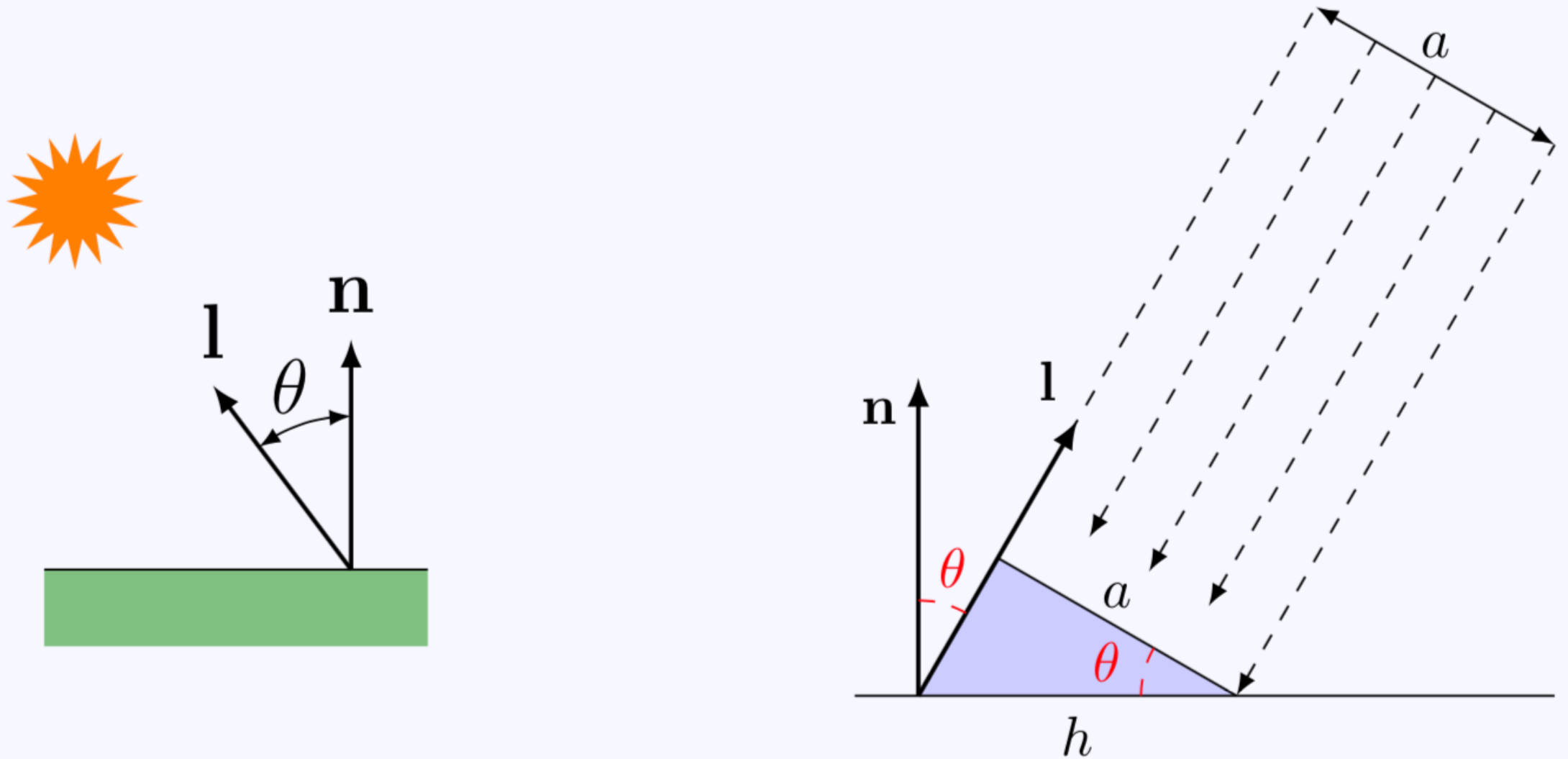
$$I = LR \frac{a}{h} = LR \cos \theta$$

# Lambertian reflection model



$$I = LR \frac{a}{h} = LR \cos \theta = LR \mathbf{n} \cdot \mathbf{l}$$

# Lambertian reflection model



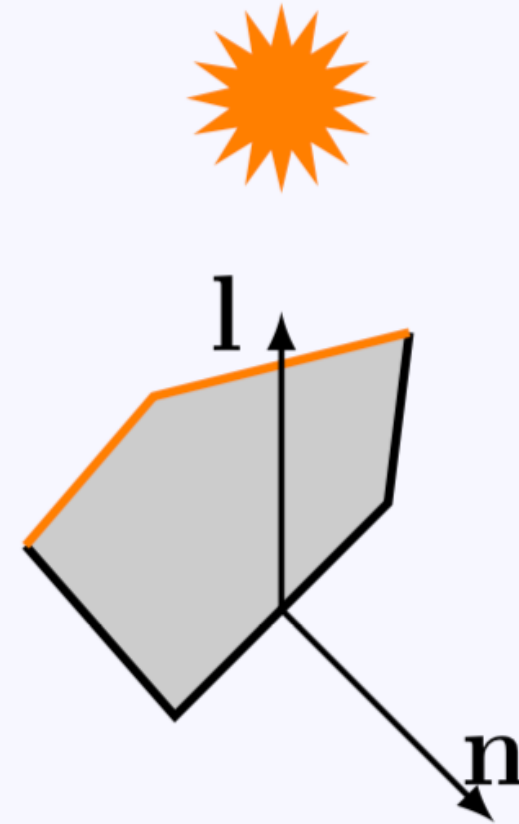
$$I = LR \frac{a}{h} = LR \cos \theta = LR \mathbf{n} \cdot \mathbf{l}$$

Avoid bug:  $I = LR \max(\mathbf{n} \cdot \mathbf{l}, 0)$

# Ambient reflection

$$I = LR \max(\mathbf{n} \cdot \mathbf{l}, 0)$$

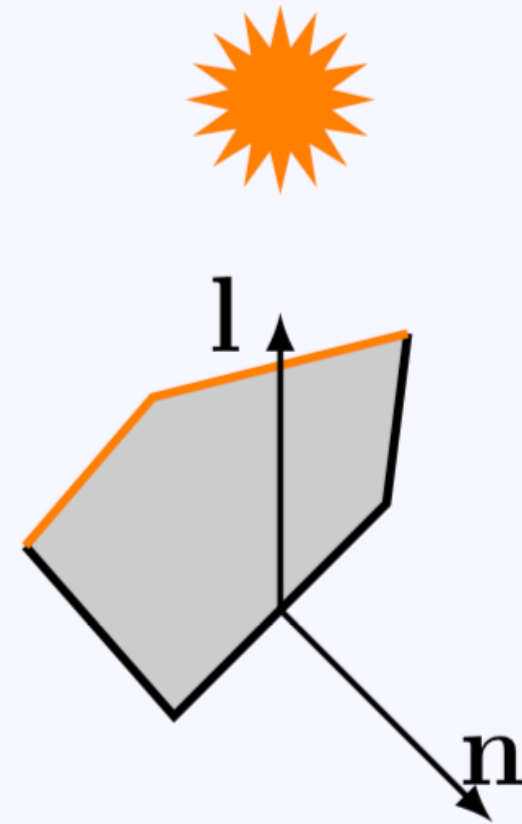
Surfaces facing away from the light will be totally **black**



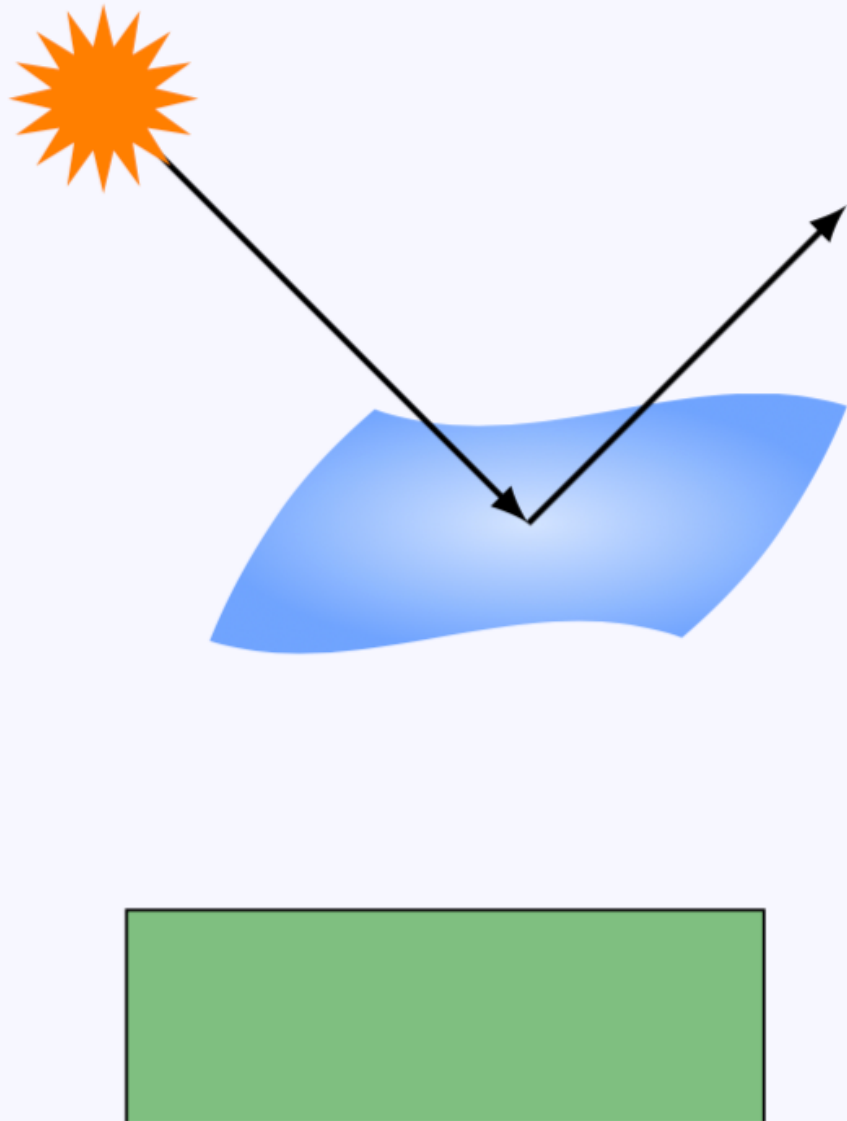
# Ambient reflection

$$I = L_a R_a + L_d R_d \max(\mathbf{n} \cdot \mathbf{l}, 0)$$

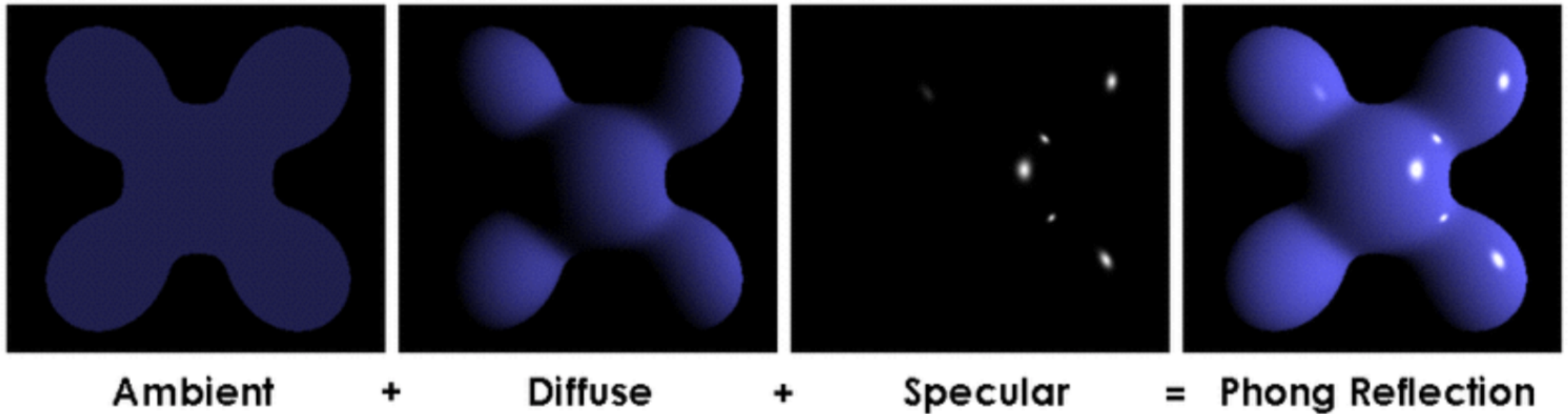
All surfaces get the same amount of ambient light



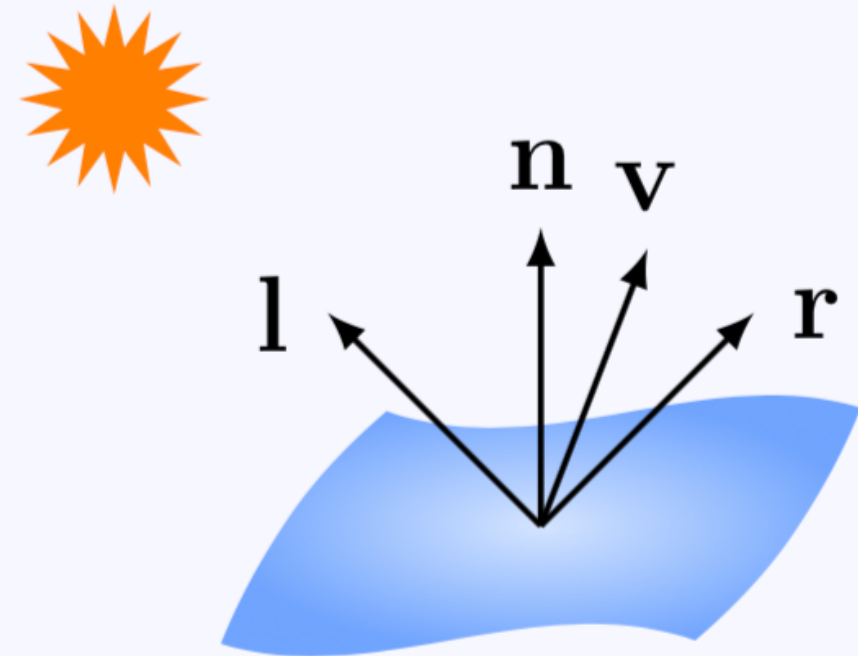
# Phong reflection model



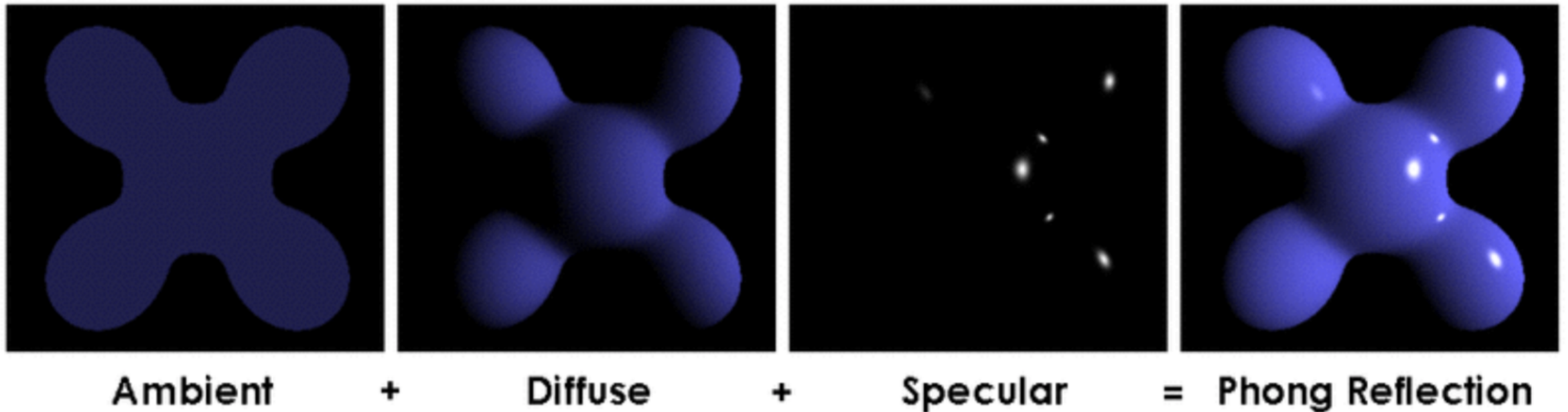
# Phong reflection model



- Efficient
- Reasonably realistic
- 3 components
- 4 vectors

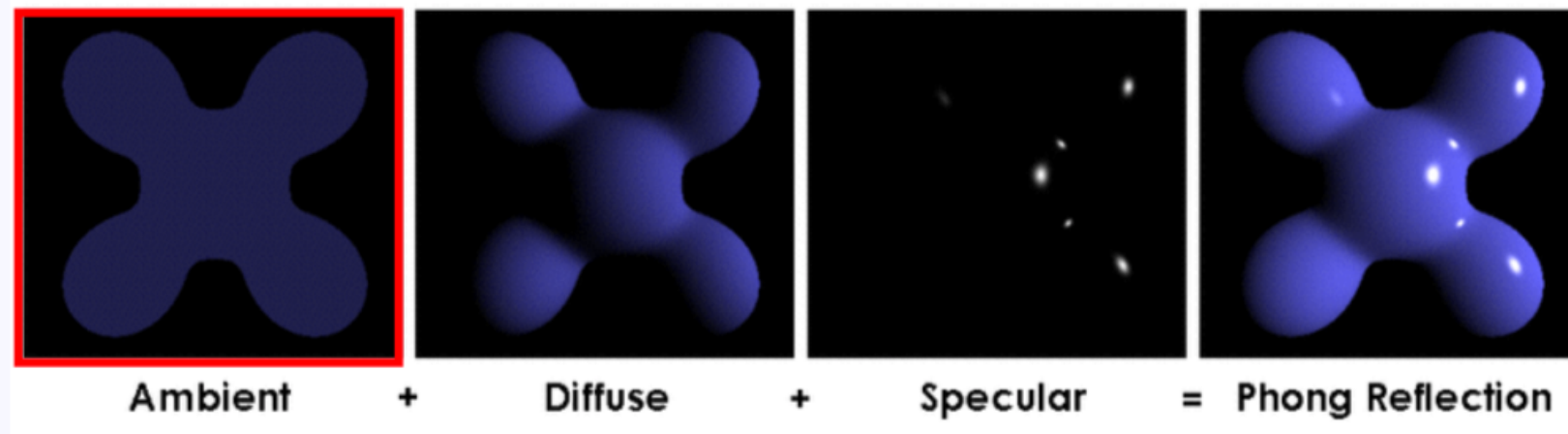


# Phong reflection model



$$\begin{aligned} I &= I_a + I_d + I_s \\ &= R_a L_a + R_d L_d \max(\mathbf{n} \cdot \mathbf{l}, 0) + R_s L_s \max(\cos \phi, 0)^\alpha \end{aligned}$$

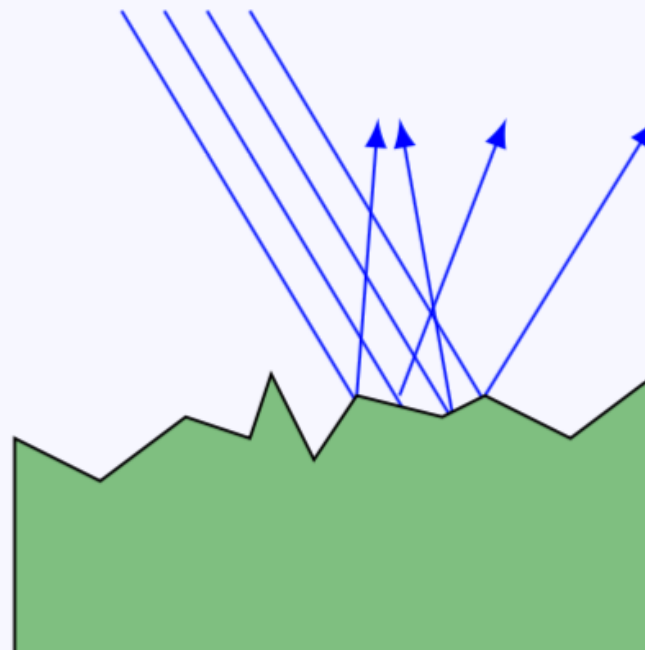
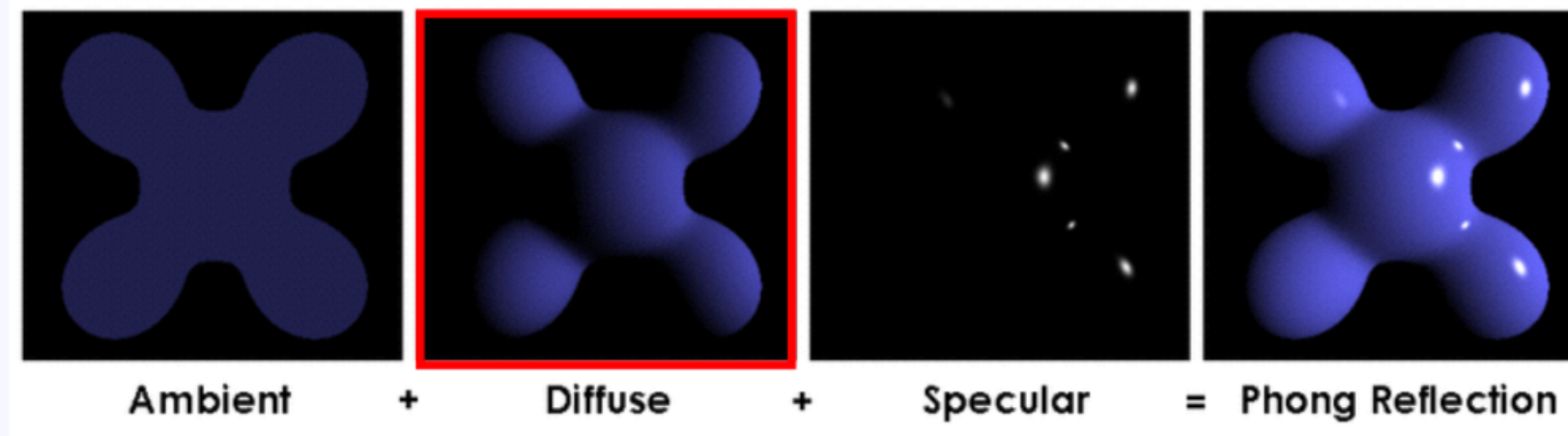
# Ambient reflection



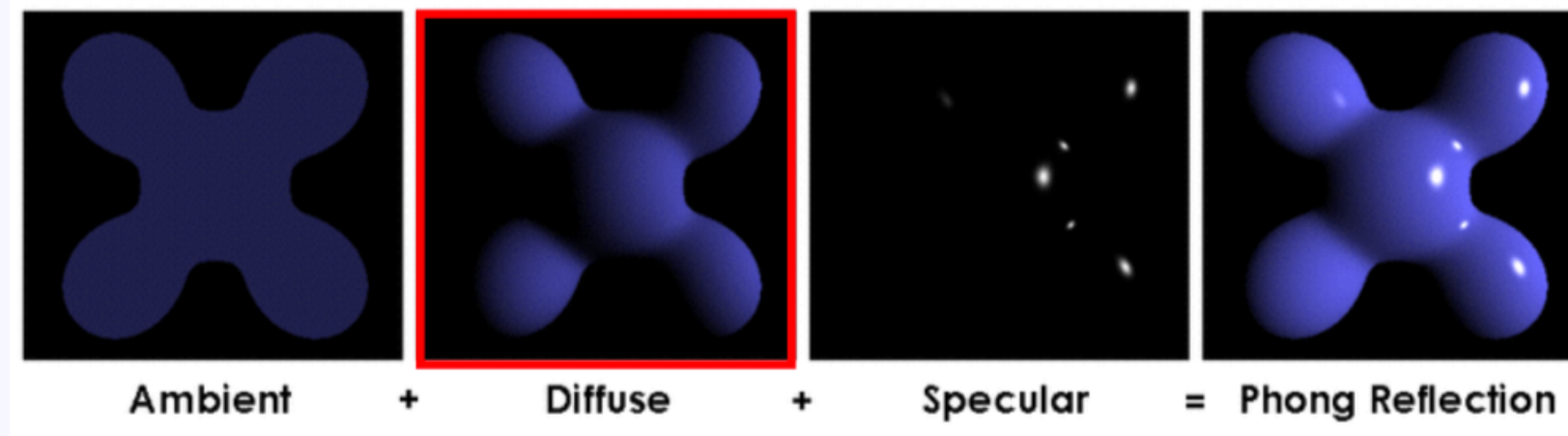
$$I_a = R_a L_a$$

$$0 \leq R_a \leq 1$$

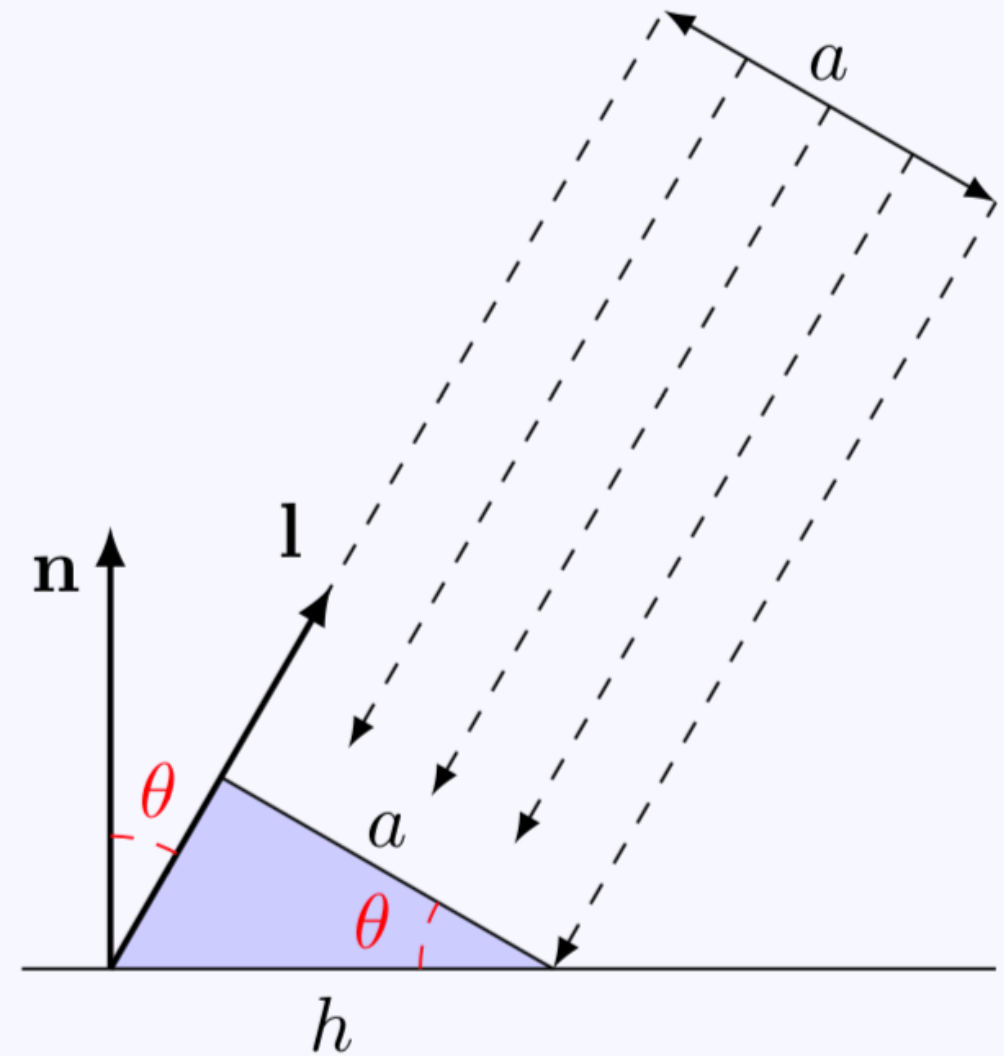
# Diffuse reflection



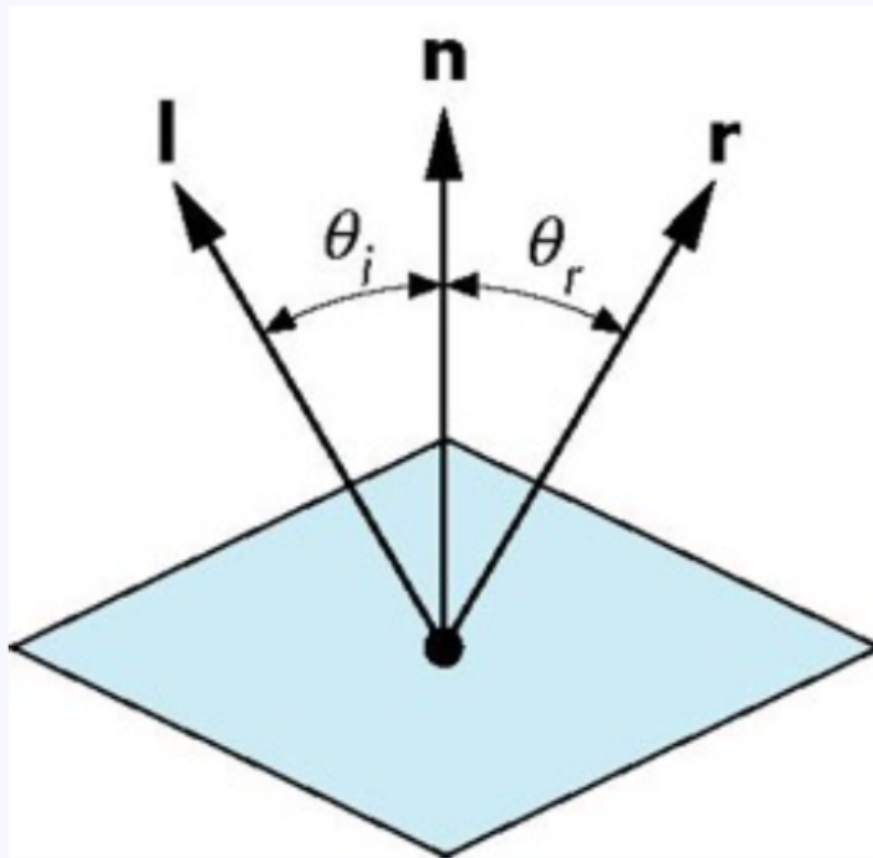
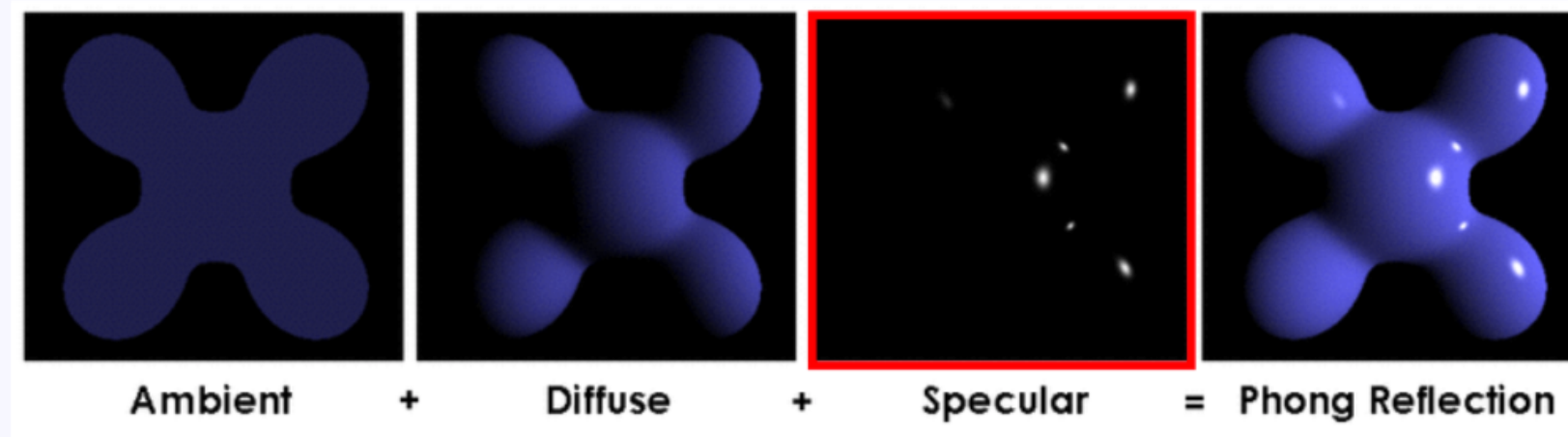
# Diffuse reflection



$$I_d = R_d L_d \max(\mathbf{n} \cdot \mathbf{l}, 0)$$



# Specular reflection

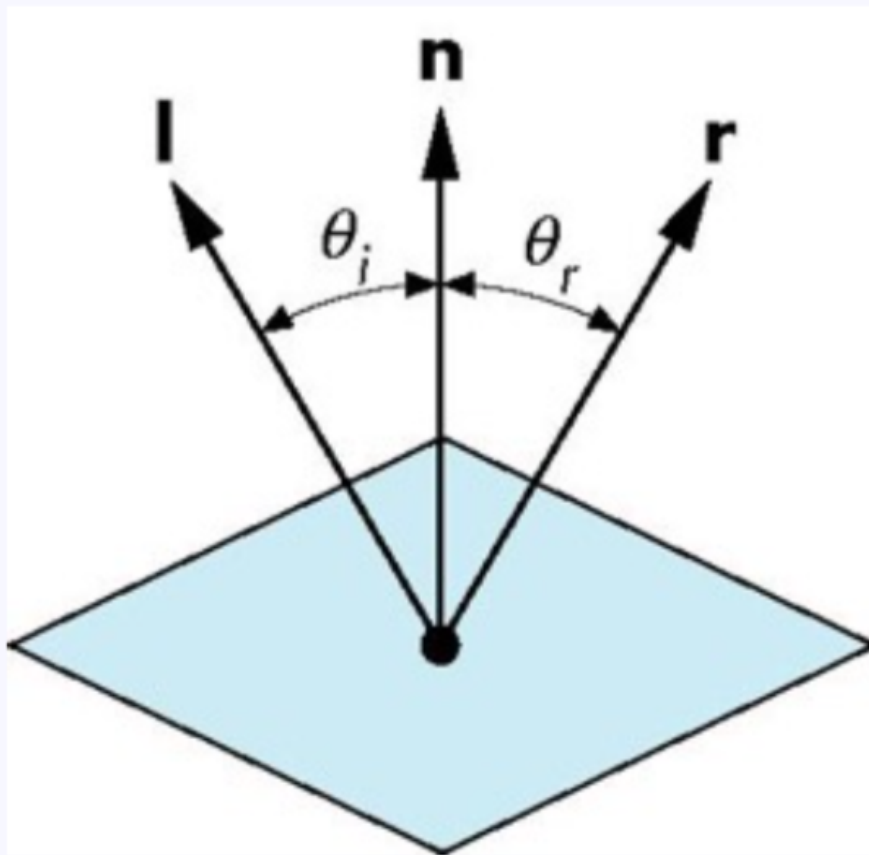
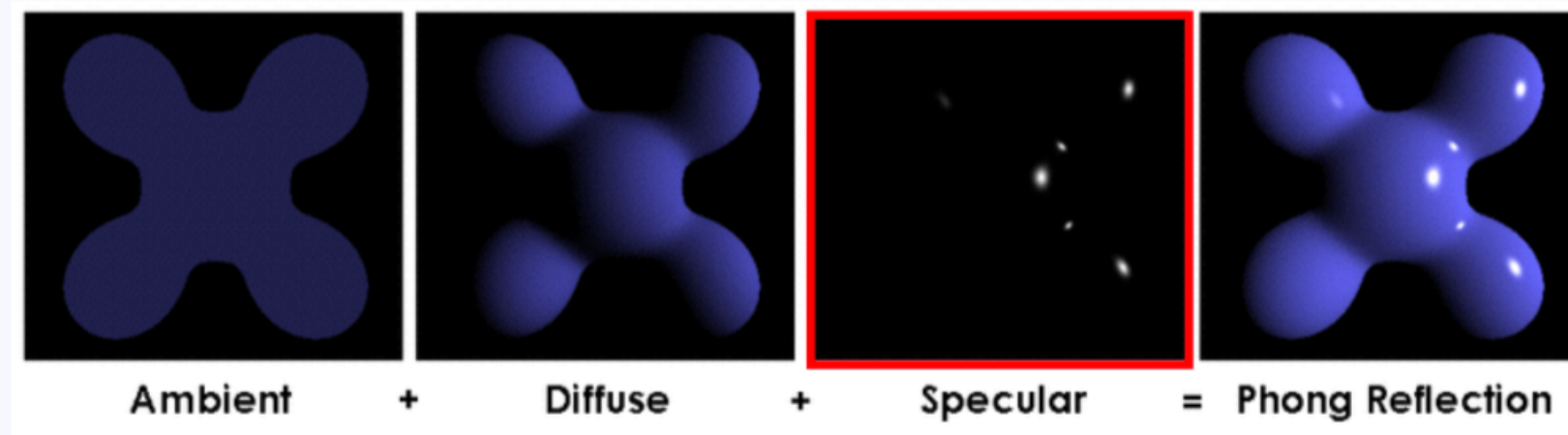


Ideal reflector

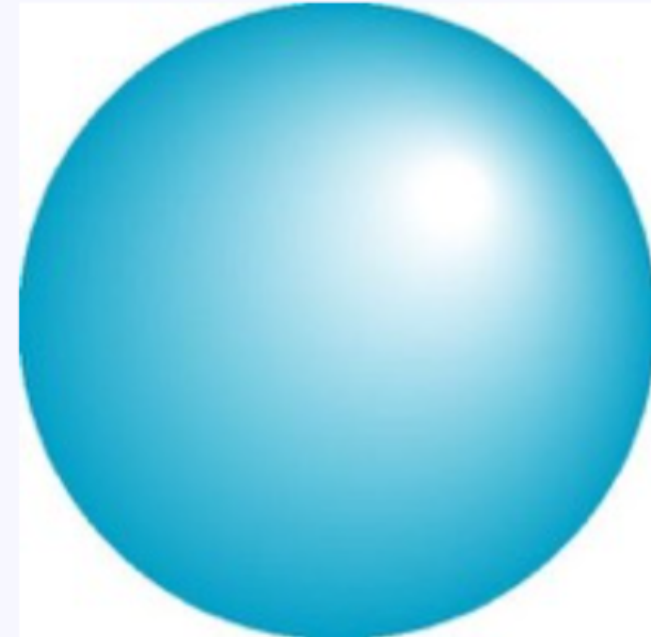
$$\theta_i = \theta_r$$

$\mathbf{r}$  is the mirror reflection direction

# Specular reflection

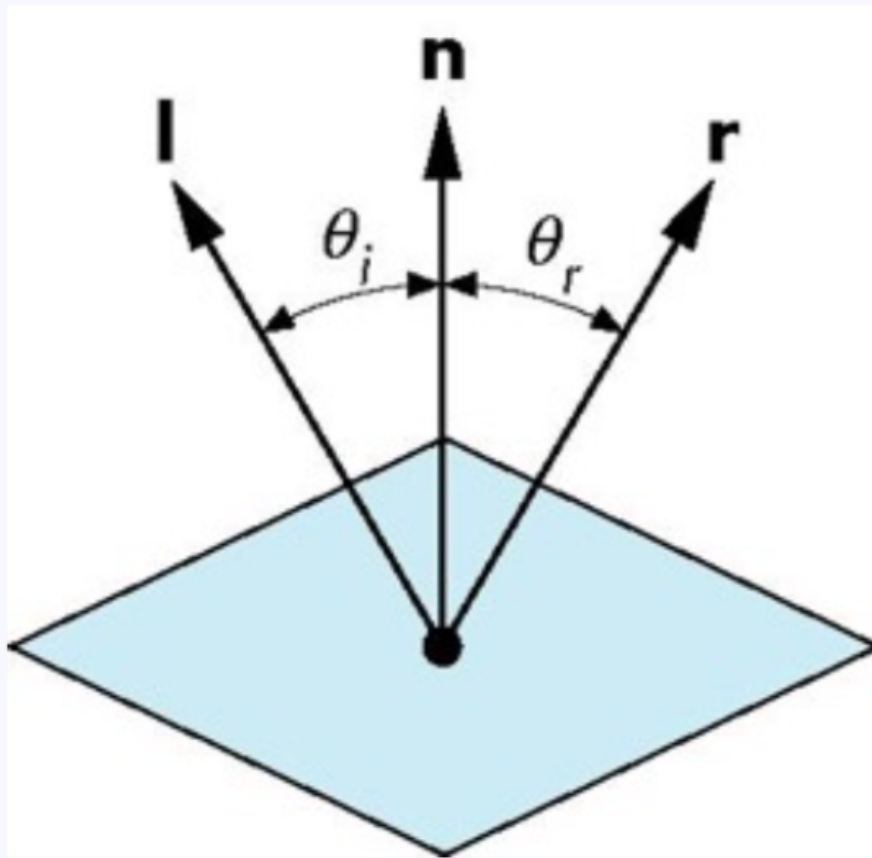
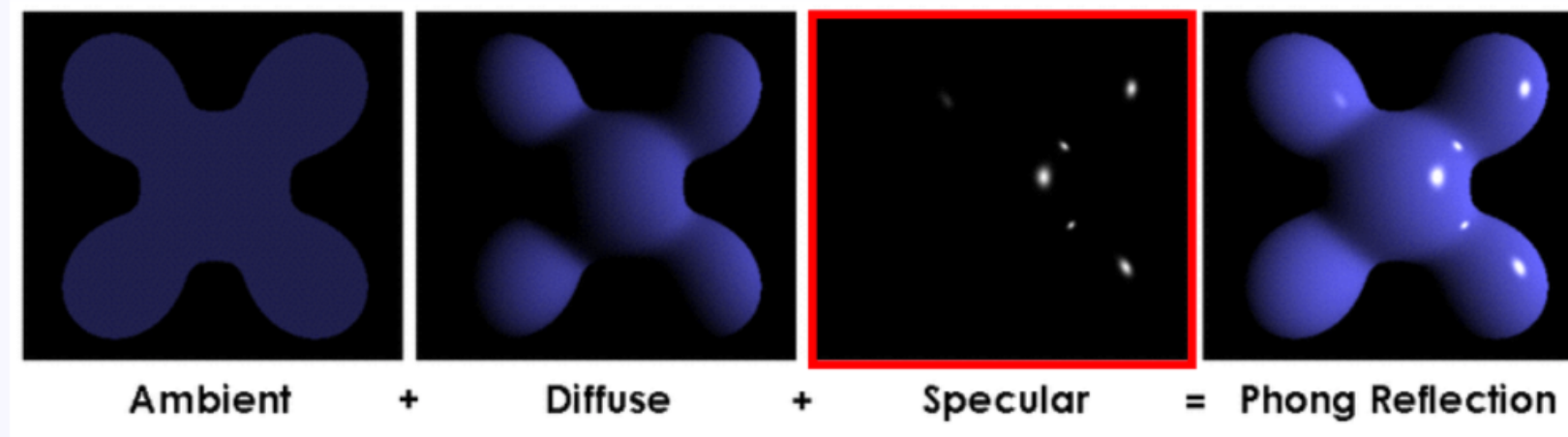


Specular surface



specular reflection is strongest in reflection direction

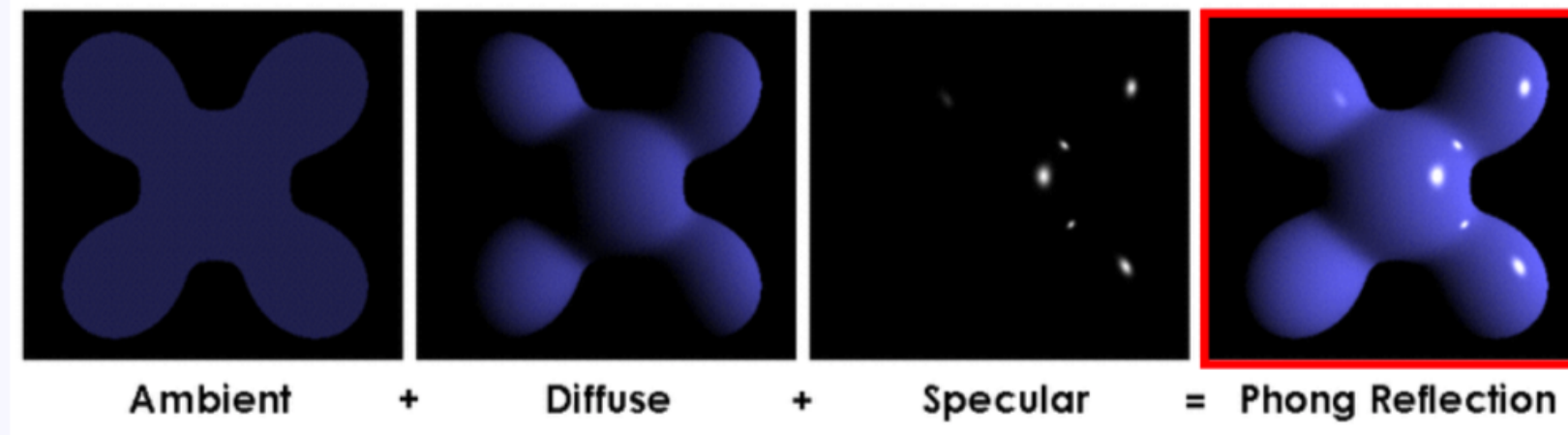
# Specular reflection



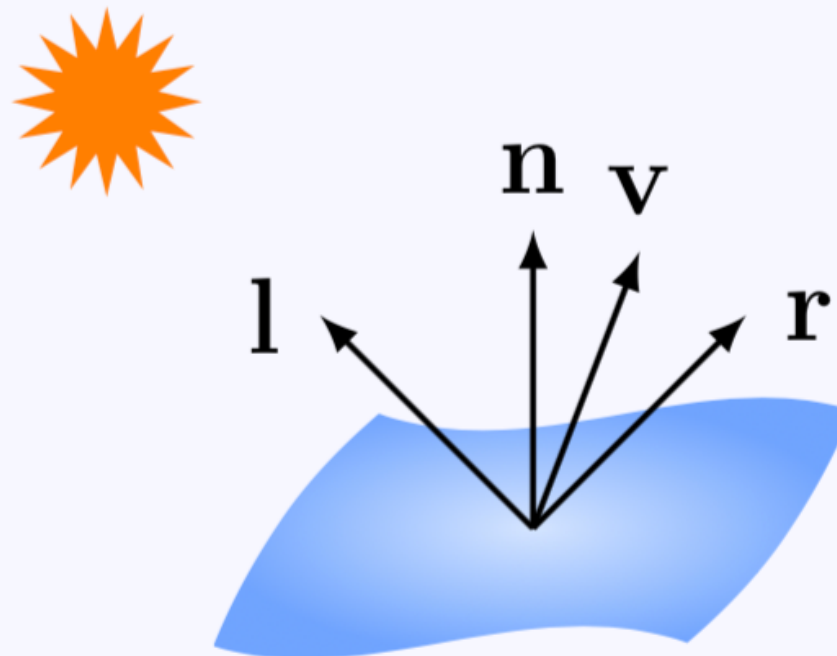
$$I_s = R_s L_s \max(\cos \phi, 0)^\alpha$$

specular reflection drops off with increasing  $\phi$

# Phong reflection model



$$I = I_a + I_d + I_s$$
$$= R_a L_a + R_d L_d \max(\mathbf{n} \cdot \mathbf{l}, 0) + R_s L_s \max(\mathbf{v} \cdot \mathbf{r}, 0)^\alpha$$



# Attribution

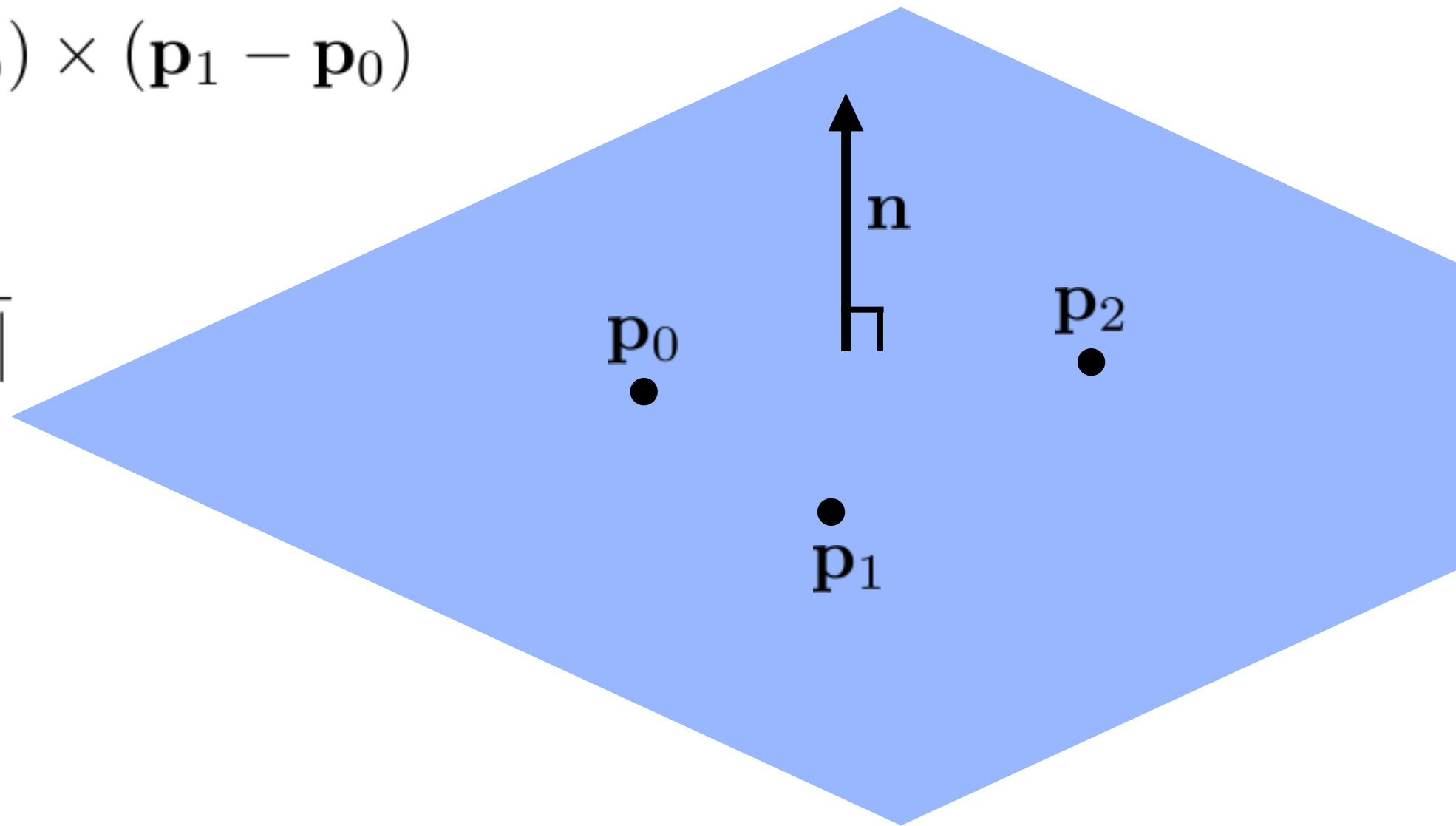
- [1] Andrea Fisher Fine Pottery. jody-folwell-jar05big.jpg.  
[https://www.eyesofthepot.com/santa-clara/jody\\_folwell](https://www.eyesofthepot.com/santa-clara/jody_folwell).

# Computing Normal Vectors

# Plane Normals

$$\mathbf{v} = (\mathbf{p}_2 - \mathbf{p}_0) \times (\mathbf{p}_1 - \mathbf{p}_0)$$

$$\mathbf{n} = \frac{\mathbf{v}}{||\mathbf{v}||}$$



# Implicit function normals

$$f(\mathbf{p}) = 0$$

$$\nabla f(\mathbf{p})$$

sphere

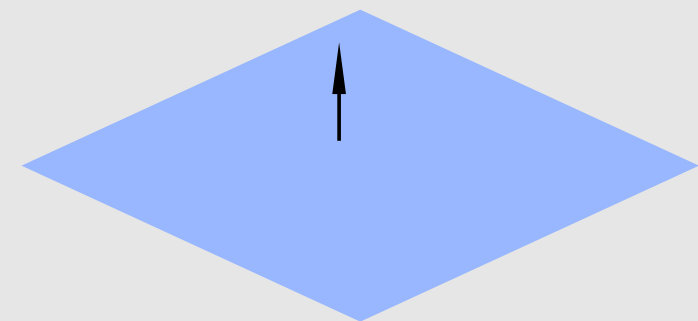
$$\mathbf{p} \cdot \mathbf{p} - r^2 = 0$$



$$\nabla f = \begin{pmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \\ \frac{\partial f}{\partial z} \end{pmatrix}$$

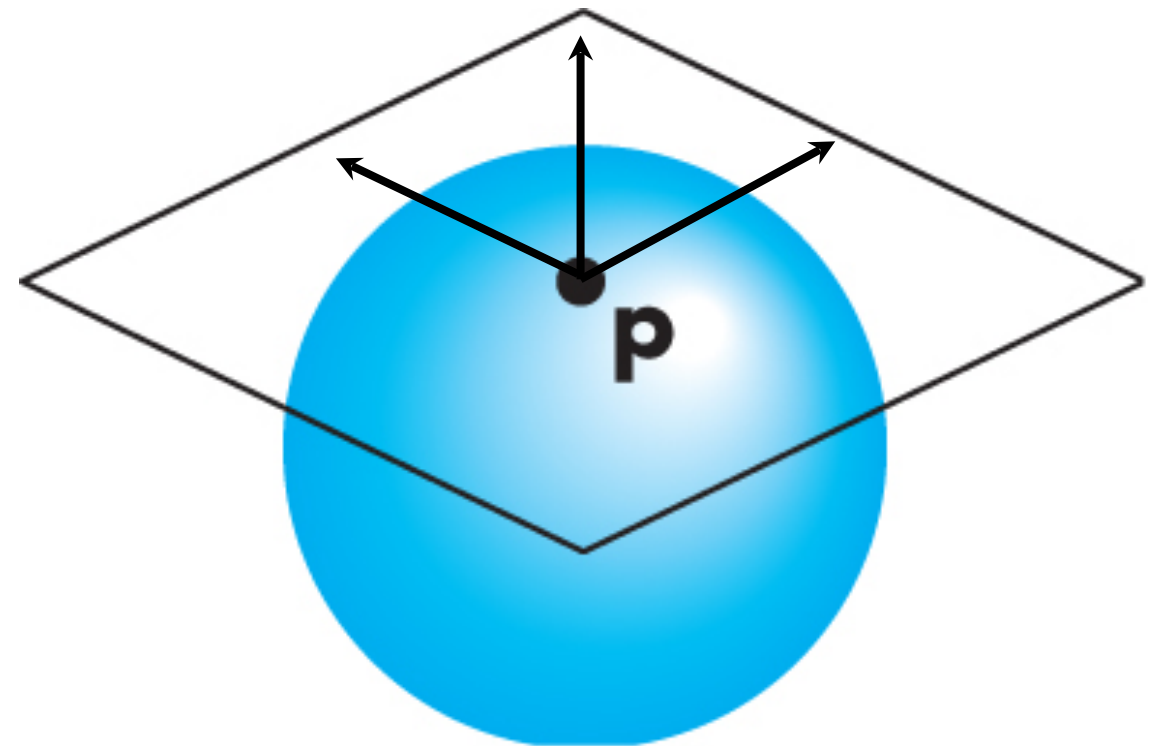
plane

$$\mathbf{n} \cdot (\mathbf{p} - \mathbf{p}_0) = 0$$



# Parametric form

$$\mathbf{p}(u, v) = \begin{pmatrix} x(u, v) \\ y(u, v) \\ z(u, v) \end{pmatrix}$$



tangent  
vectors

$$\frac{\partial \mathbf{p}}{\partial u} \quad \frac{\partial \mathbf{p}}{\partial v}$$

normal

$$\frac{\frac{\partial \mathbf{p}}{\partial u} \times \frac{\partial \mathbf{p}}{\partial v}}{\left\| \frac{\partial \mathbf{p}}{\partial u} \times \frac{\partial \mathbf{p}}{\partial v} \right\|}$$