

# Digitalfotografie – Teil I

## Licht & Linsen

Tim Hegemann

*Offenes Kolloquium am 16. Juli 2025*

# Camera Obscura

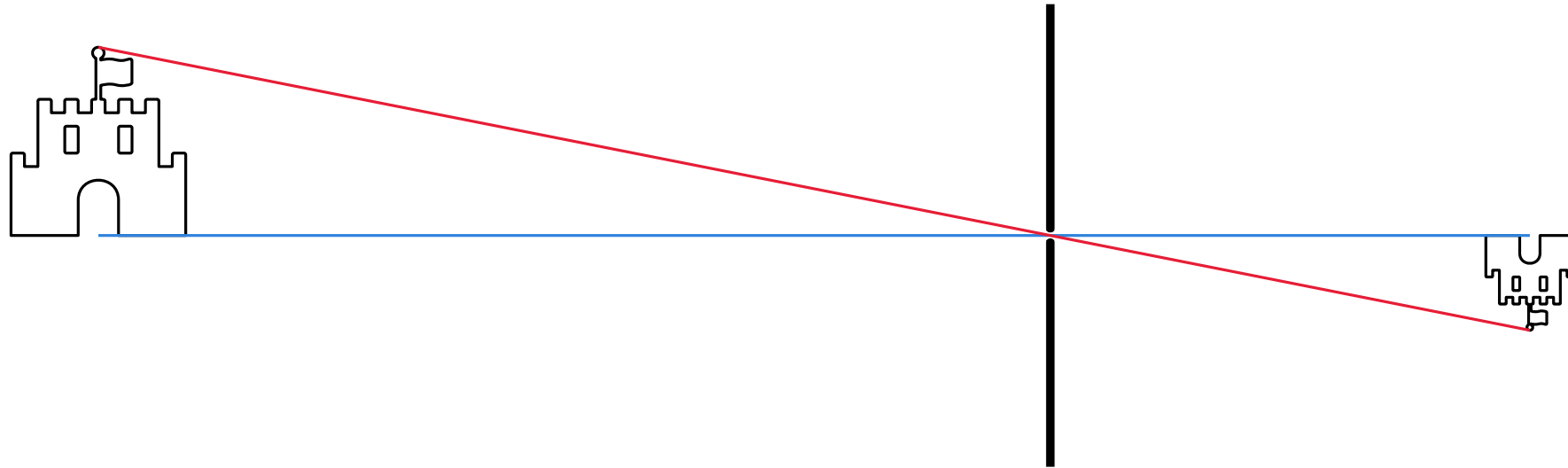


$\approx 18\text{mm}$   
 $\approx f/36$   
 $1/30\text{ s}$   
ISO 100

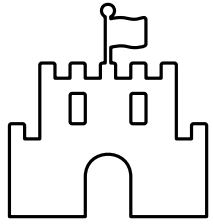
# Camera Obscura



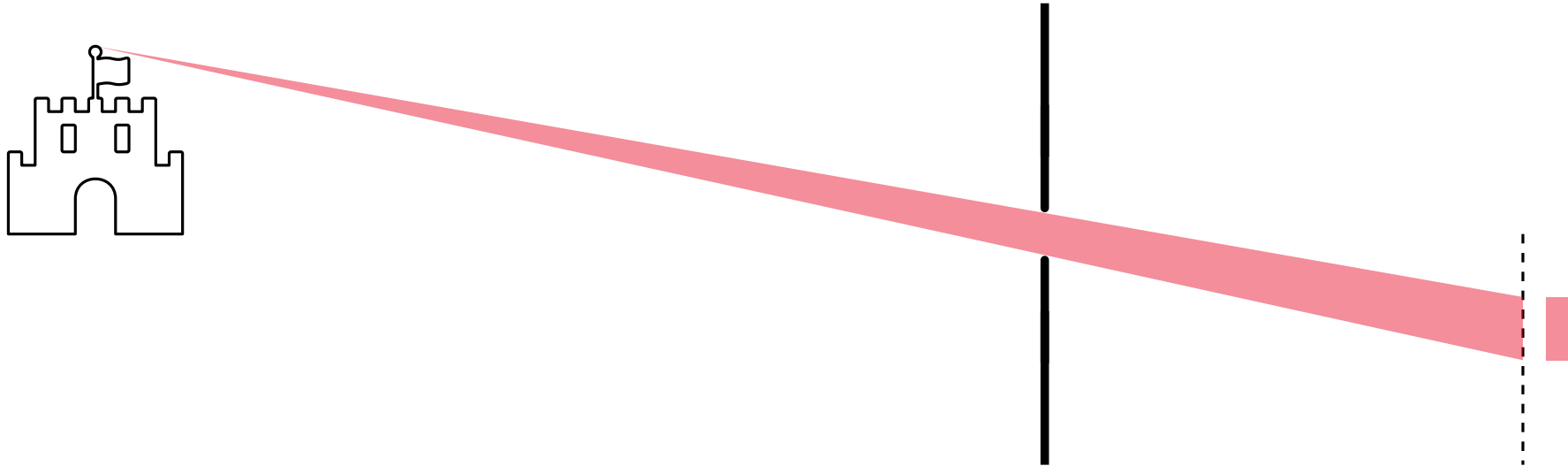
# Camera Obscura



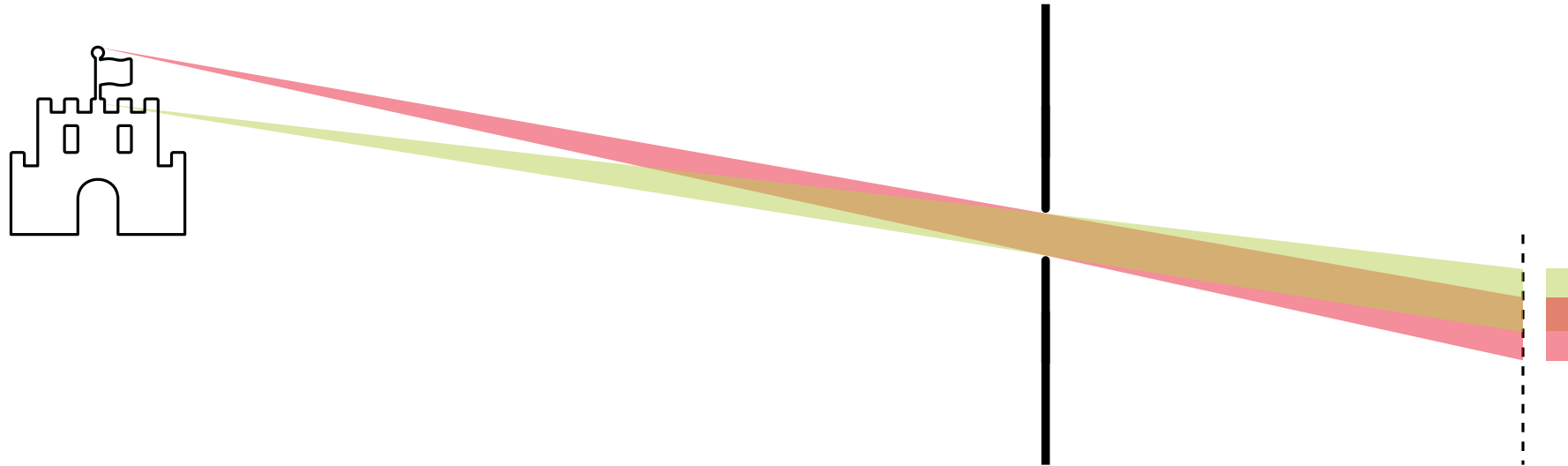
# Camera Obscura



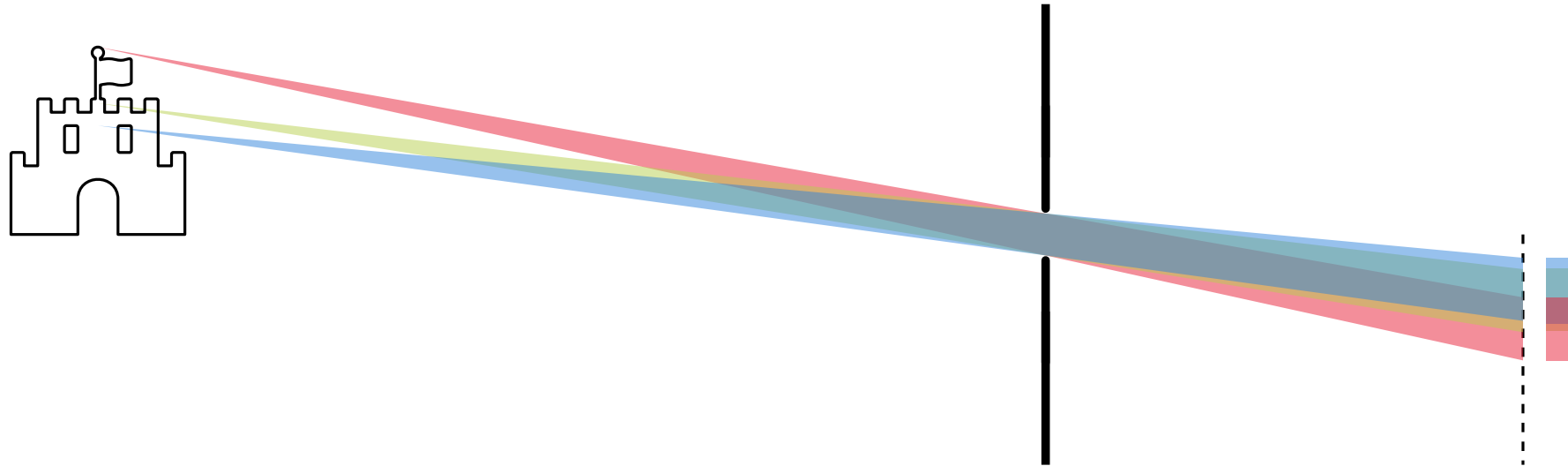
# Camera Obscura



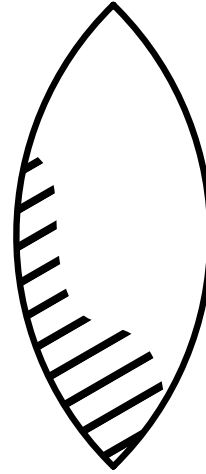
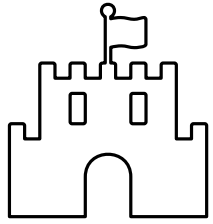
# Camera Obscura



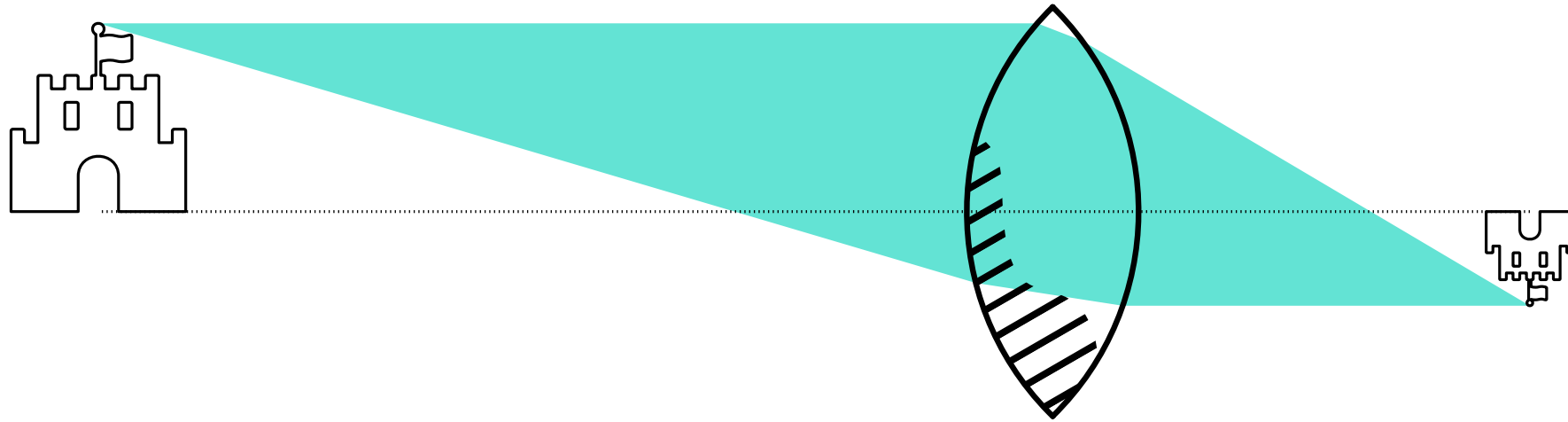
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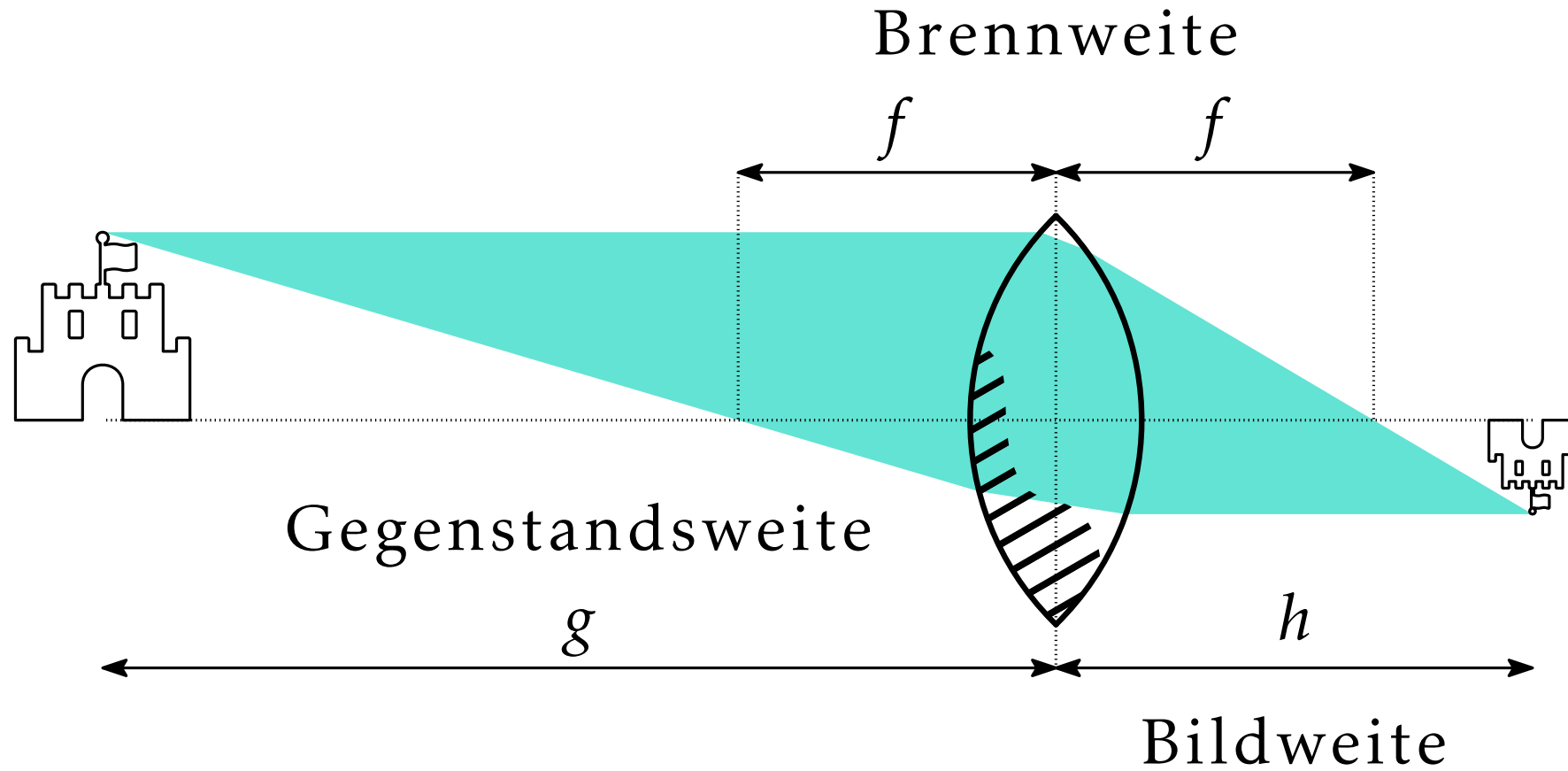
# Optische Linsen



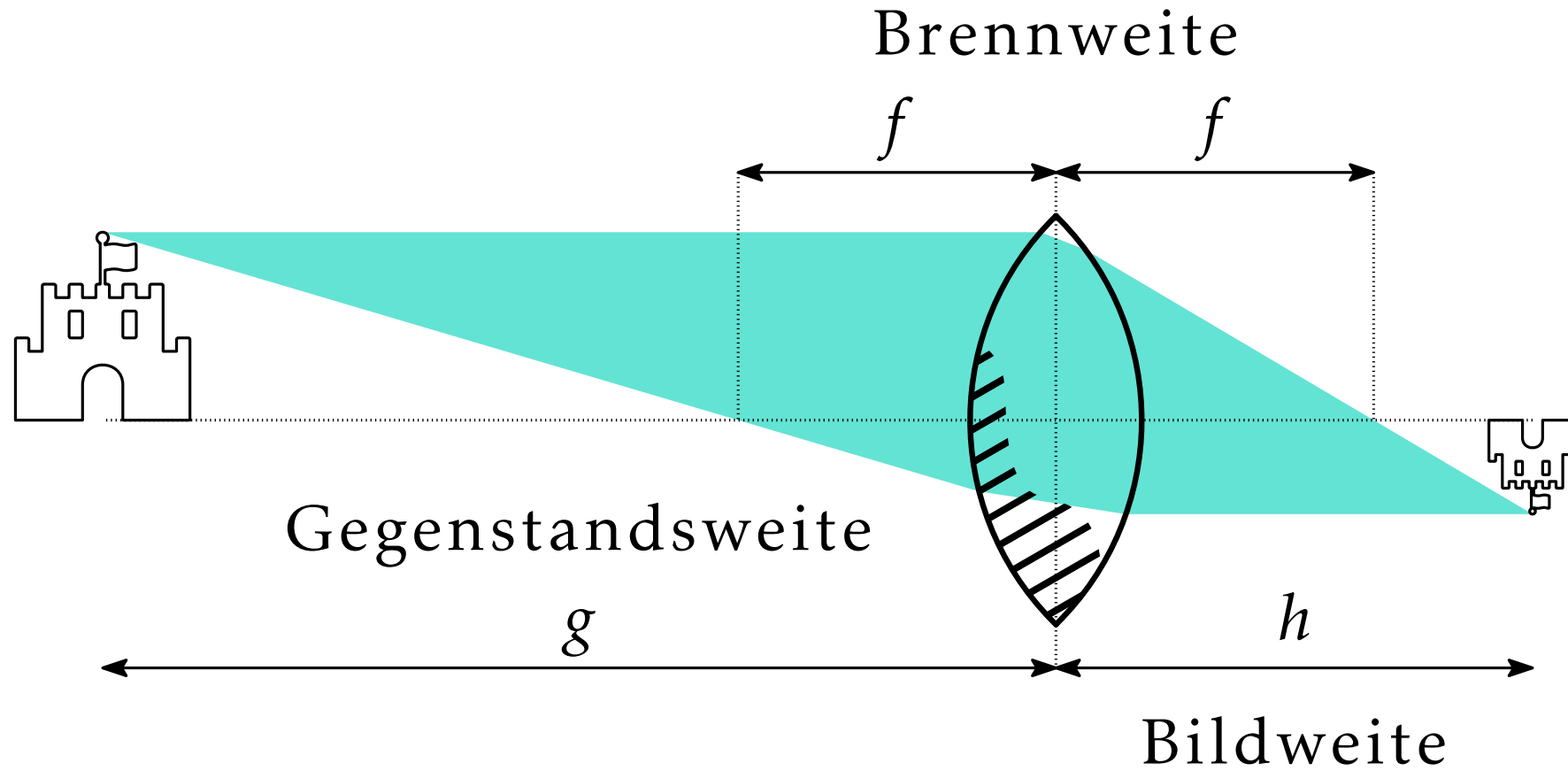
# Optische Linsen



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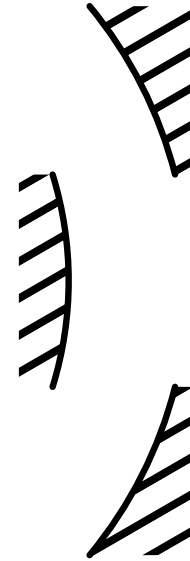
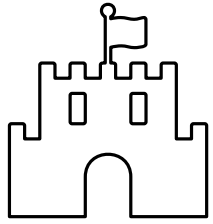


# Optische Linsen

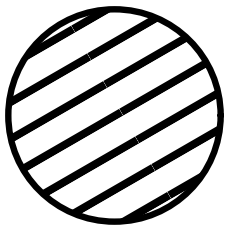
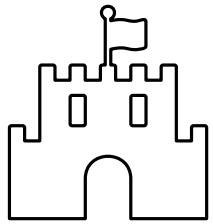


Linsengleichung:  $\frac{1}{f} = \frac{1}{g} + \frac{1}{h}$

# Exkurs: Spiegel

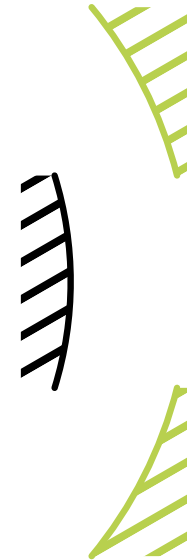


# Exkurs: Spiegel

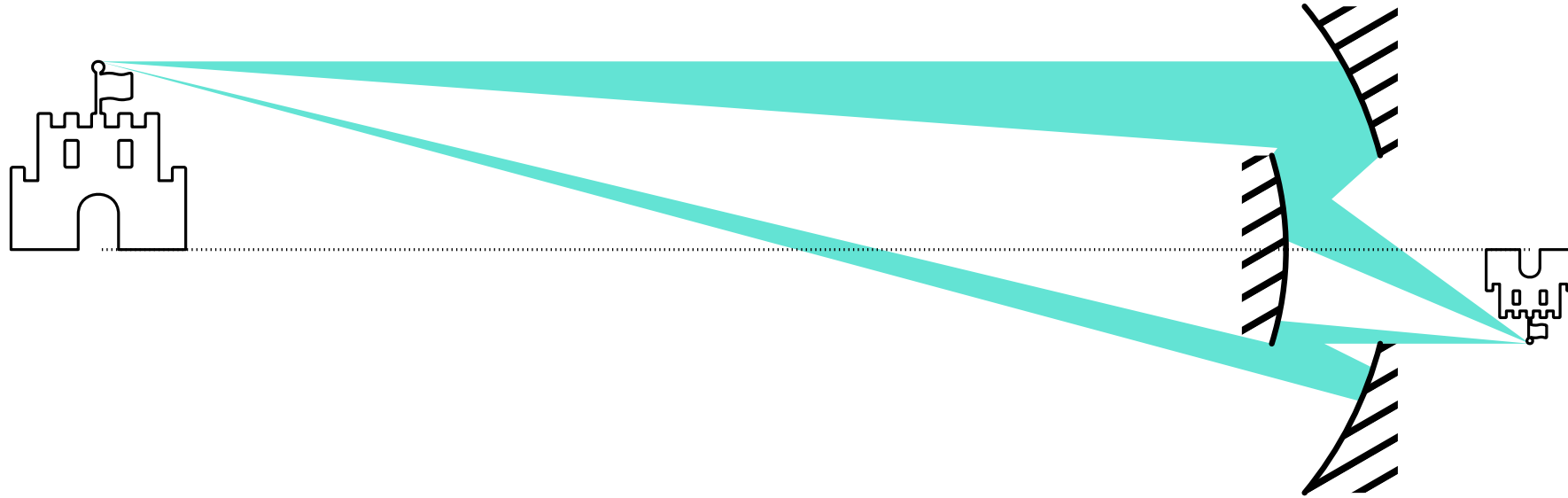


Sekundärspiegel

Primärspiegel



# Exkurs: Spiegel



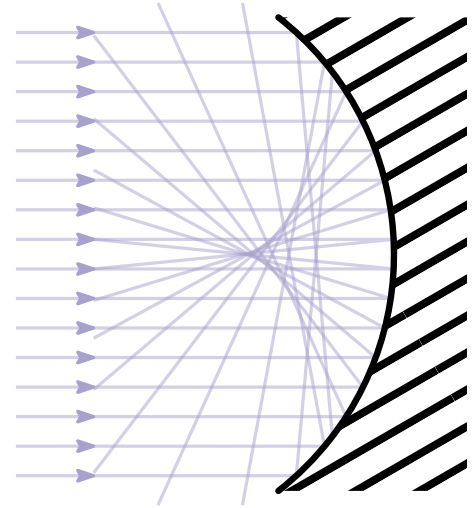
# Abbildungsfehler



105mm  
 $f/8,0$   
1/125 s  
ISO 200

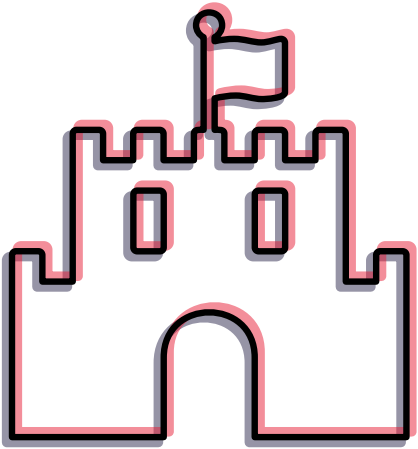
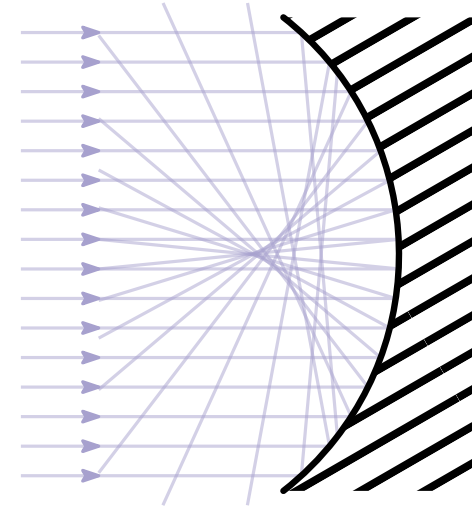
# Abbildungsfehler

Sphärische Abberation



# Abbildungsfehler

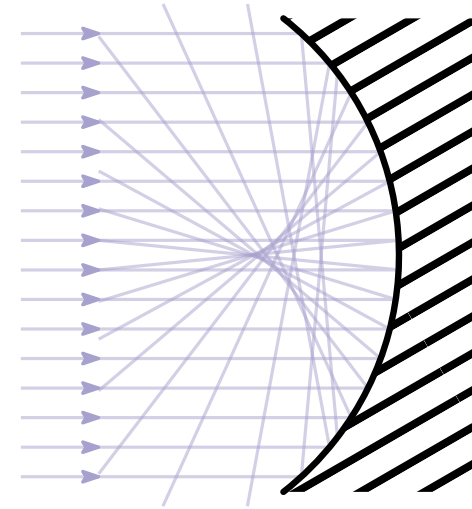
Sphärische Abberation



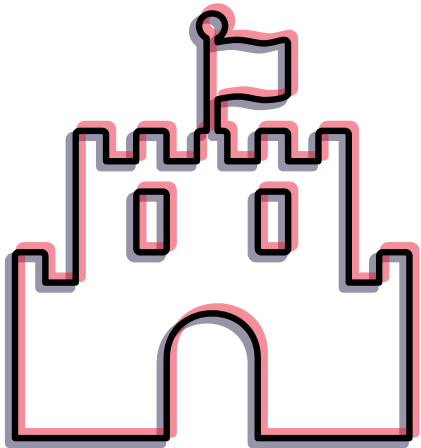
Chromatische Abberation

# Abbildungsfehler

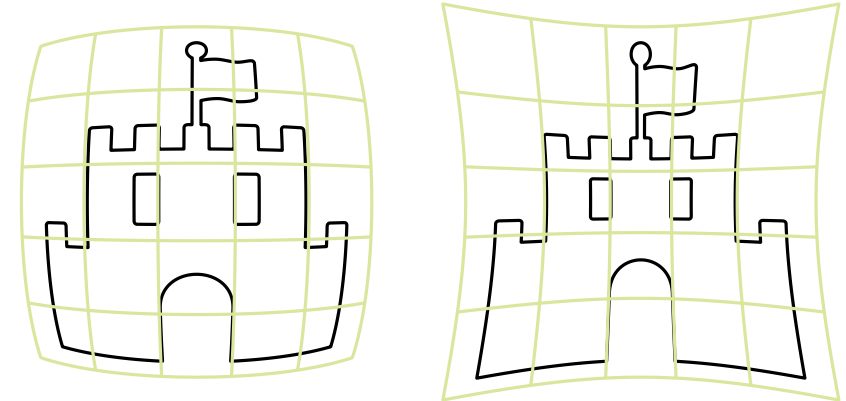
Sphärische Abberation



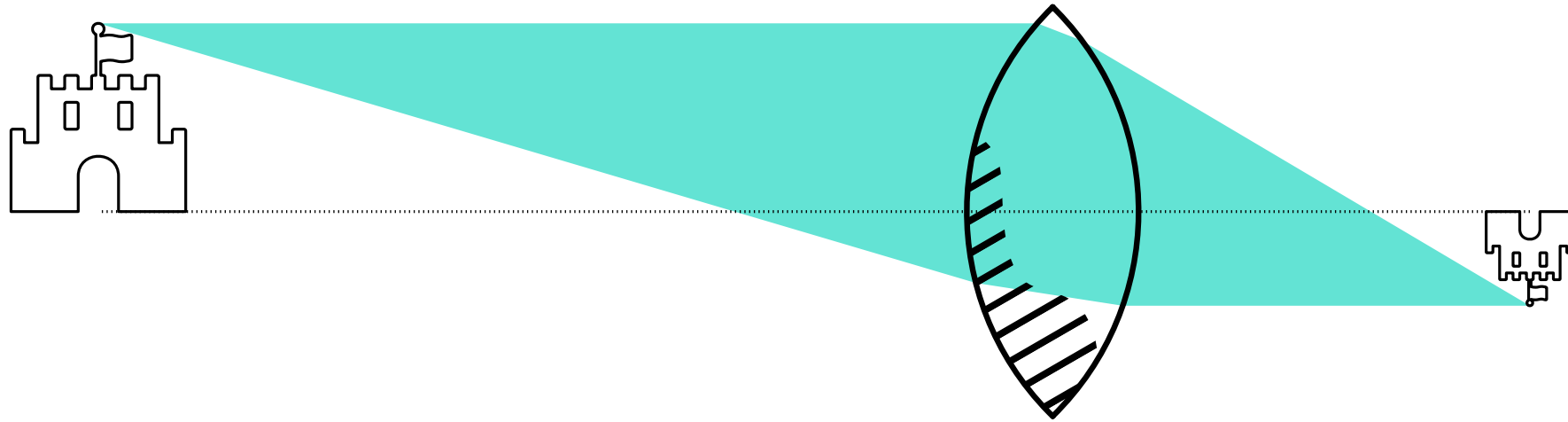
Chromatische Abberation



Verzeichnung



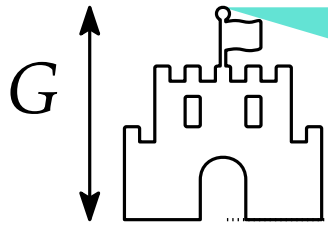
# Abbildungsmaßstab



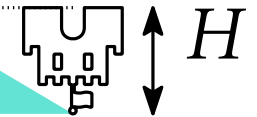
# Abbildungsmaßstab

$$\beta = \frac{H}{G}$$

Gegenstandshöhe



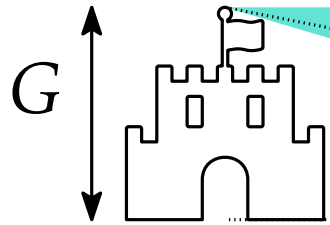
Bildhöhe



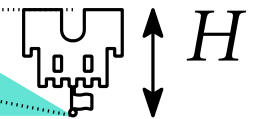
# Abbildungsmaßstab

$$\beta = \frac{H}{G} = \frac{h}{g}$$

Gegenstandshöhe



Bildhöhe

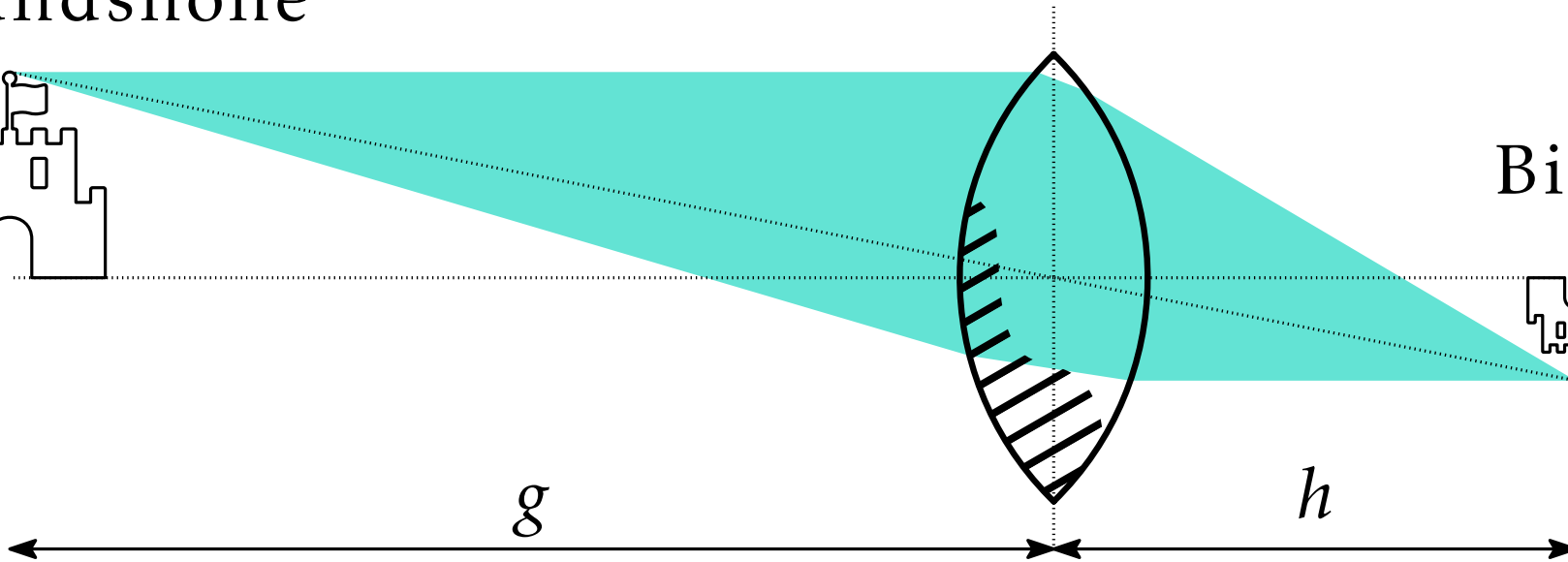


$g$

Gegenstandsweite

$h$

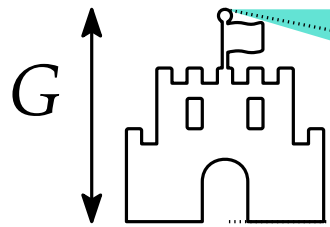
Bildweite



# Abbildungsmaßstab

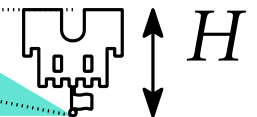
$$\beta = \frac{H}{G} = \frac{h}{g} \quad f \ll g \quad \approx \quad \frac{f}{d}$$

Gegenstandshöhe



$f$  Brennweite

Bildhöhe



$g$   
Gegenstandsweite

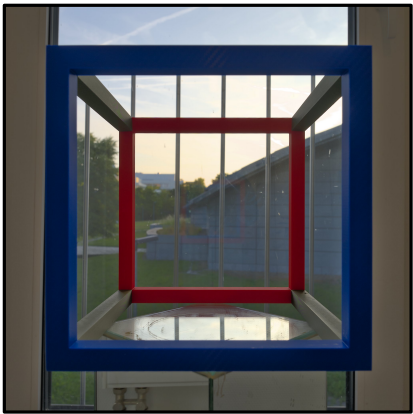
$h$   
Bildweite

$d$   
Fokusdistanz

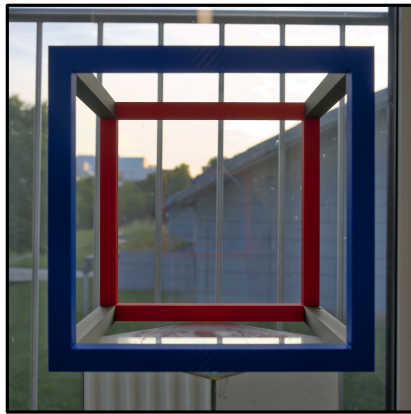
# Abbildungsmaßstab

Brennweite:

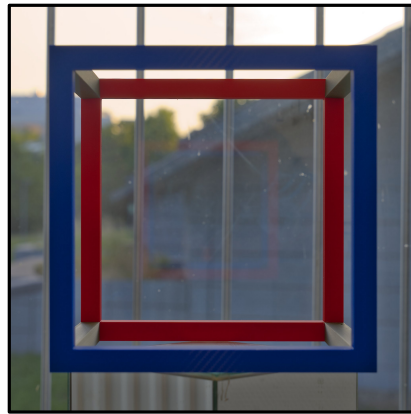
16 mm



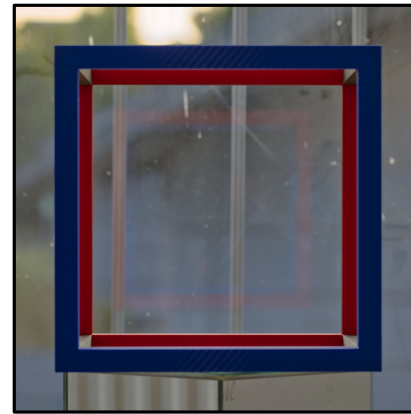
25 mm



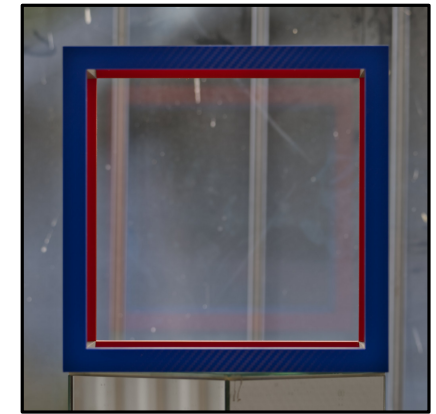
50 mm



100 mm



200 mm

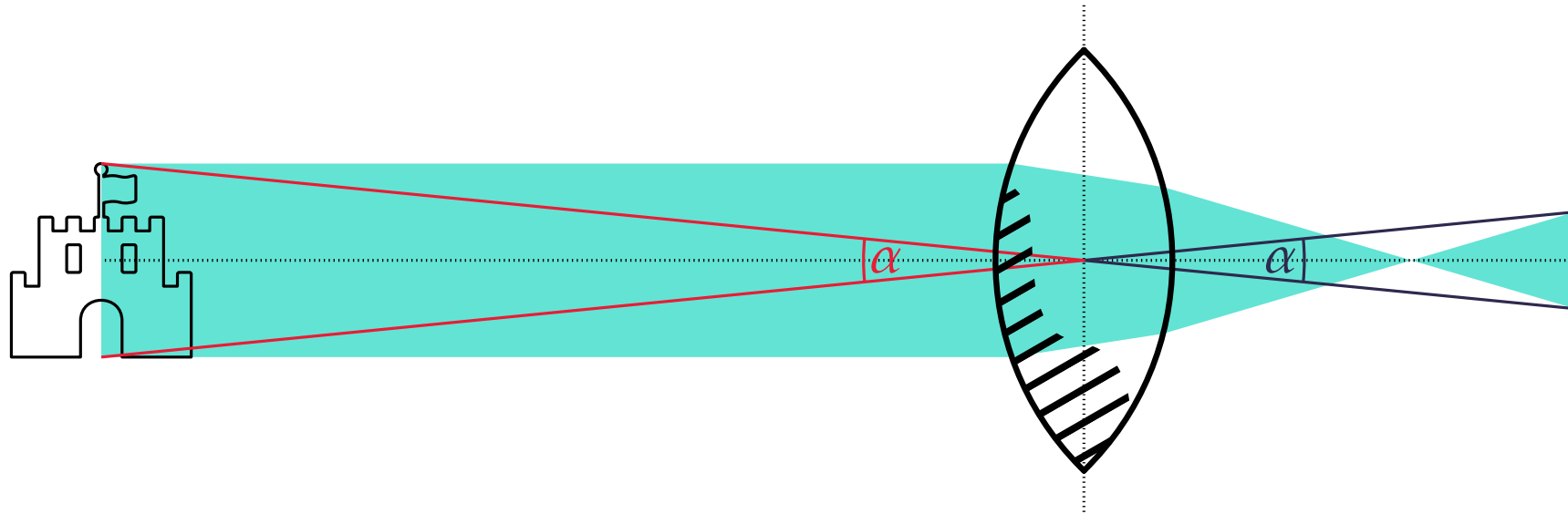


*konstanter Abbildungsmaßstab*

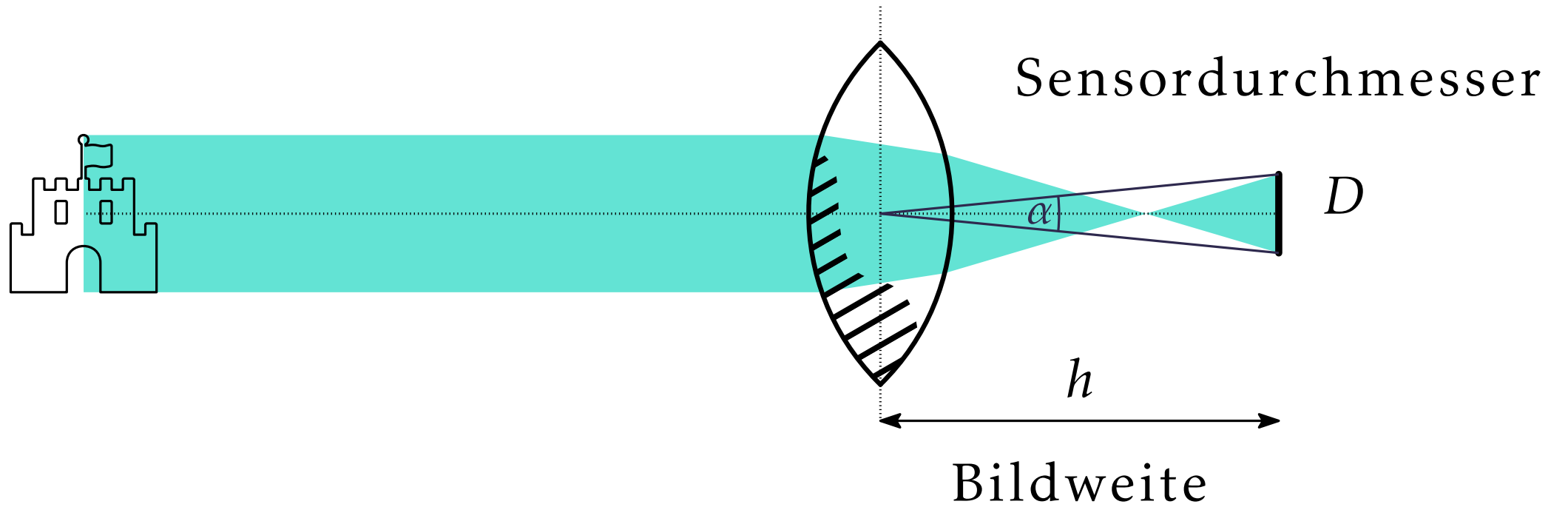
# Bildwinkel



# Bildwinkel

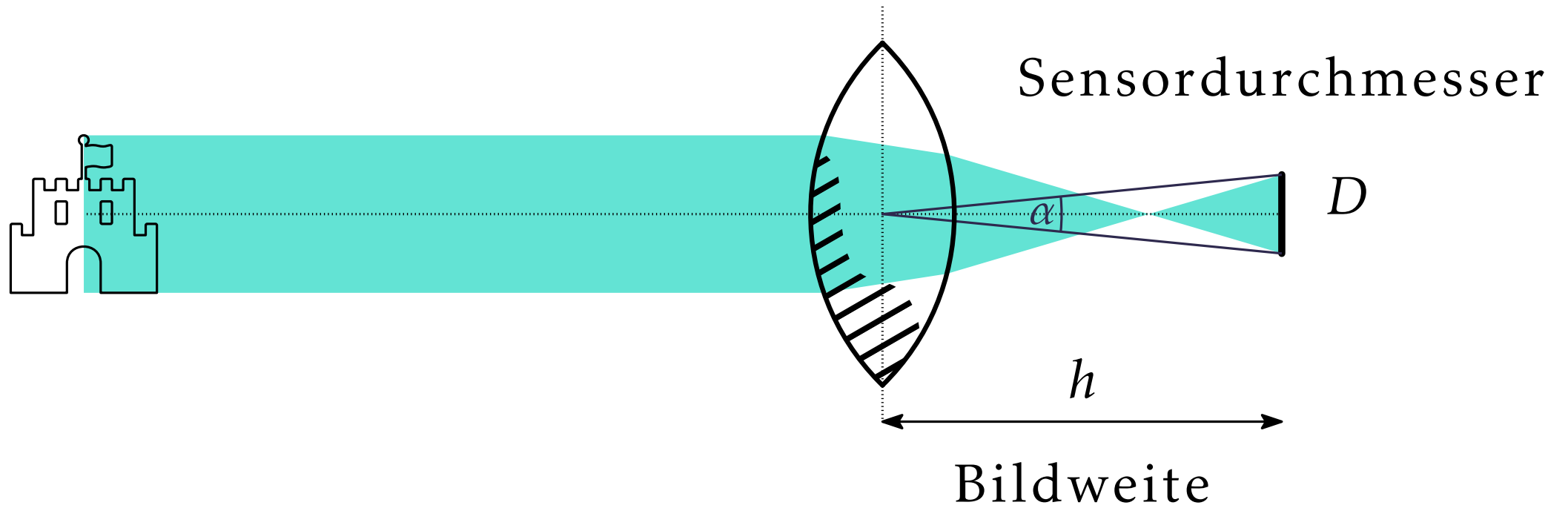


# Bildwinkel



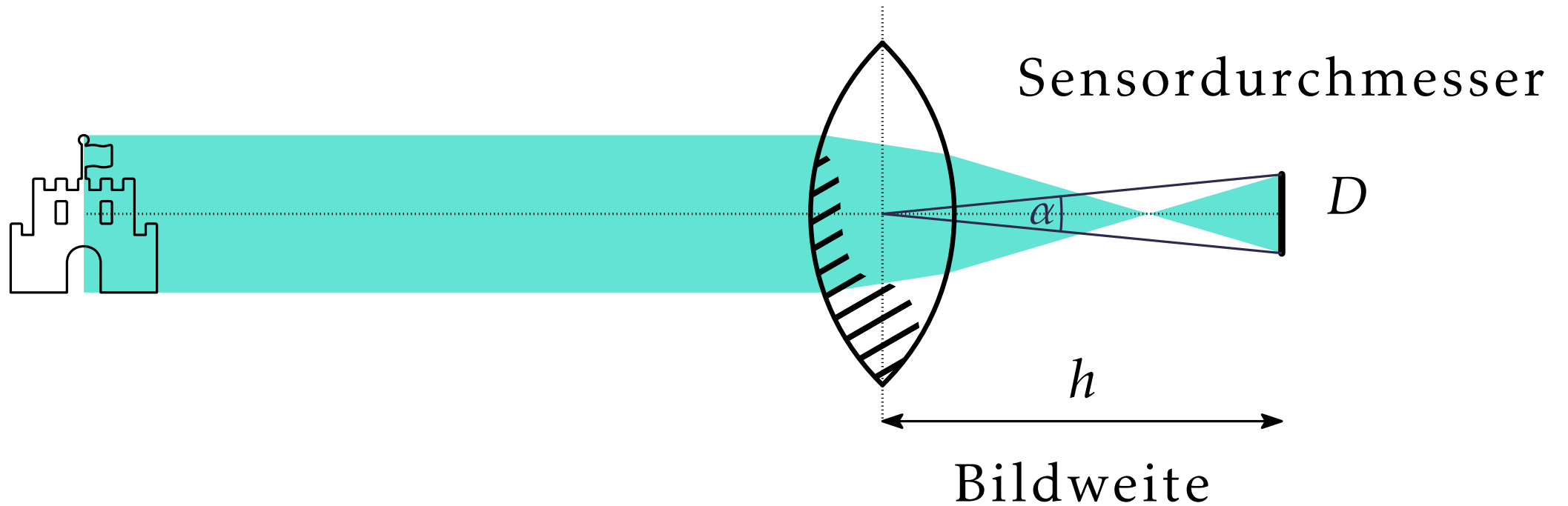
# Bildwinkel

$$\alpha = 2 \tan^{-1} \left( \frac{D}{2h} \right)$$



# Bildwinkel

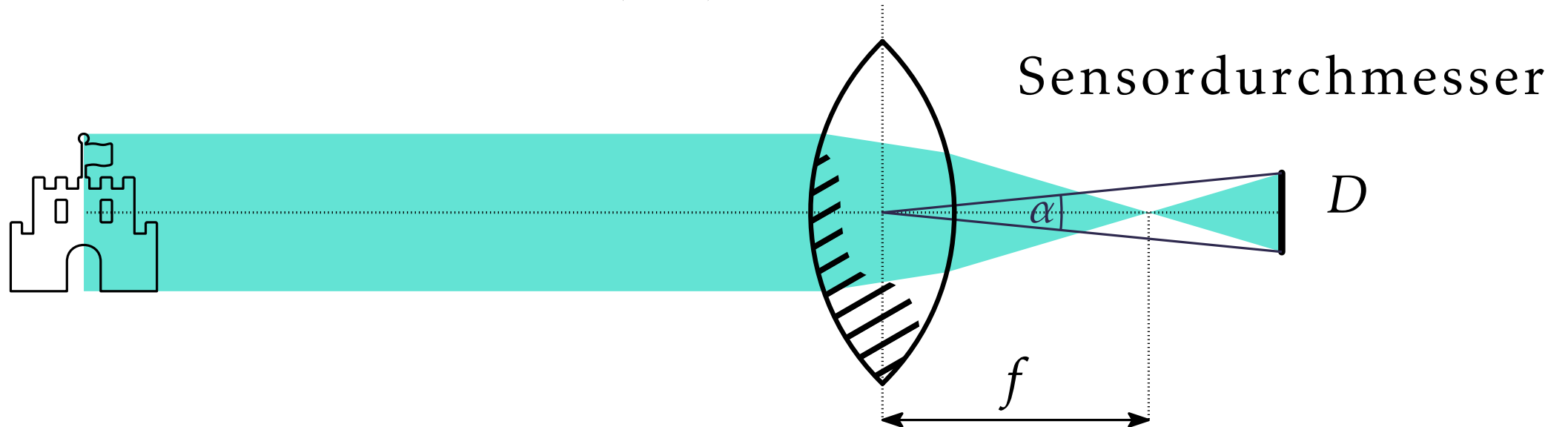
$$\alpha = 2 \tan^{-1} \left( \frac{D}{2h} \right)$$



Linsengleichung:  $\frac{1}{f} = \frac{1}{g} + \frac{1}{h}$

# Bildwinkel

$$\alpha = 2 \tan^{-1} \left( \frac{D}{2h} \right) \stackrel{g \rightarrow \infty}{\approx} 2 \tan^{-1} \left( \frac{D}{2f} \right)$$

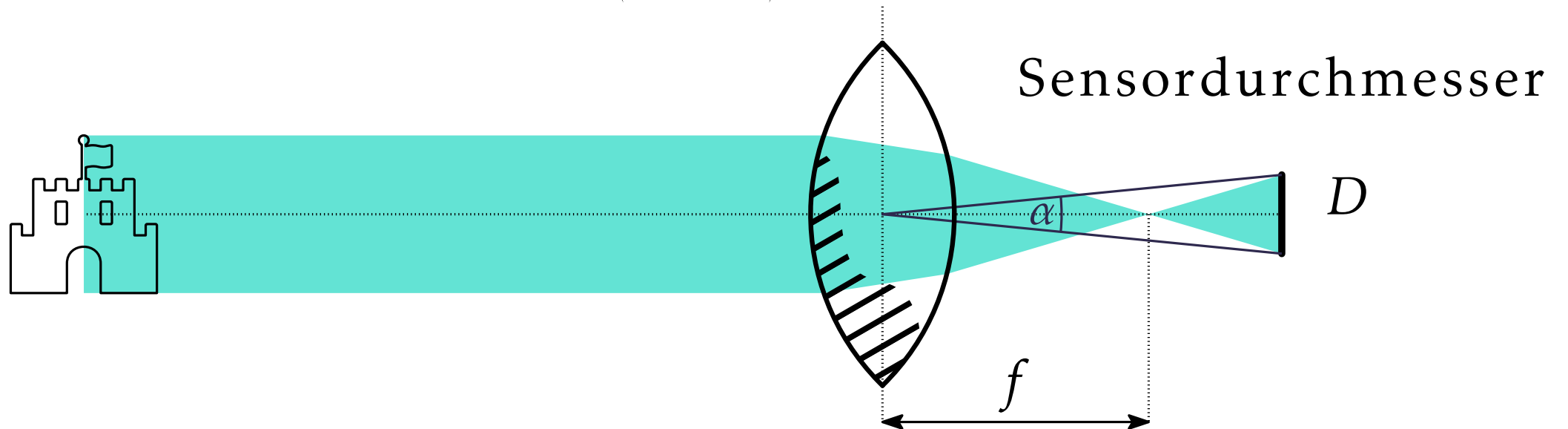


Linsengleichung:  $\frac{1}{f} = \frac{1}{g} + \frac{1}{h}$

# Bildwinkel

Formatfaktor  
*crop factor*

$$\alpha = 2 \tan^{-1} \left( \frac{D}{2h} \right) \stackrel{g \rightarrow \infty}{\approx} 2 \tan^{-1} \left( \frac{D \cdot x}{2f \cdot x} \right)$$

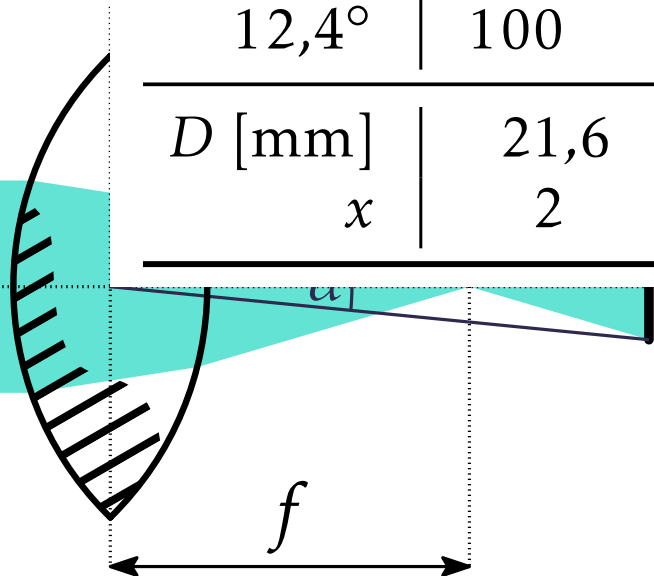
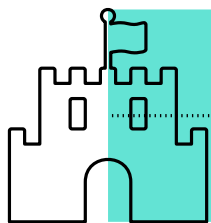


Linsengleichung:  $\frac{1}{f} = \frac{1}{g} + \frac{1}{h}$

# Bildwinkel

Formatfaktor  
*crop factor*

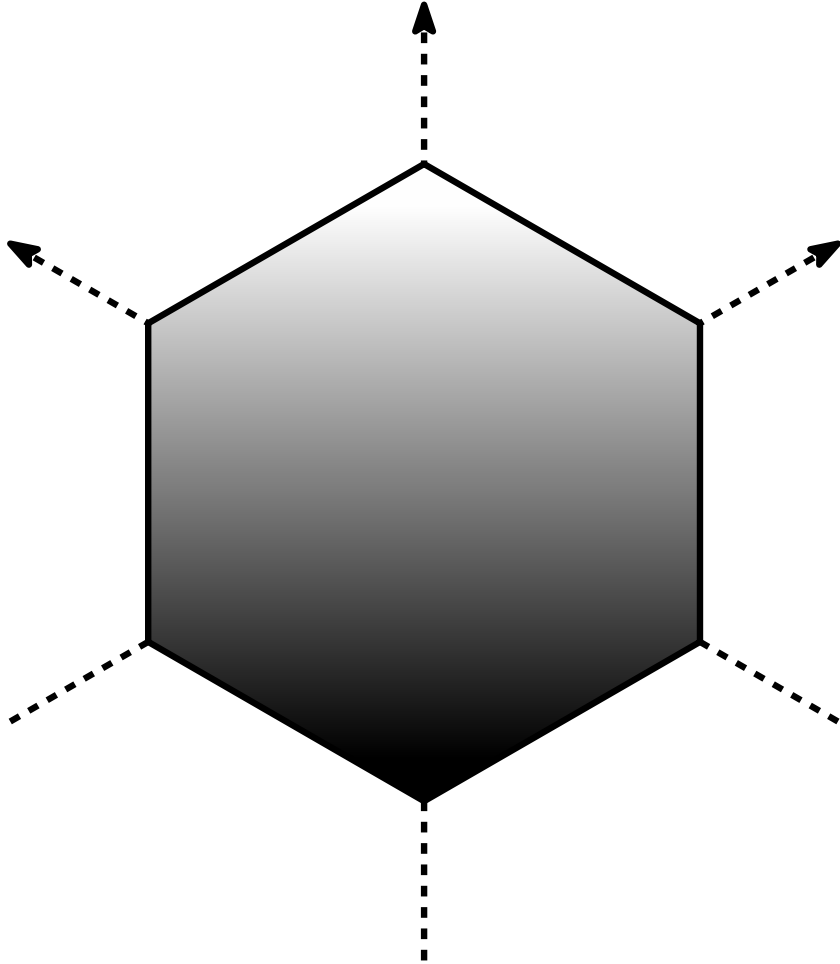
$$\alpha = 2 \tan^{-1} \left( \frac{D}{2h} \right) \stackrel{g \rightarrow \infty}{\approx} 2 \tan^{-1} \left( \frac{D \cdot x}{2f \cdot x} \right)$$



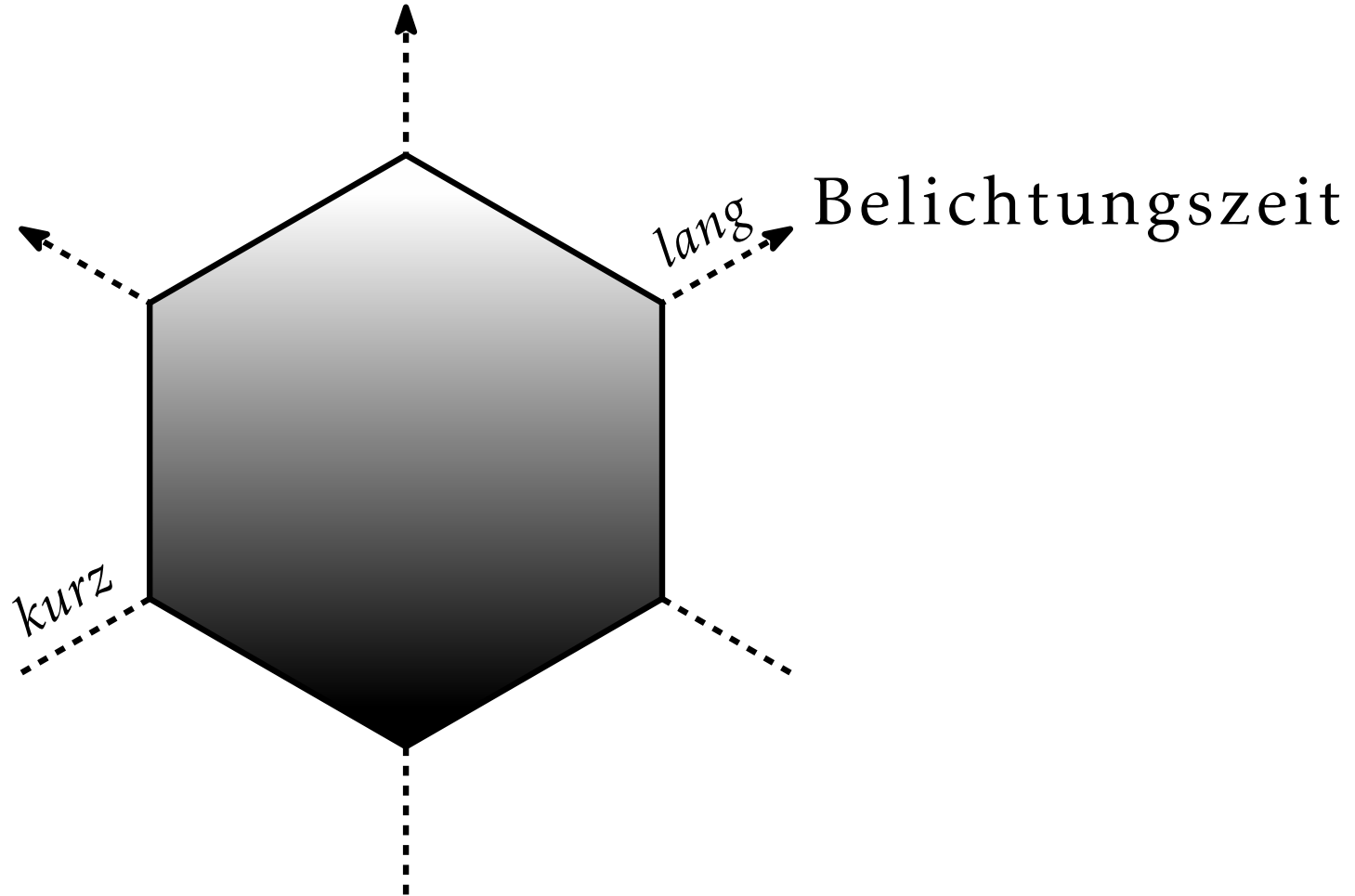
| $\alpha$ | $f$ [mm] |       |      |
|----------|----------|-------|------|
|          | MFT      | APS-C | FF   |
| 107,1°   | 8        | 12    | 16   |
| 81,8°    | 12,5     | 16,7  | 25   |
| 46,8°    | 25       | 33,3  | 50   |
| 24,4°    | 50       | 66,7  | 100  |
| 12,4°    | 100      | 133   | 200  |
| $D$ [mm] | 21,6     | 28,3  | 43,3 |
| $x$      | 2        | 1,5   | 1    |

Linsengleichung:  $\frac{1}{f} = \frac{1}{g} + \frac{1}{h}$

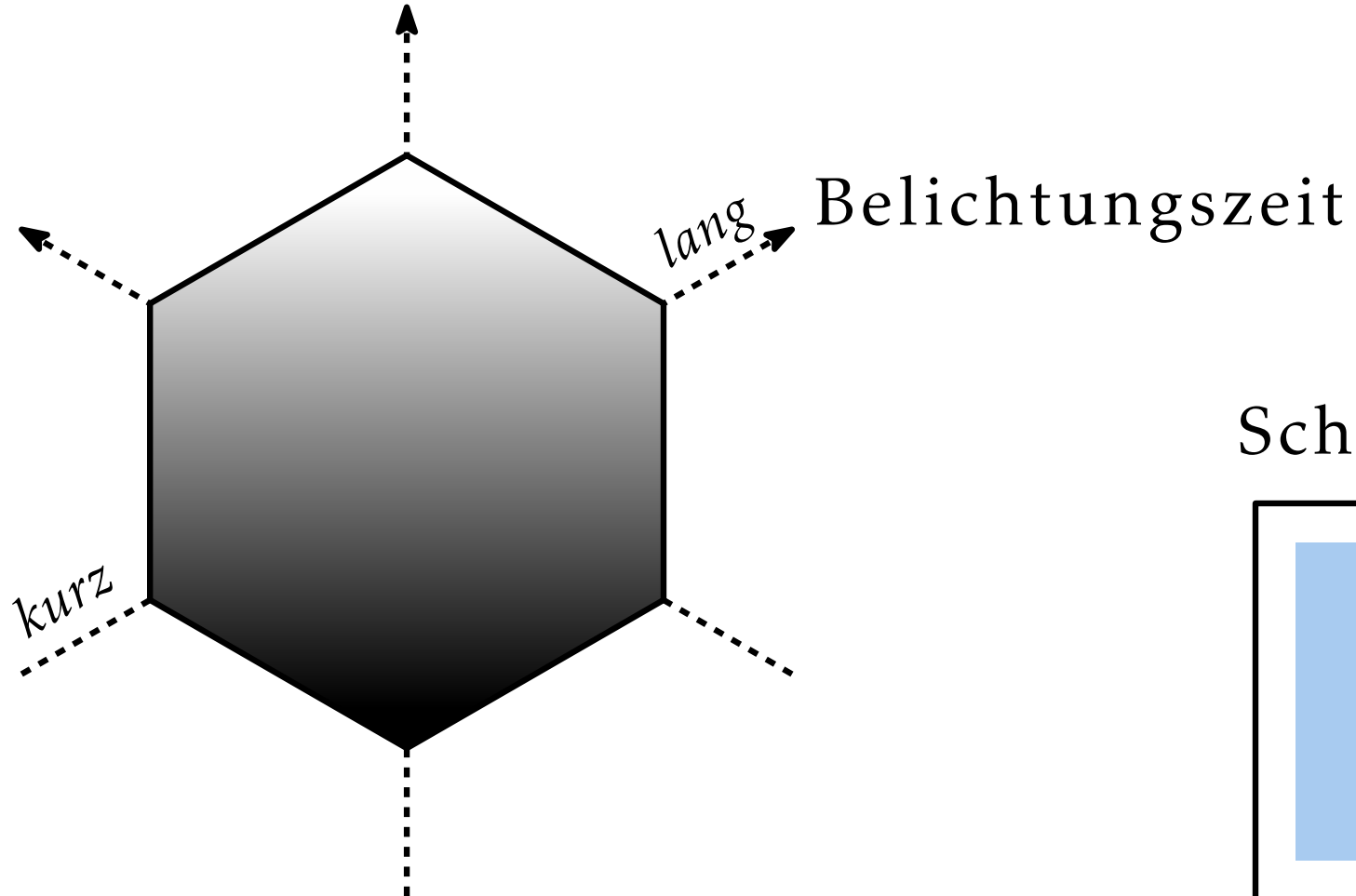
# Belichtung



# Belichtung



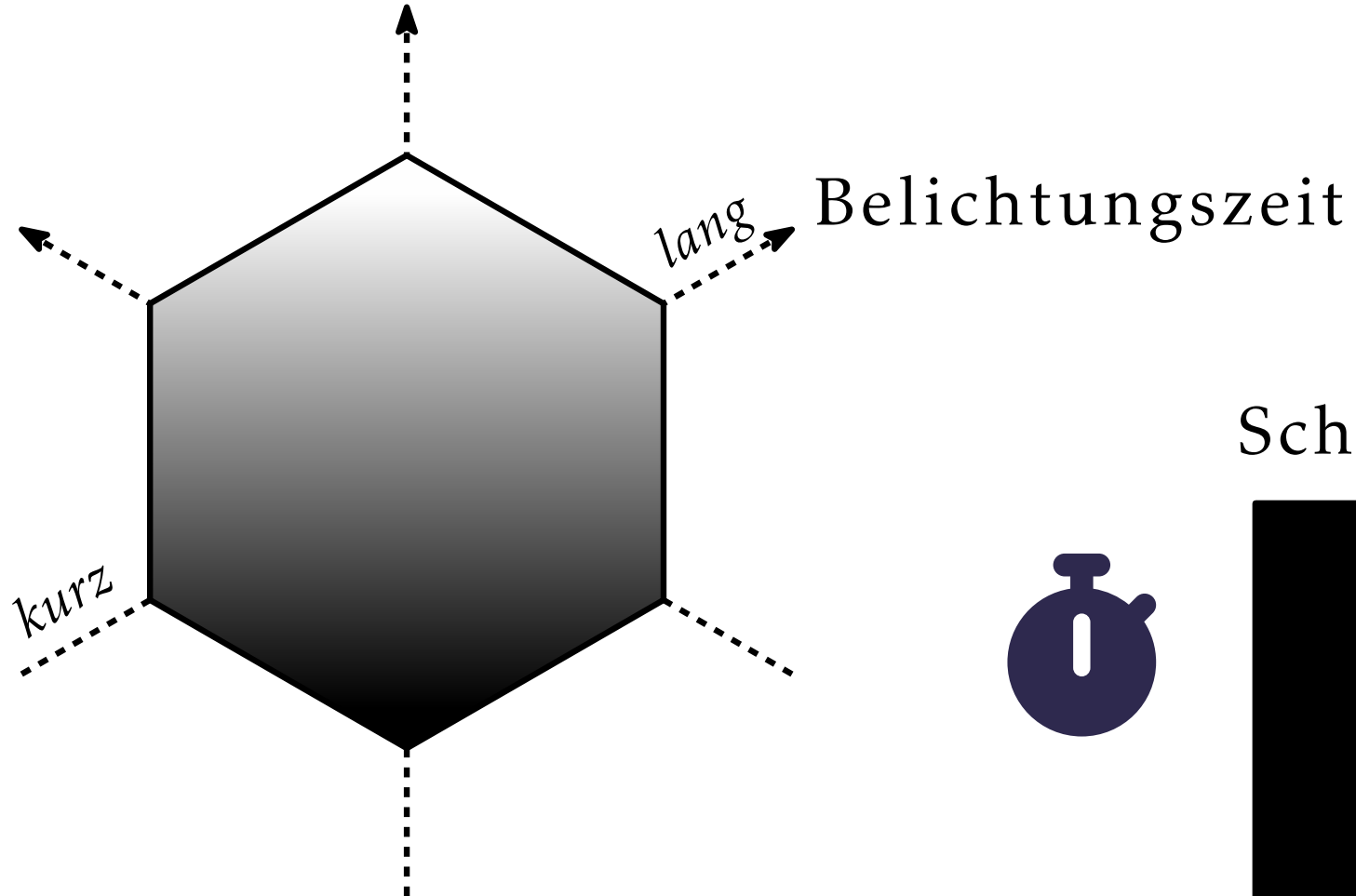
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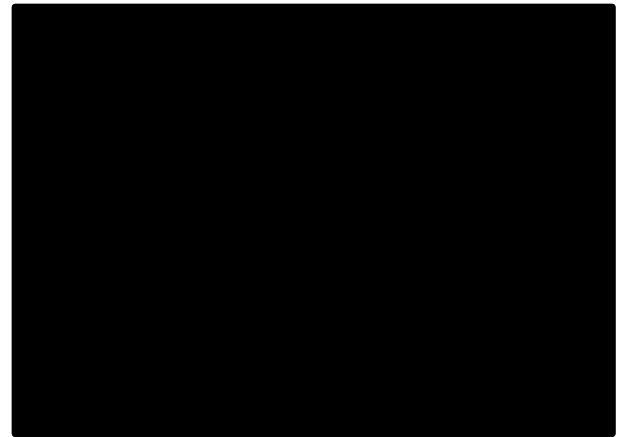
Schlitzverschluss



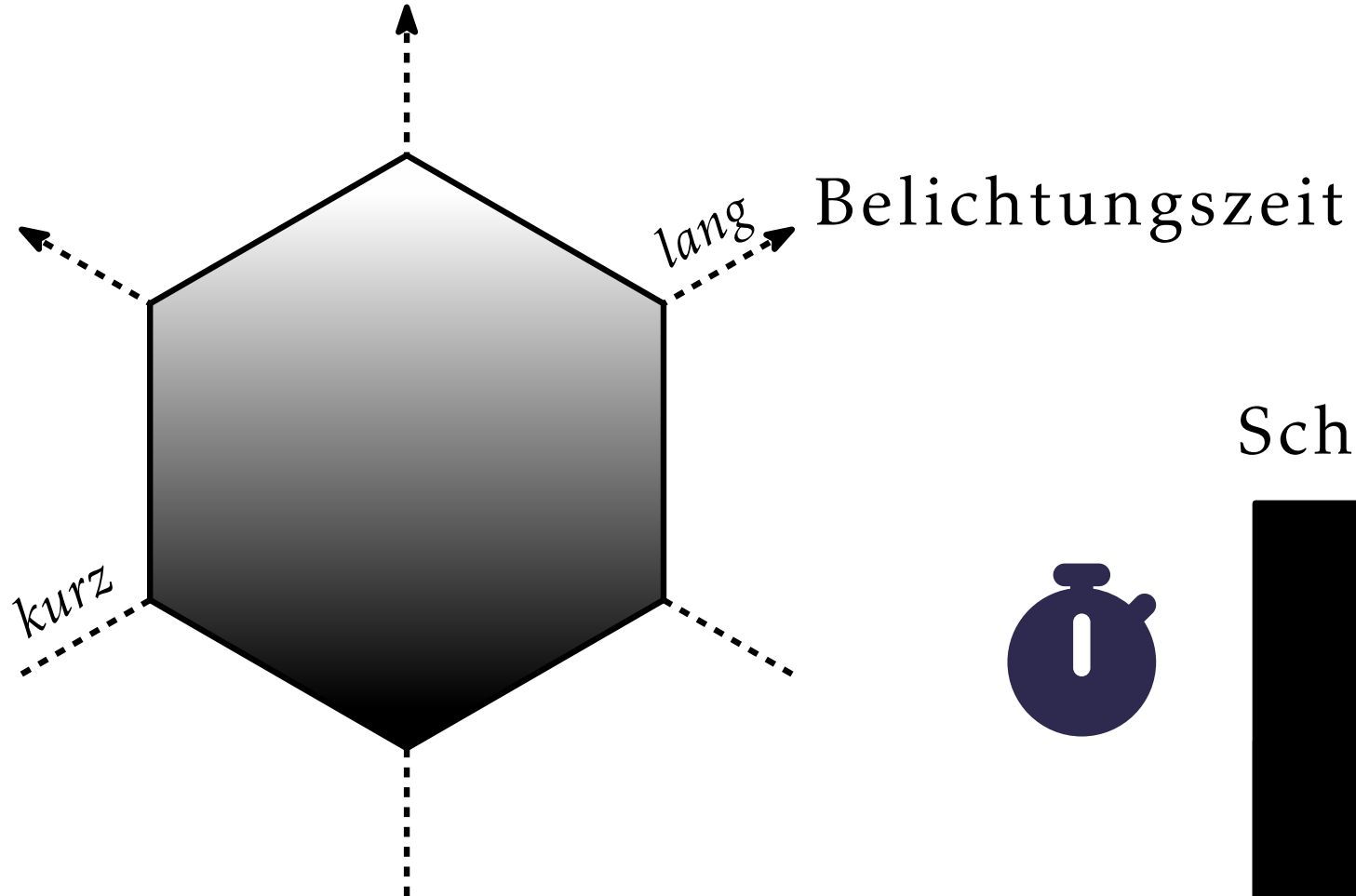
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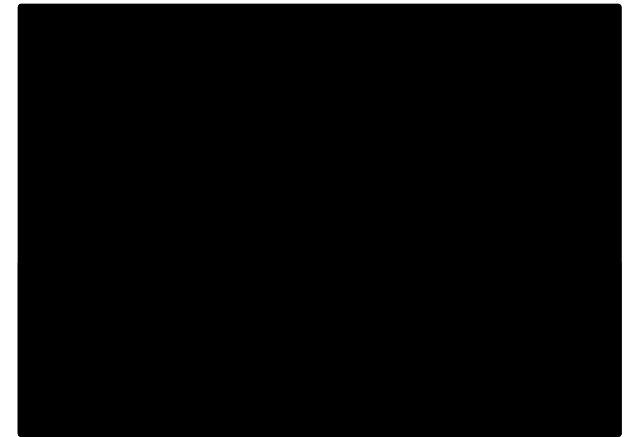
Schlitzverschluss



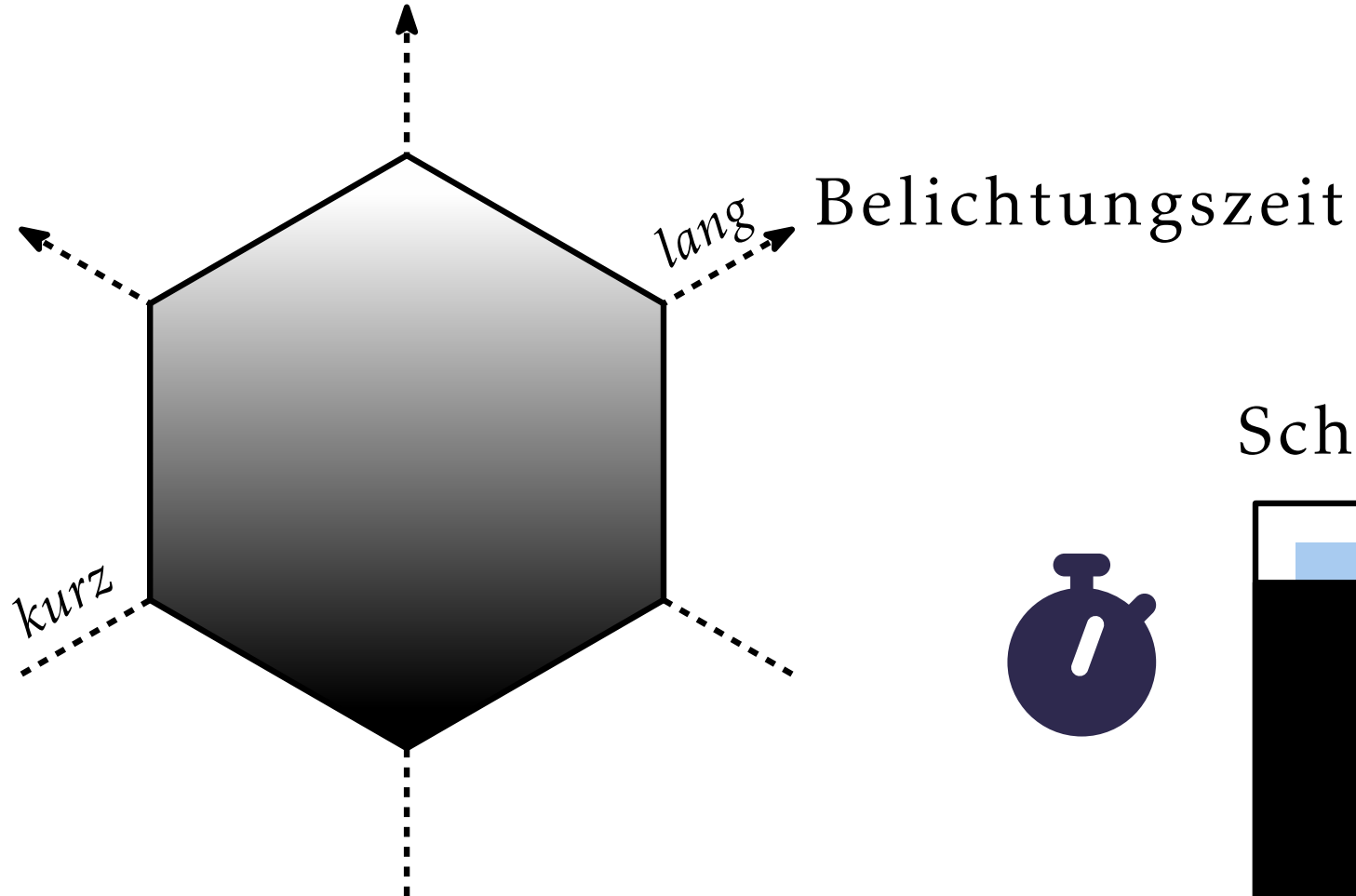
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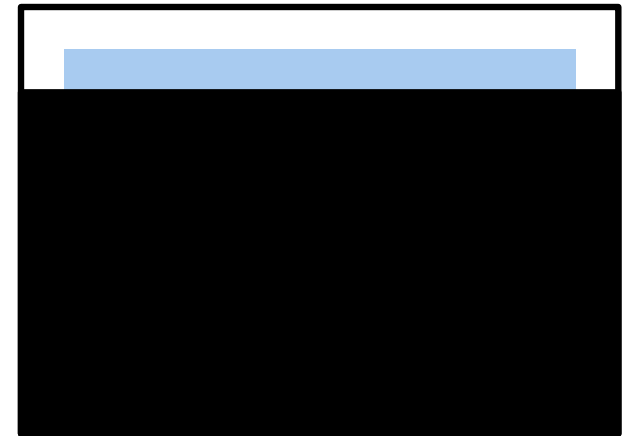
Schlitzverschluss



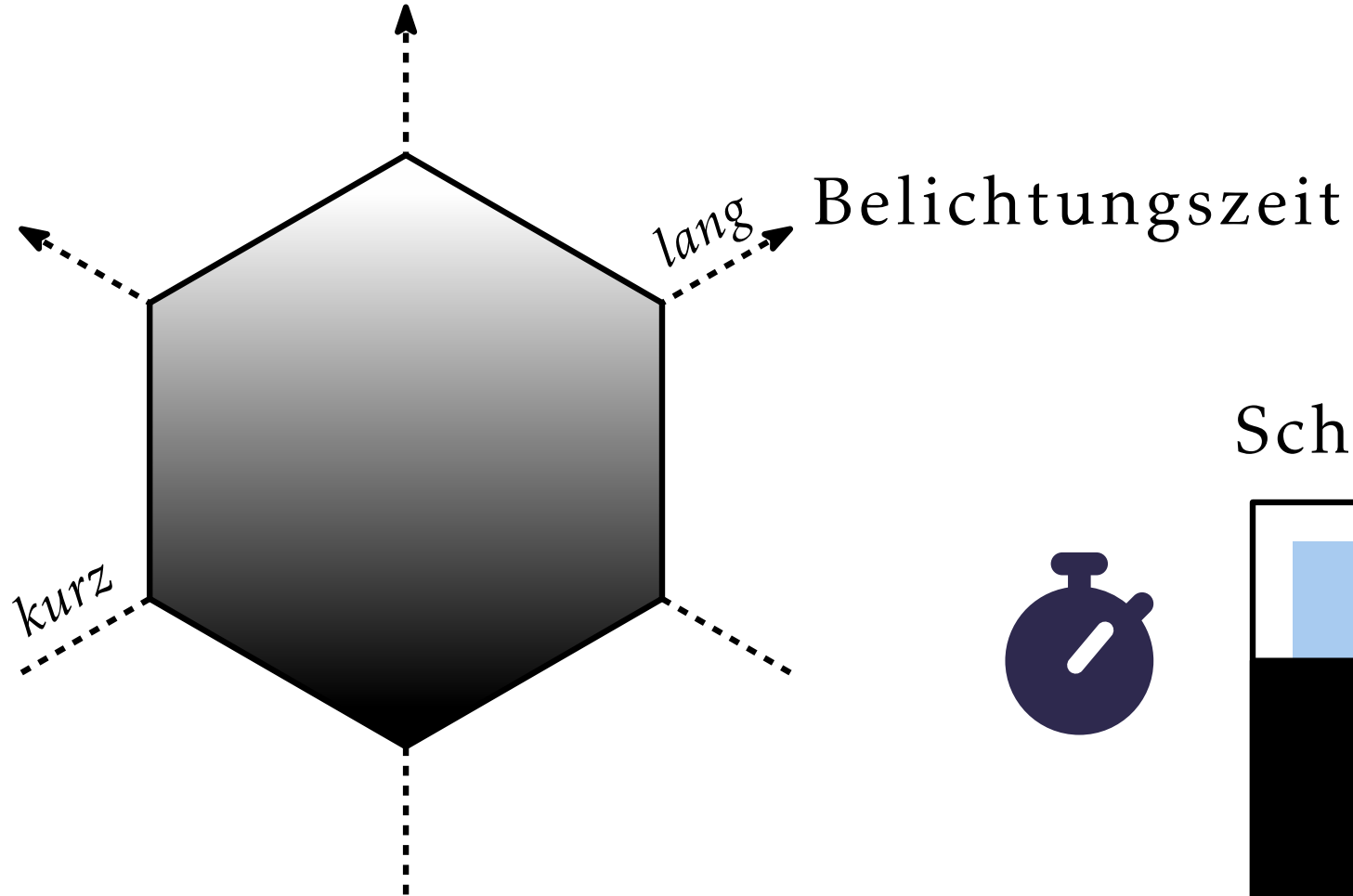
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Schlitzverschluss



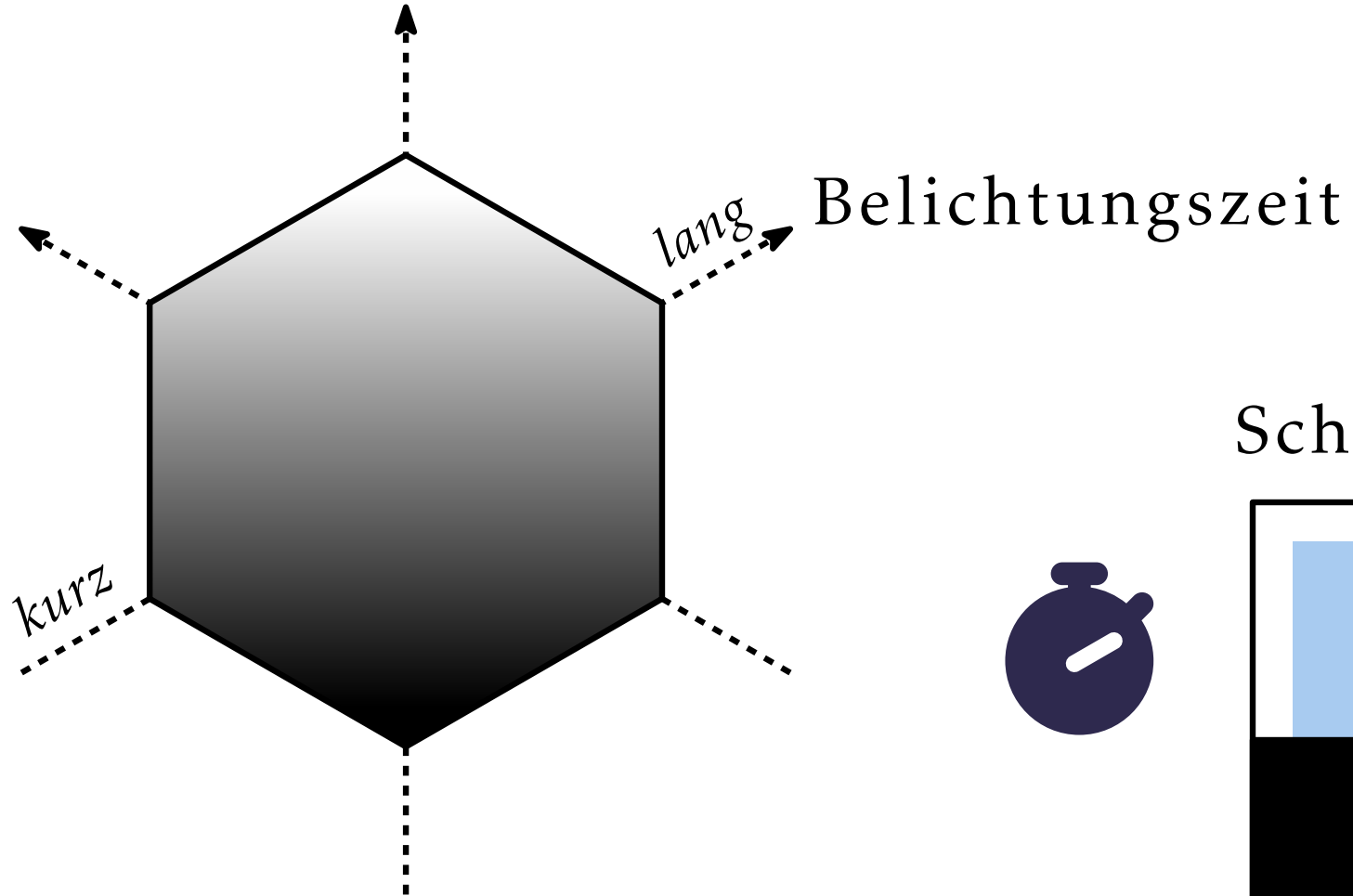
# Belichtung



Schlitzverschluss



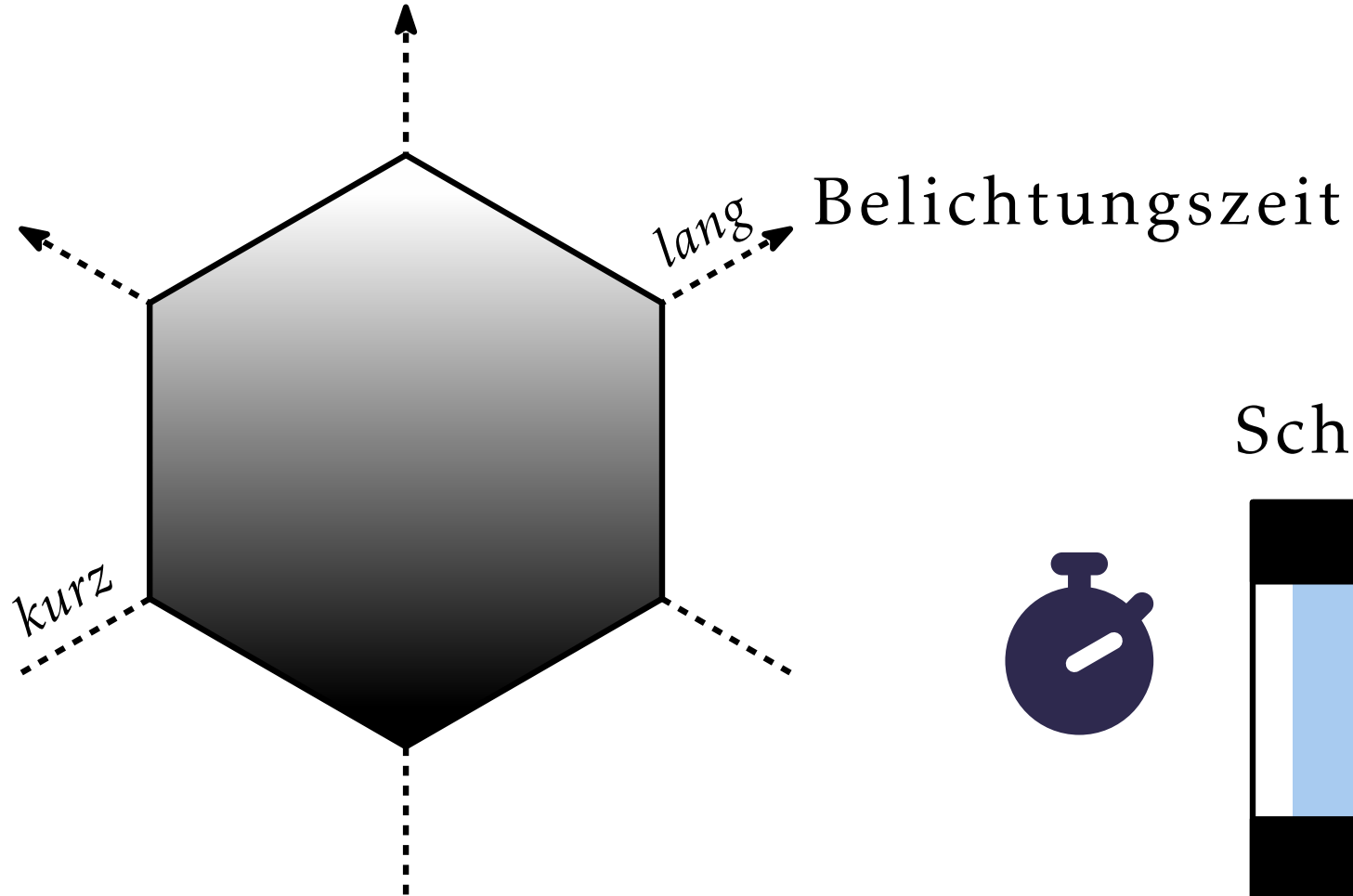
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Schlitzverschluss



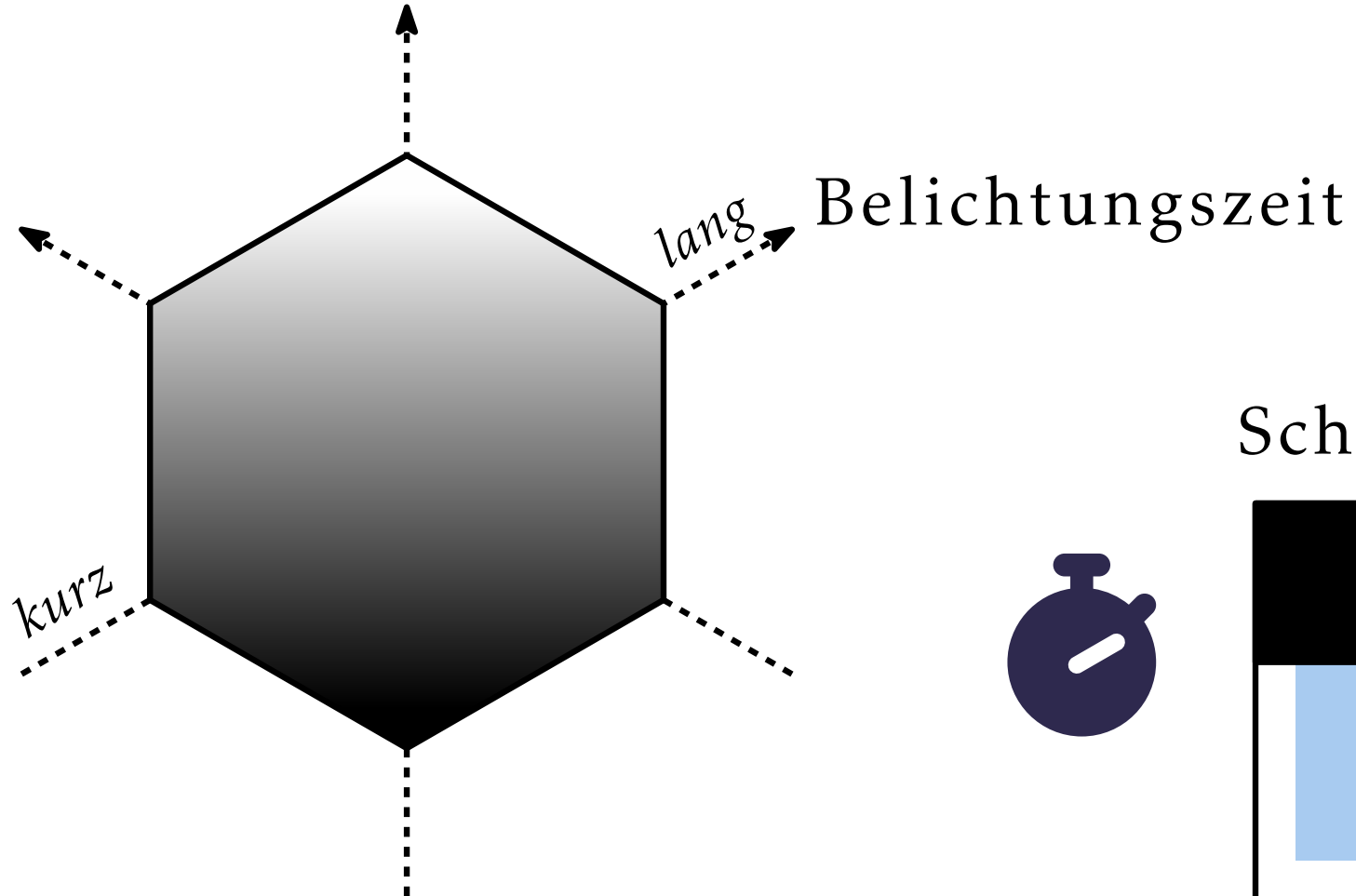
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Schlitzverschluss



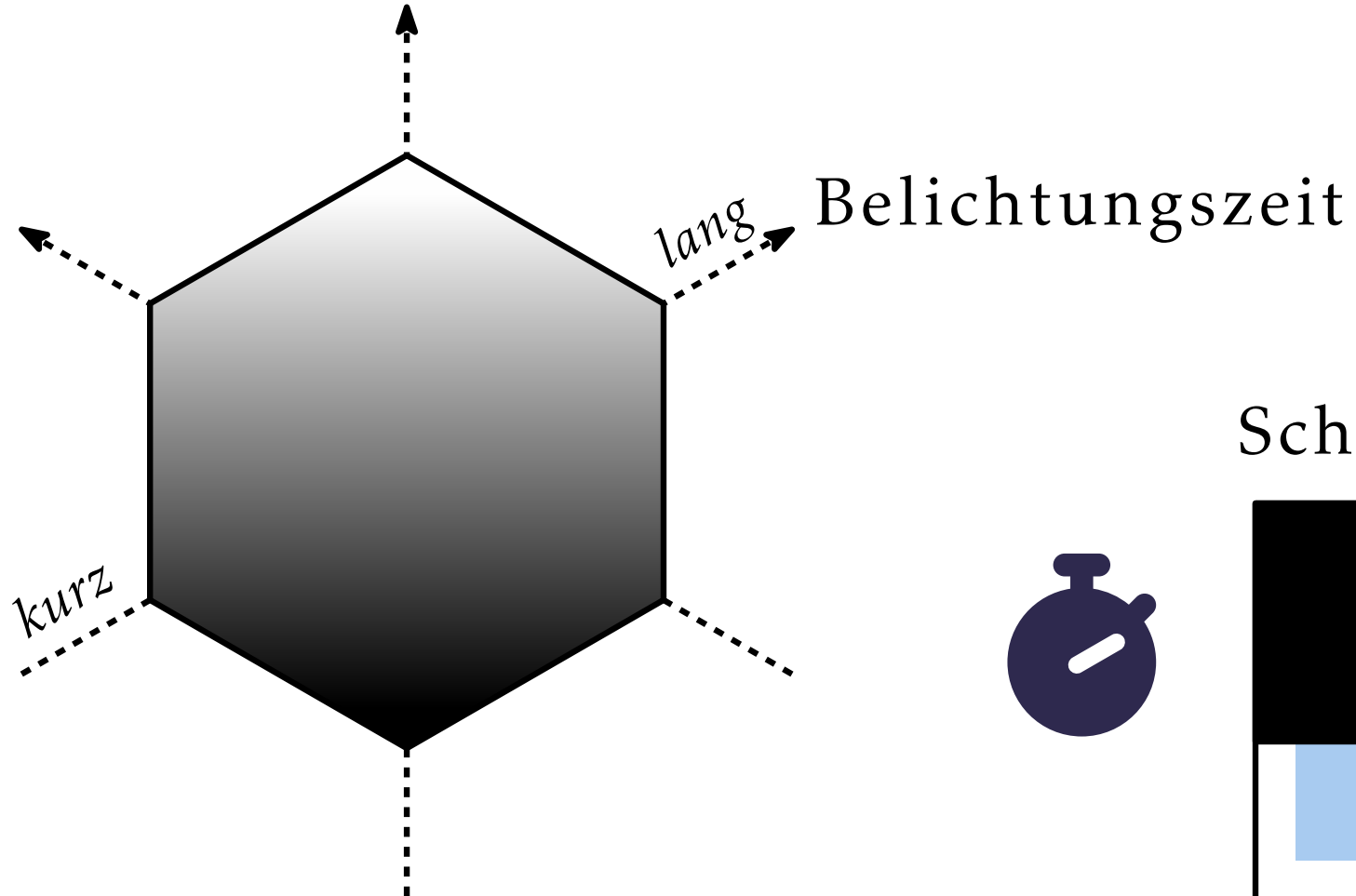
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Schlitzverschluss



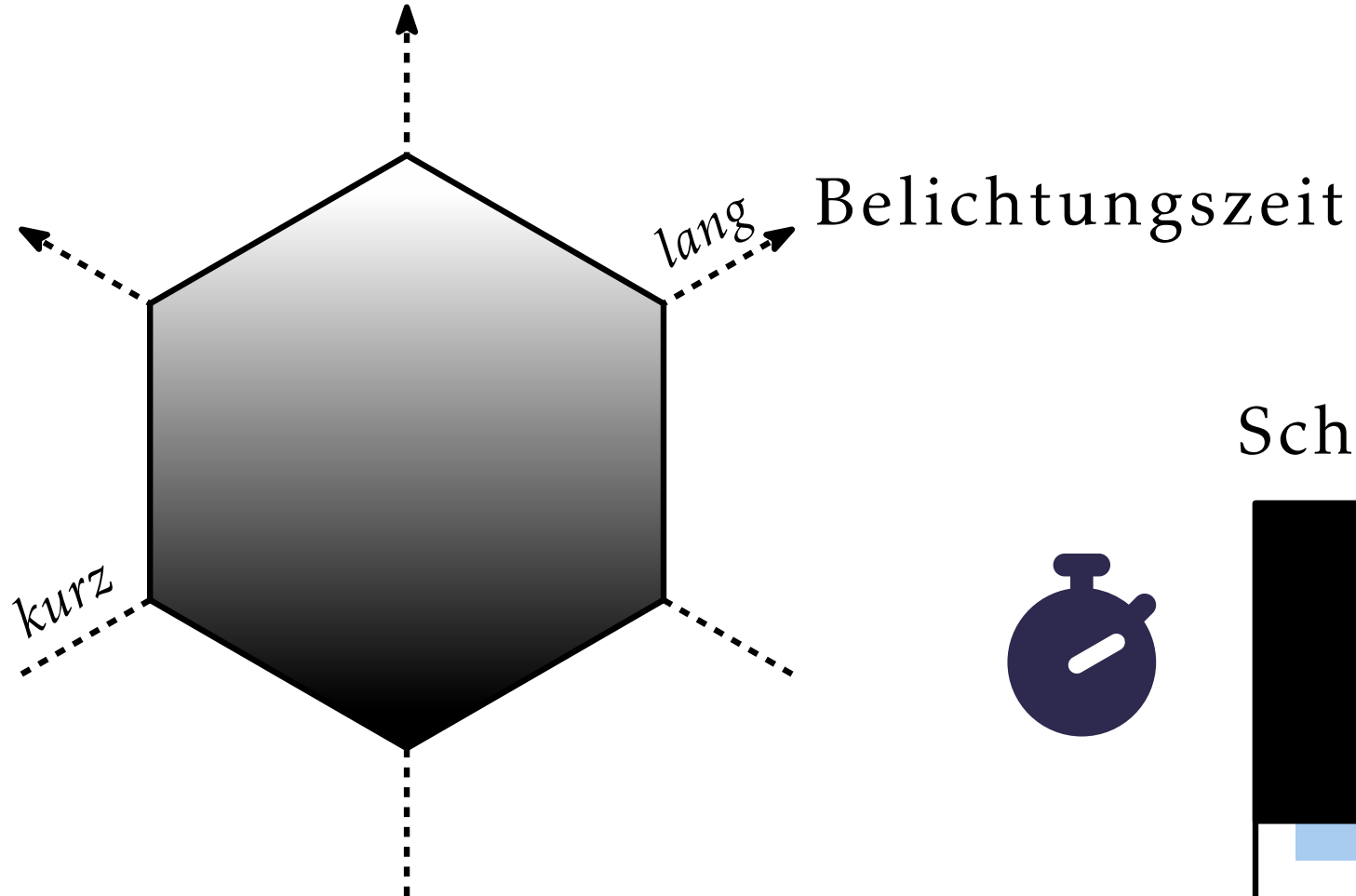
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Schlitzverschluss



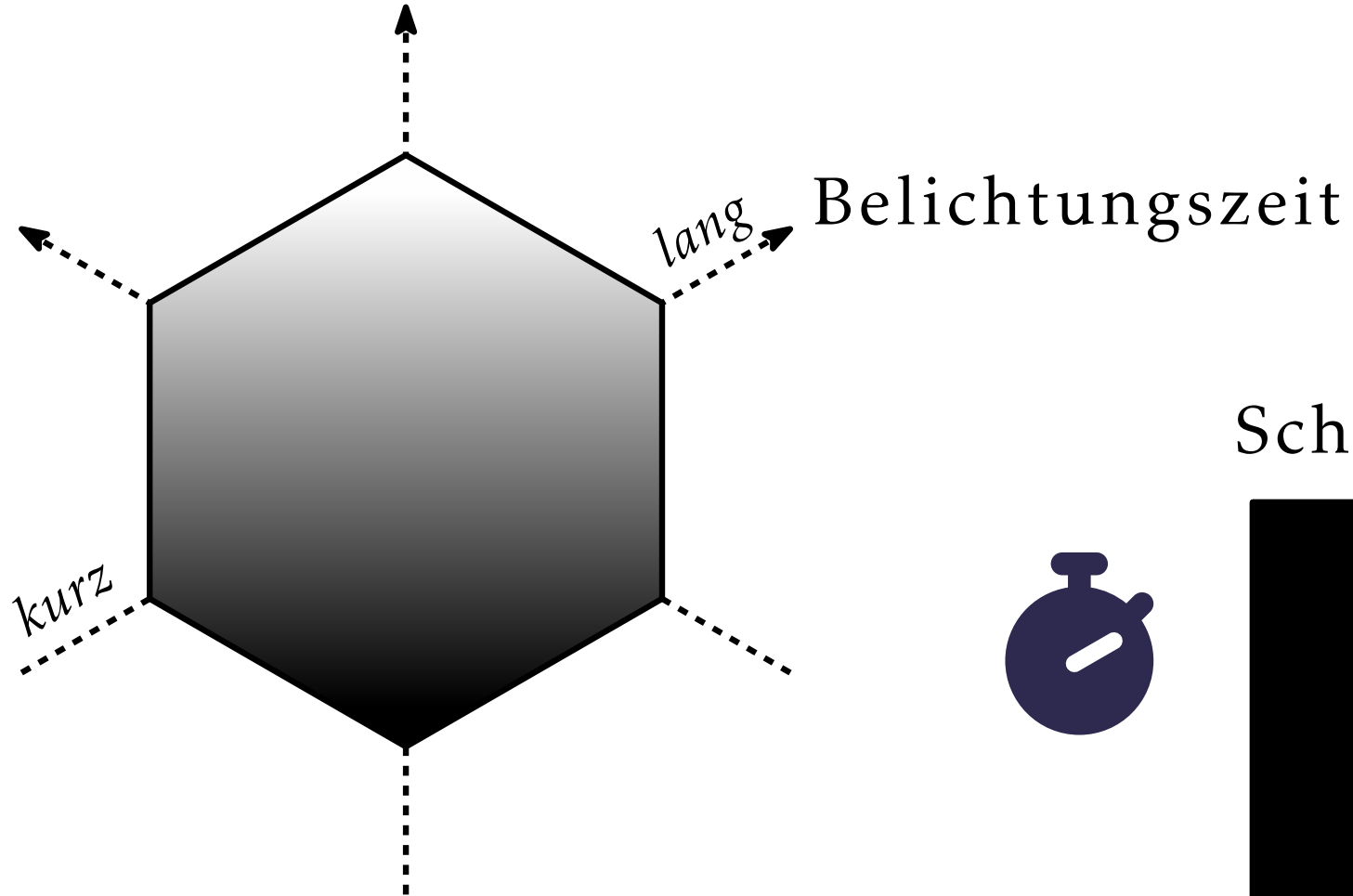
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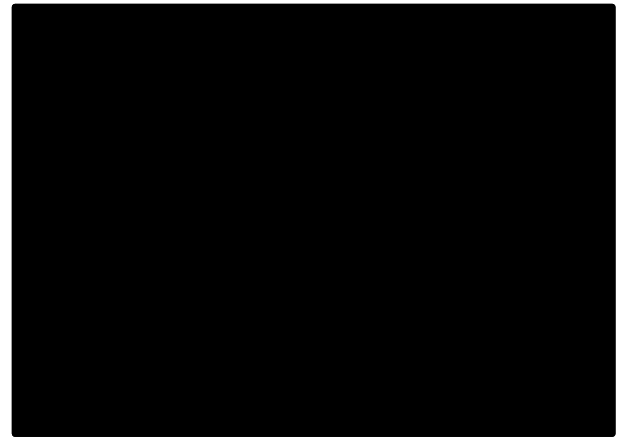
Schlitzverschluss



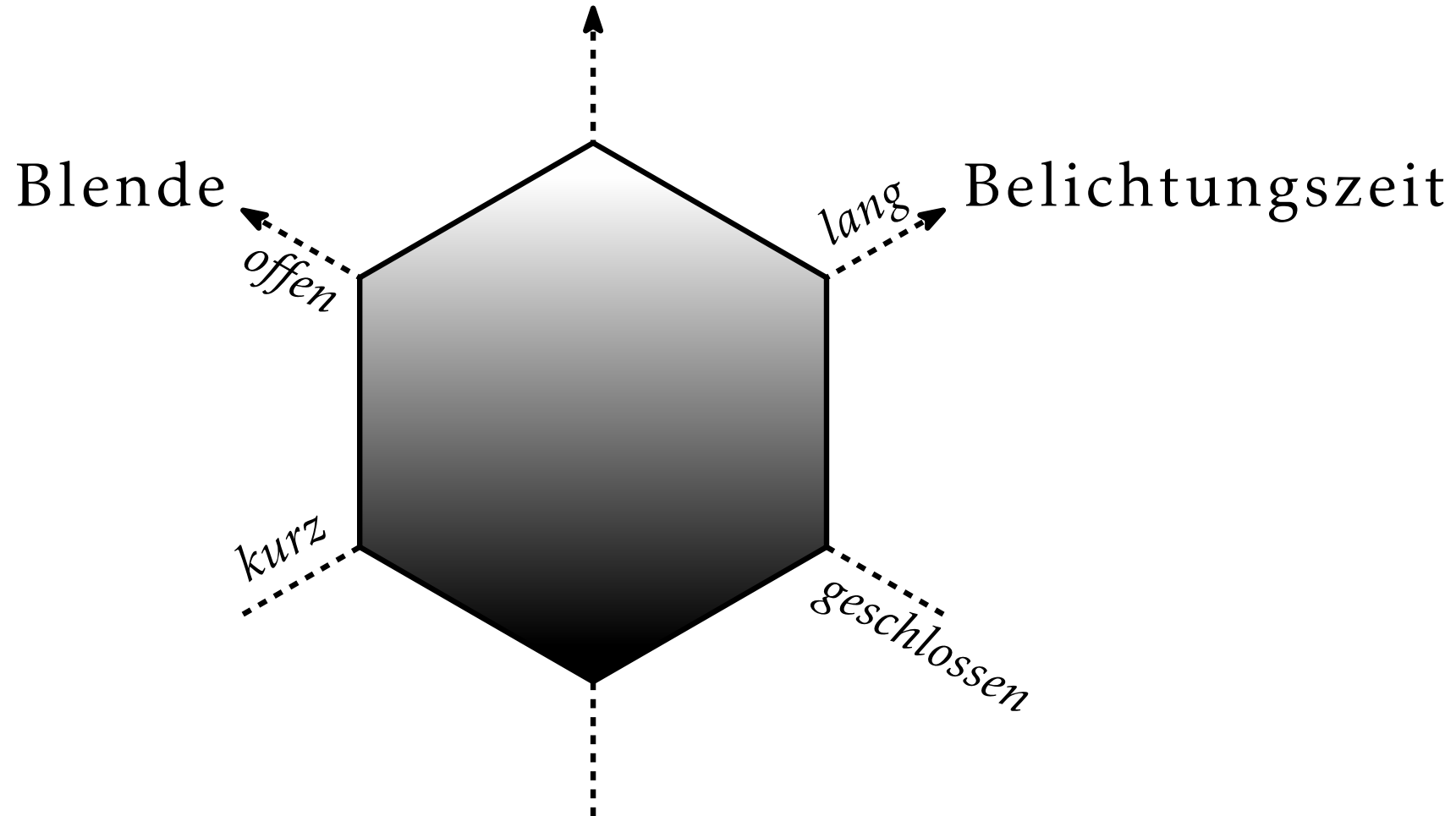
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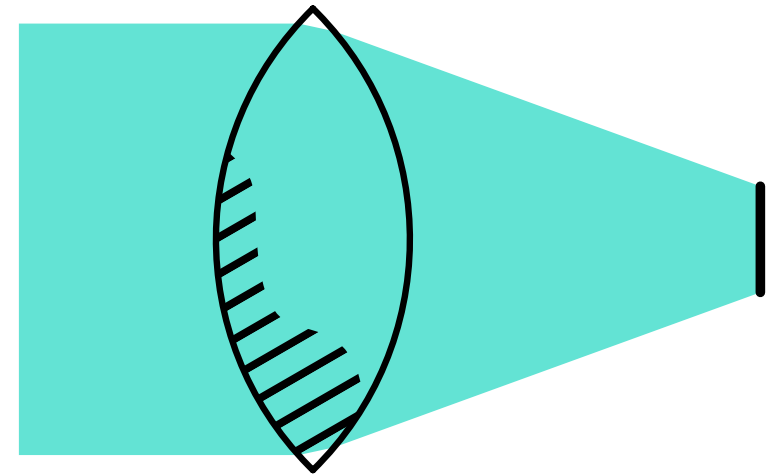
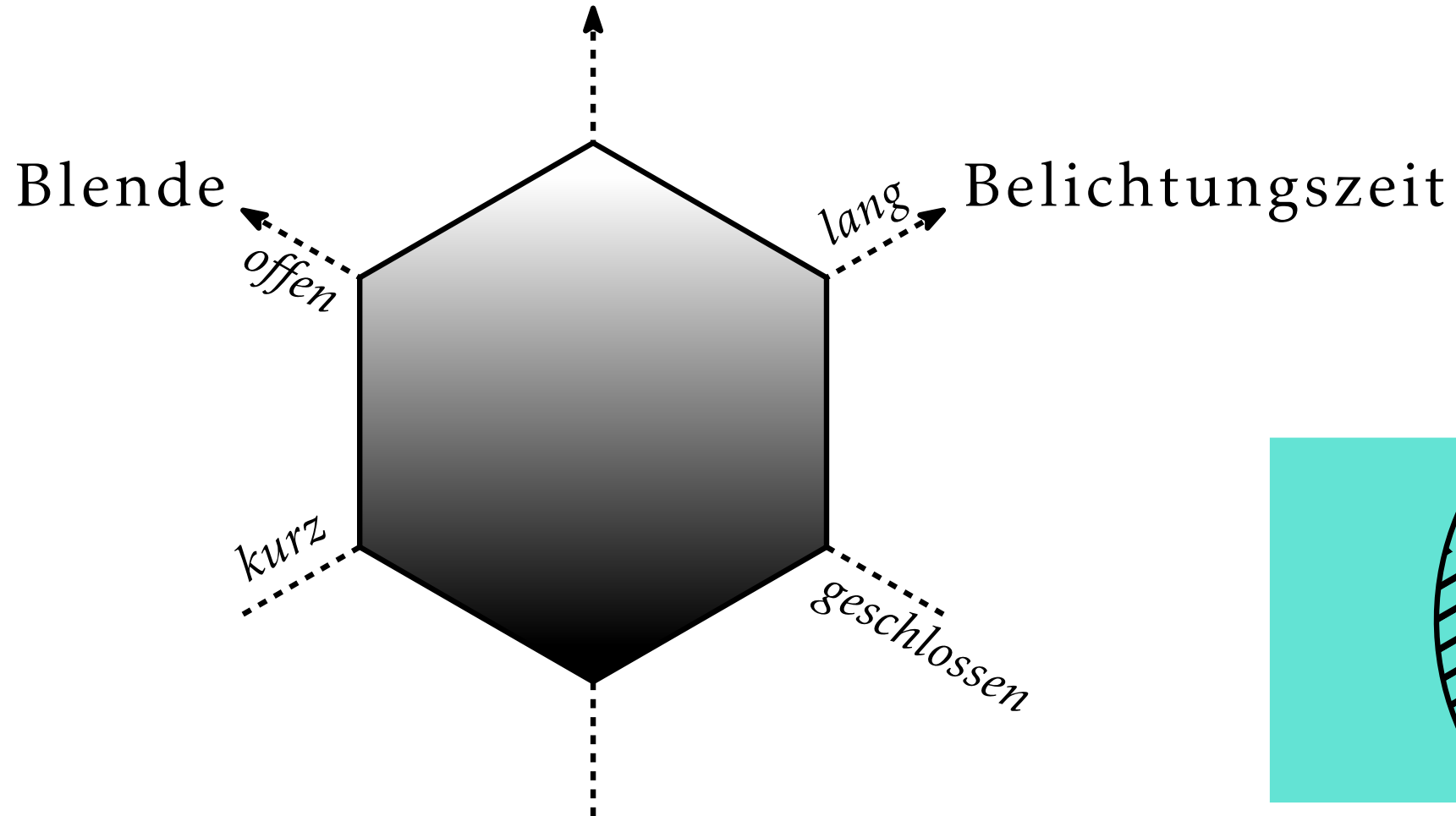
Schlitzverschluss



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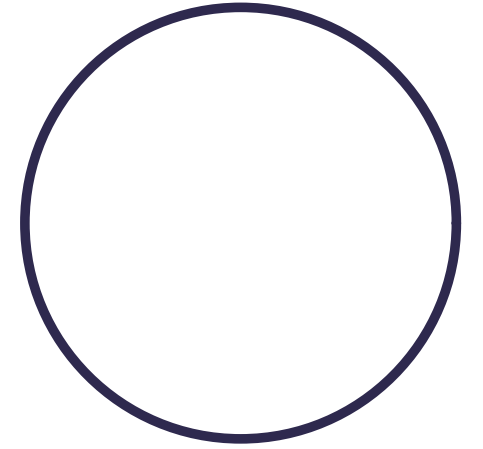


# Belichtung



# Belichtung

Irisblende



Blende

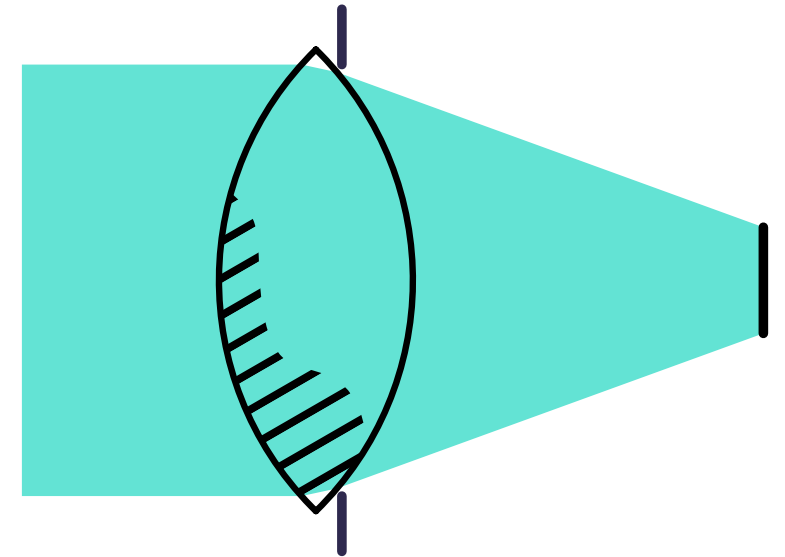
*offen*

*lang*

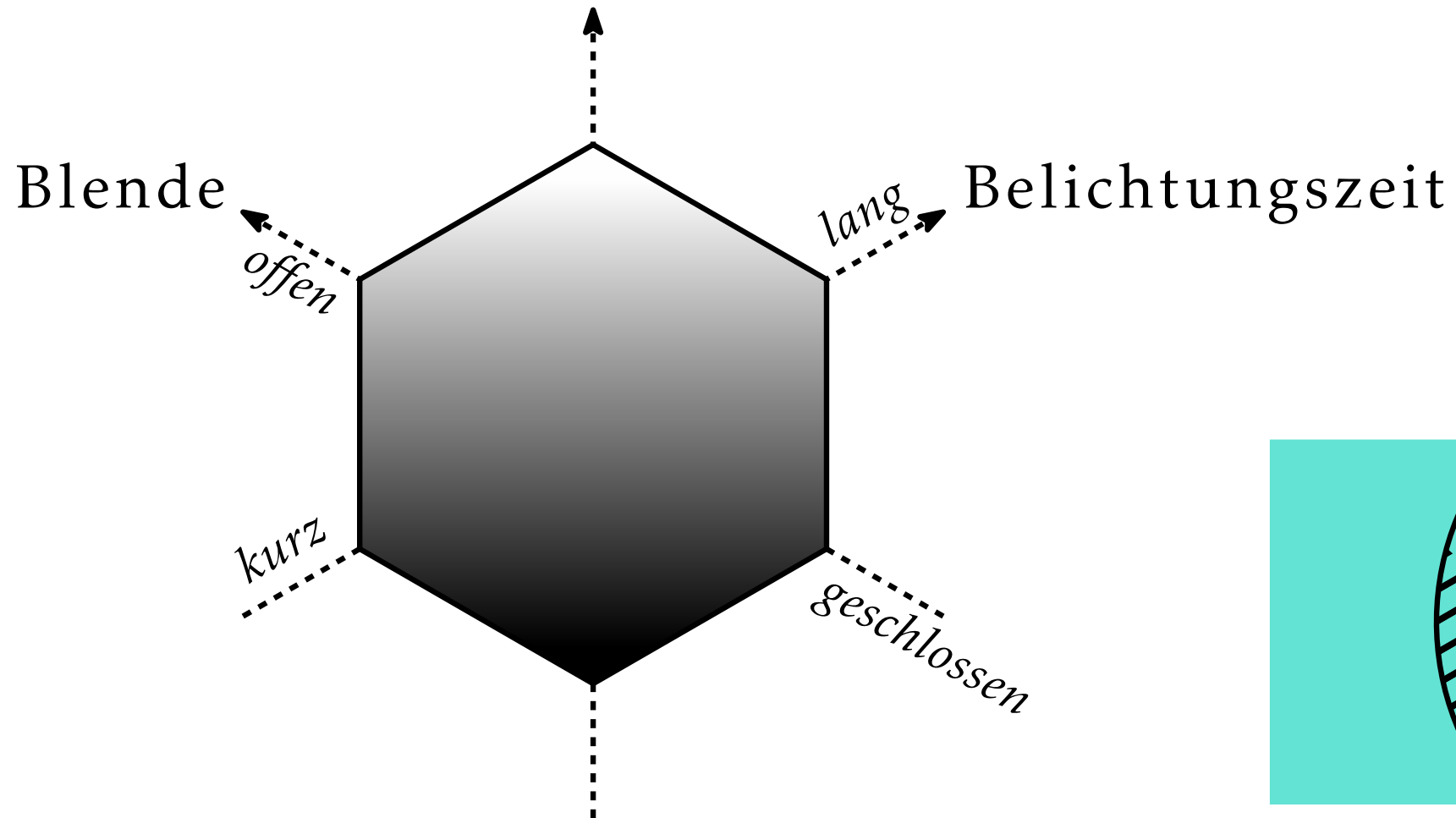
Belichtungszeit

*kurz*

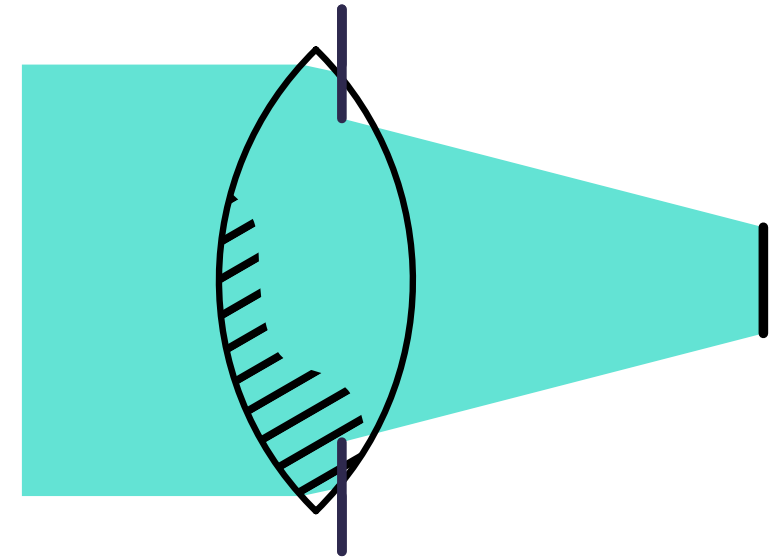
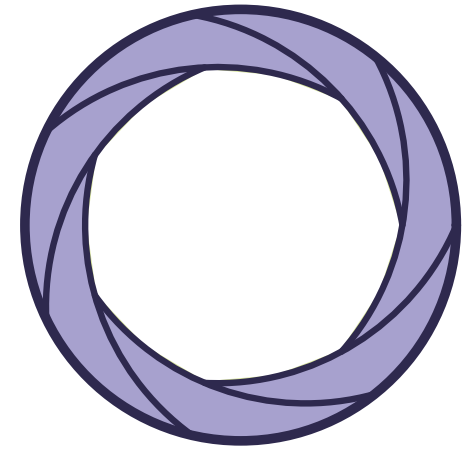
*geschlossen*



# Belichtung

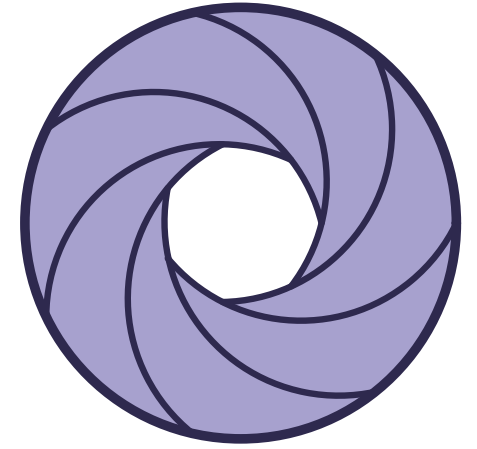


Irisblende



# Belichtung

Irisblende



Blende

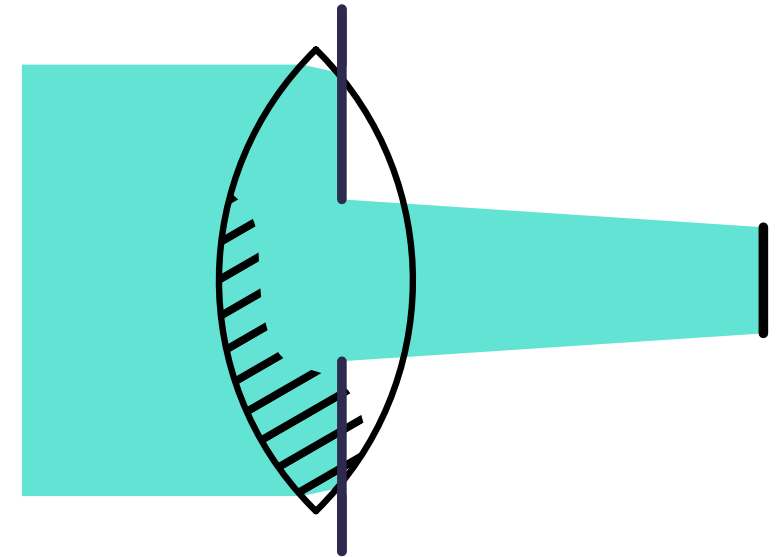
*offen*

*lang*

Belichtungszeit

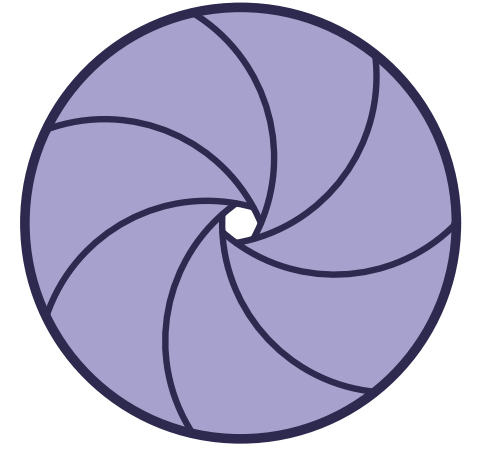
*kurz*

*geschlossen*



# Belichtung

Irisblende



Blende

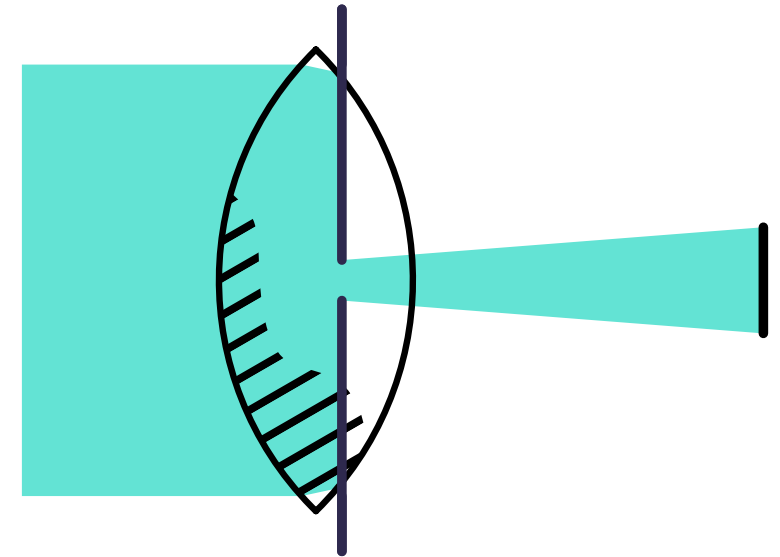
*offen*

*lang*

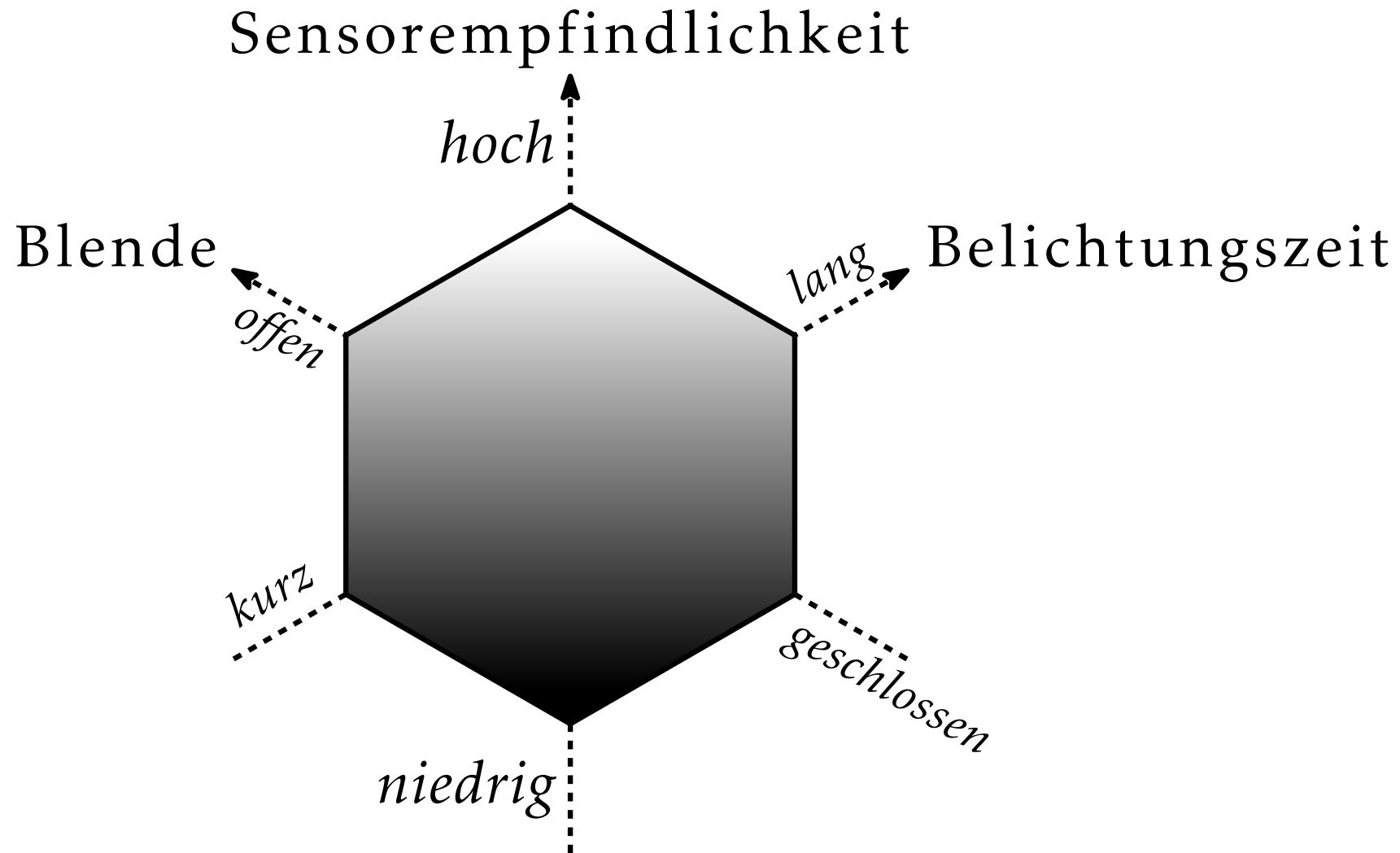
Belichtungszeit

*kurz*

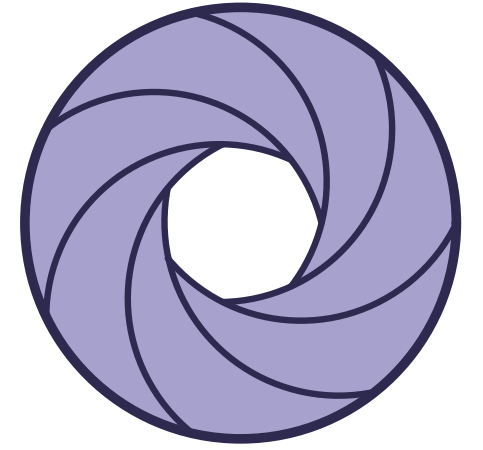
*geschlossen*



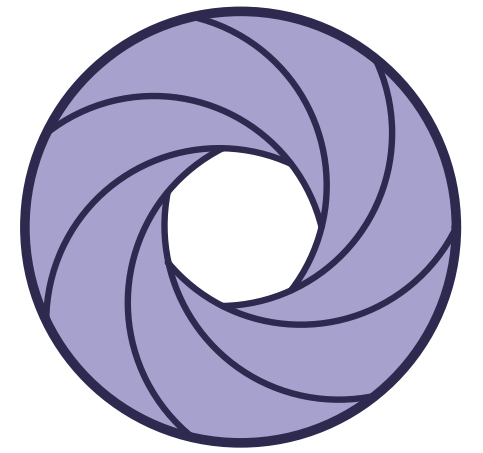
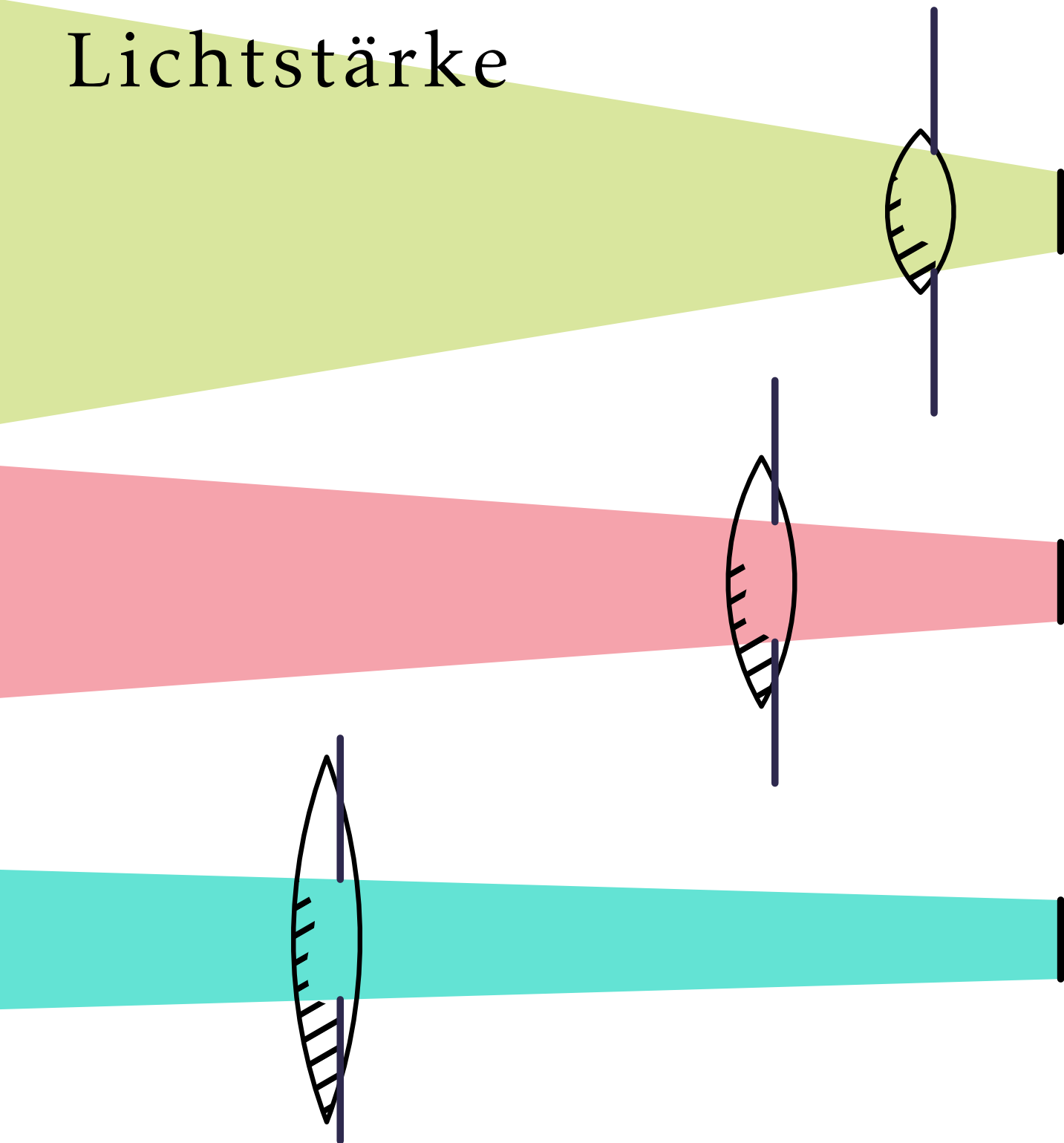
# Belichtung



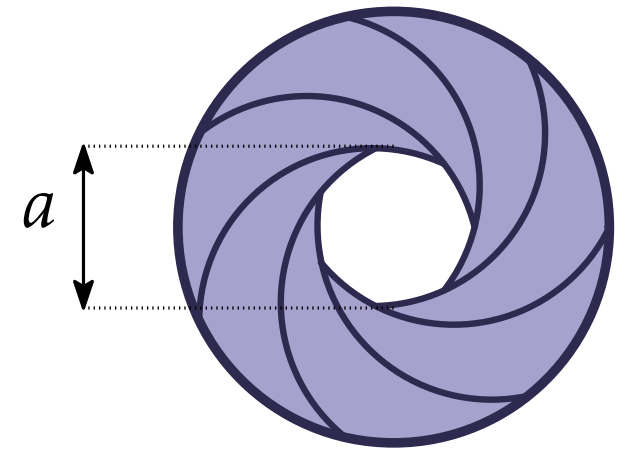
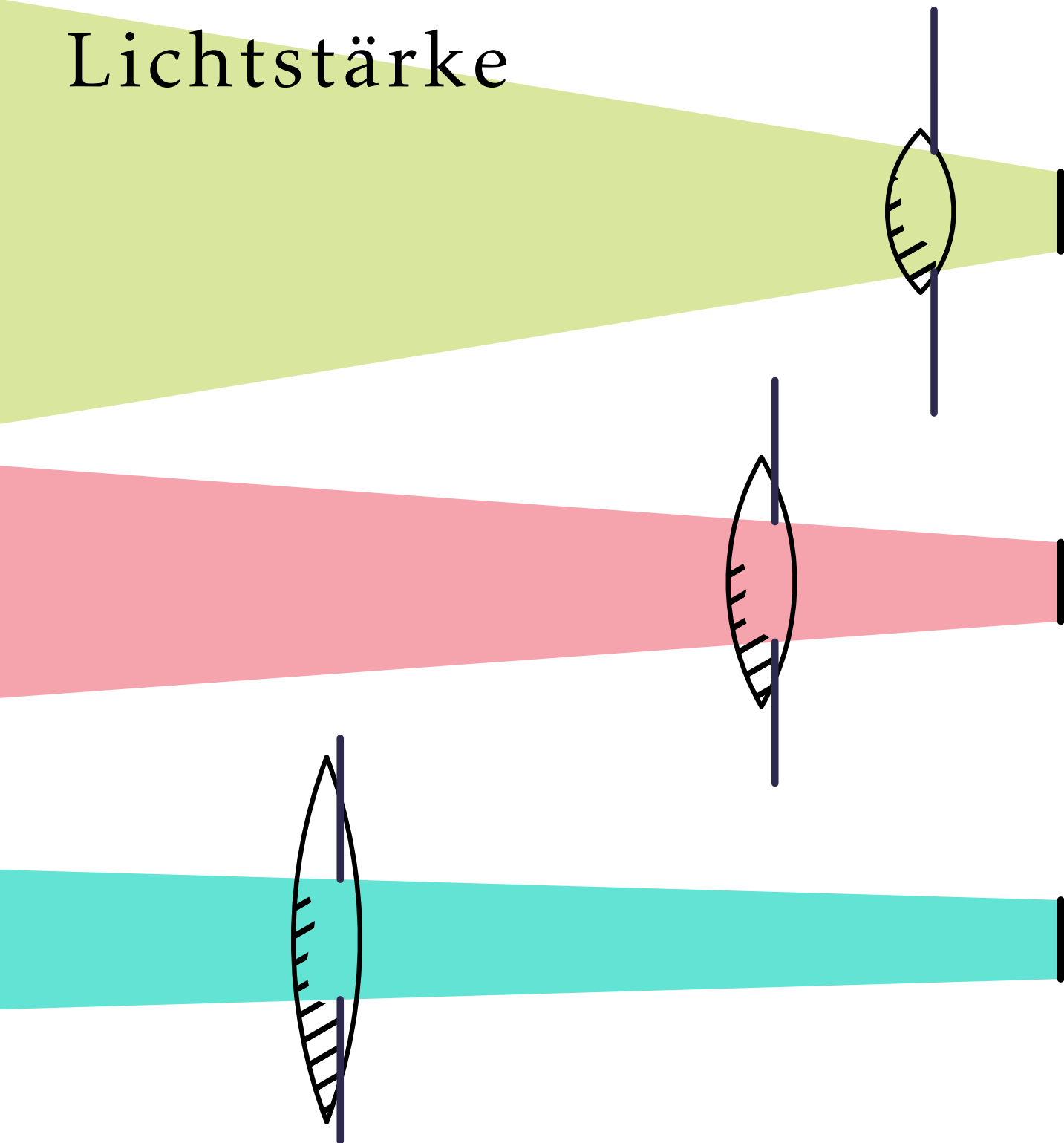
# Lichtstärke



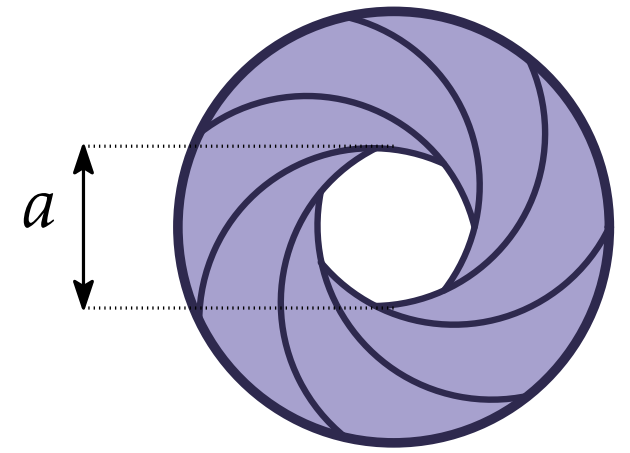
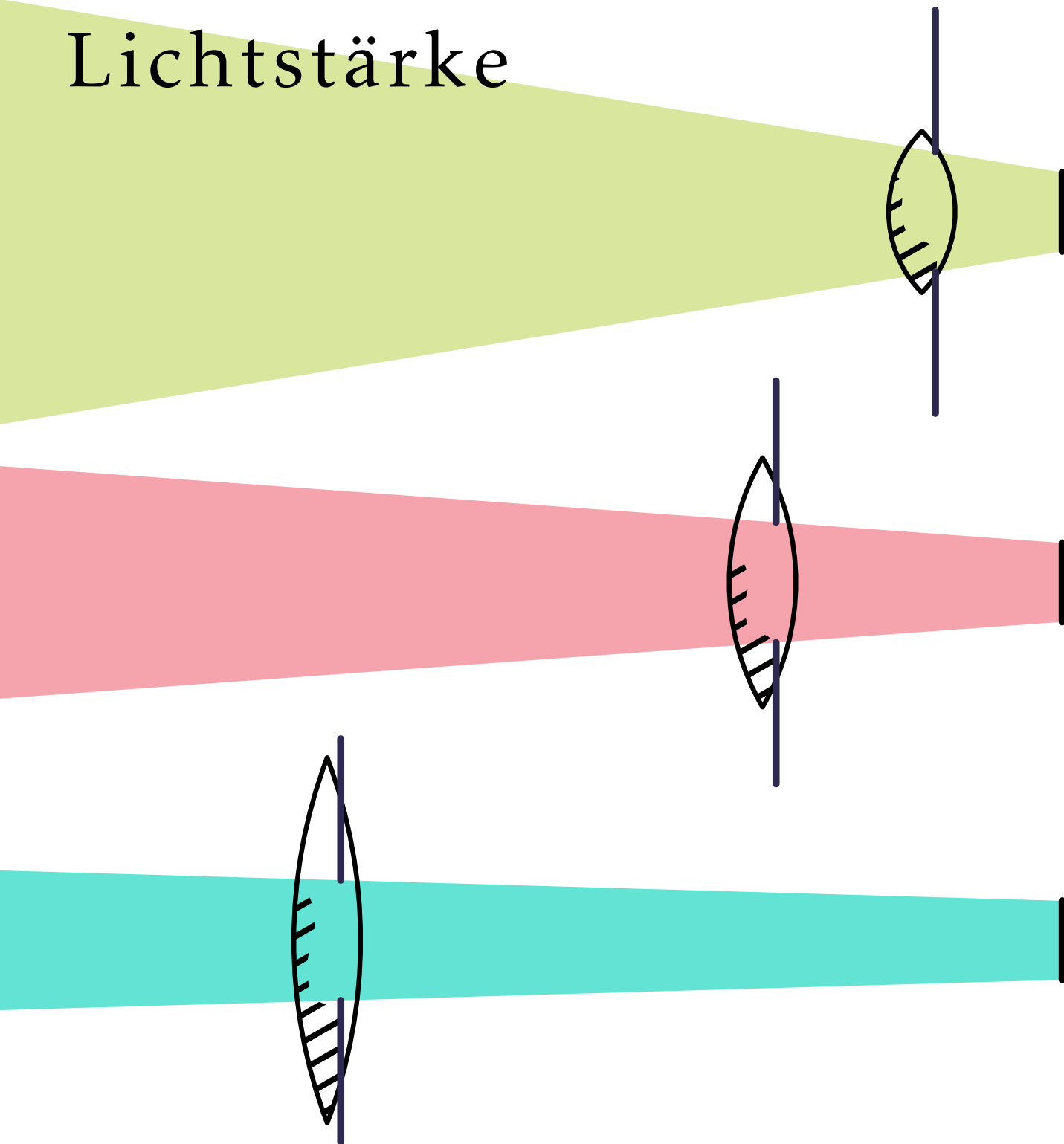
# Lichtstärke



Lichtstärke



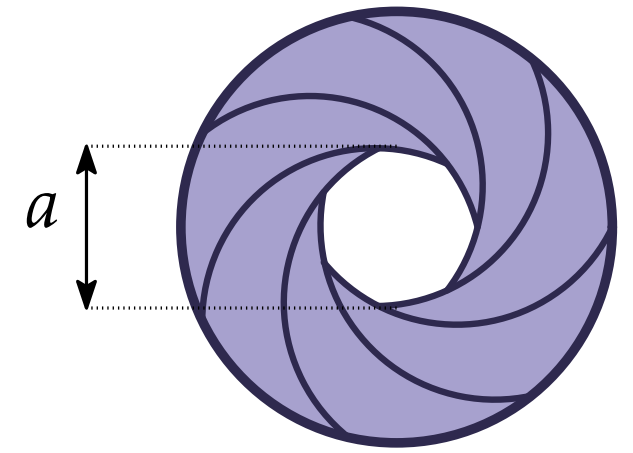
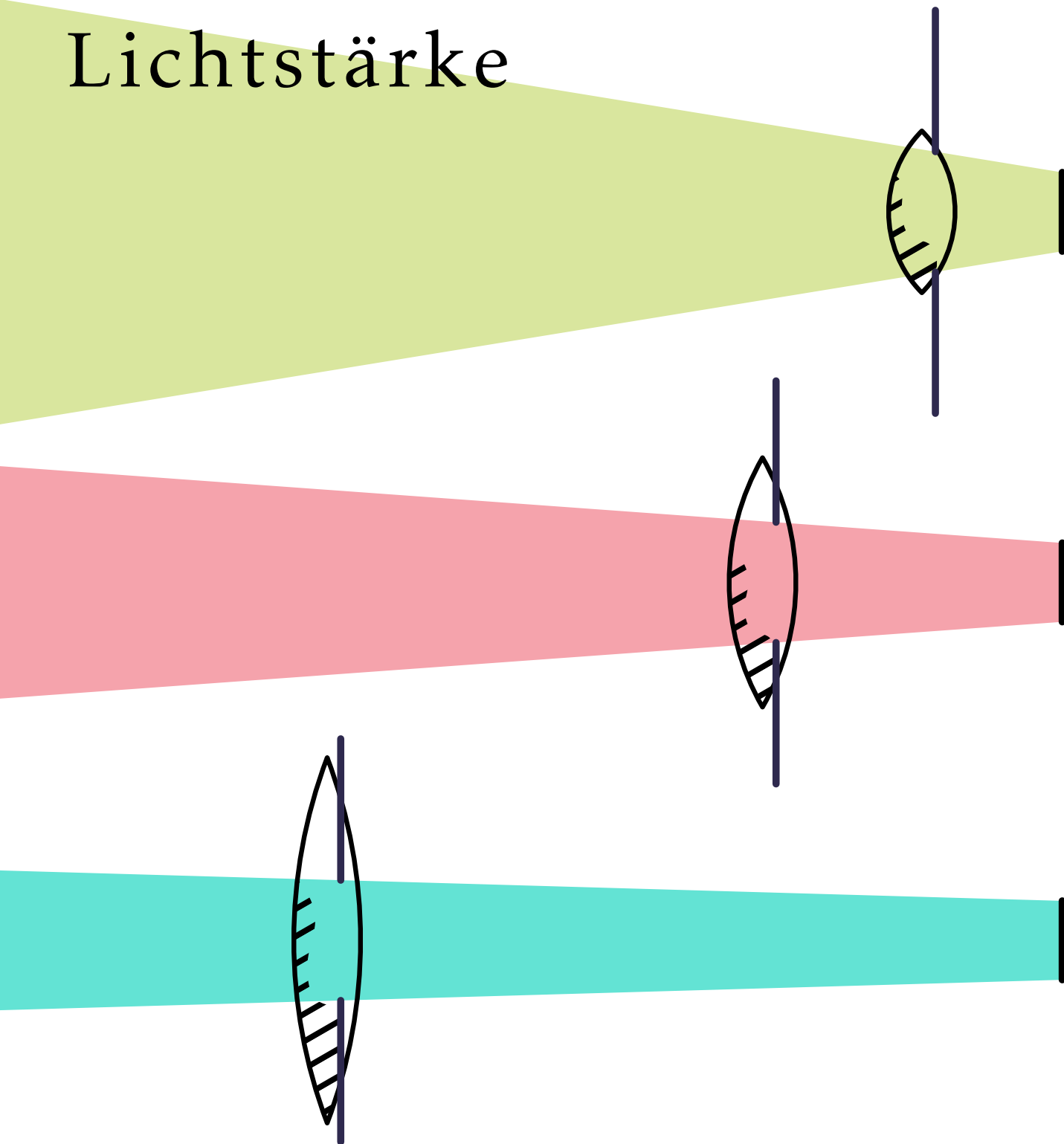
# Lichtstärke



## Abbildungsmaßstab

$$\beta \stackrel{f \ll g}{\approx} \frac{f}{d}$$

Lichtstärke



Abbildungsmaßstab

$$\beta \stackrel{f \ll g}{\approx} \frac{f}{d}$$

Blendenzahl

$$A = \frac{f}{a}$$

# Belichtung in der Praxis

|         |     |        |        |       |       |       |      |      |       |       |     |     |   |     |
|---------|-----|--------|--------|-------|-------|-------|------|------|-------|-------|-----|-----|---|-----|
| $t$ [s] | ... | 1/2000 | 1/1000 | 1/500 | 1/250 | 1/125 | 1/60 | 1/30 | 1/15  | 1/8   | 1/4 | 1/2 | 1 | ... |
| $f/$    | 1,0 | 1,4    | 2,0    | 2,8   | 4,0   | 5,6   | 8,0  | 11   | 16    | 22    | ... |     |   |     |
| ISO     | 50  | 100    | 200    | 400   | 800   | 1600  | 3200 | 6400 | 12800 | 25600 | ... |     |   |     |

# Belichtung in der Praxis

|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis

|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis

|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

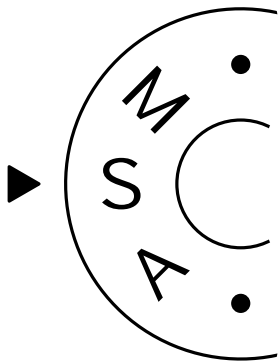
# Belichtung in der Praxis

|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis

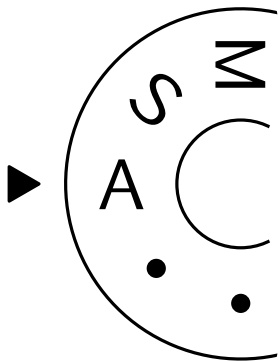
|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis



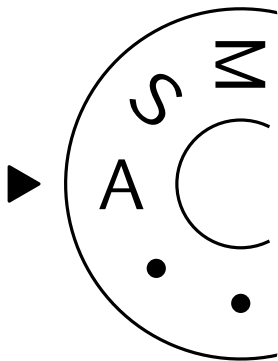
|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis



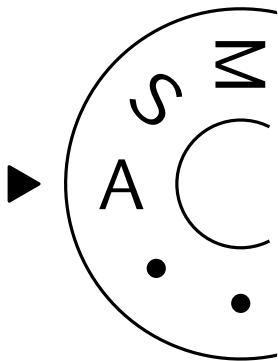
|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis



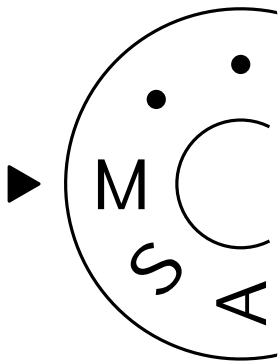
|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis



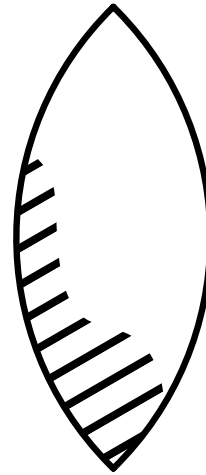
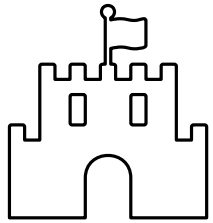
|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

# Belichtung in der Praxis

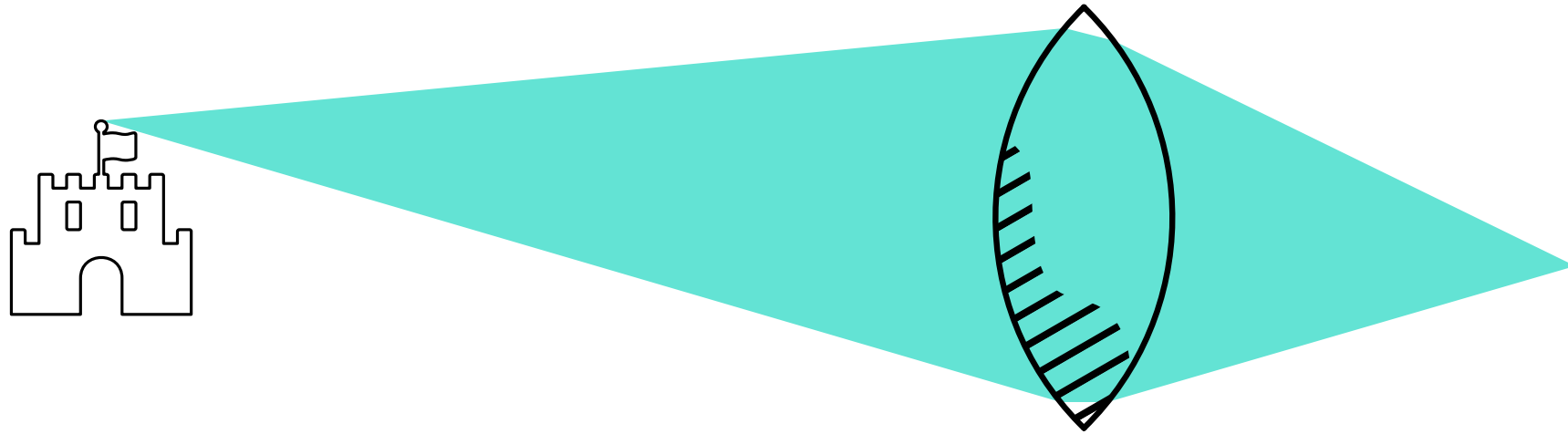


|         |     |          |          |         |         |         |        |        |        |       |       |       |   |     |
|---------|-----|----------|----------|---------|---------|---------|--------|--------|--------|-------|-------|-------|---|-----|
| $t$ [s] | ... | $1/2000$ | $1/1000$ | $1/500$ | $1/250$ | $1/125$ | $1/60$ | $1/30$ | $1/15$ | $1/8$ | $1/4$ | $1/2$ | 1 | ... |
| $f/$    | 1,0 | 1,4      | 2,0      | 2,8     | 4,0     | 5,6     | 8,0    | 11     | 16     | 22    | ...   |       |   |     |
| ISO     | 50  | 100      | 200      | 400     | 800     | 1600    | 3200   | 6400   | 12800  | 25600 | ...   |       |   |     |

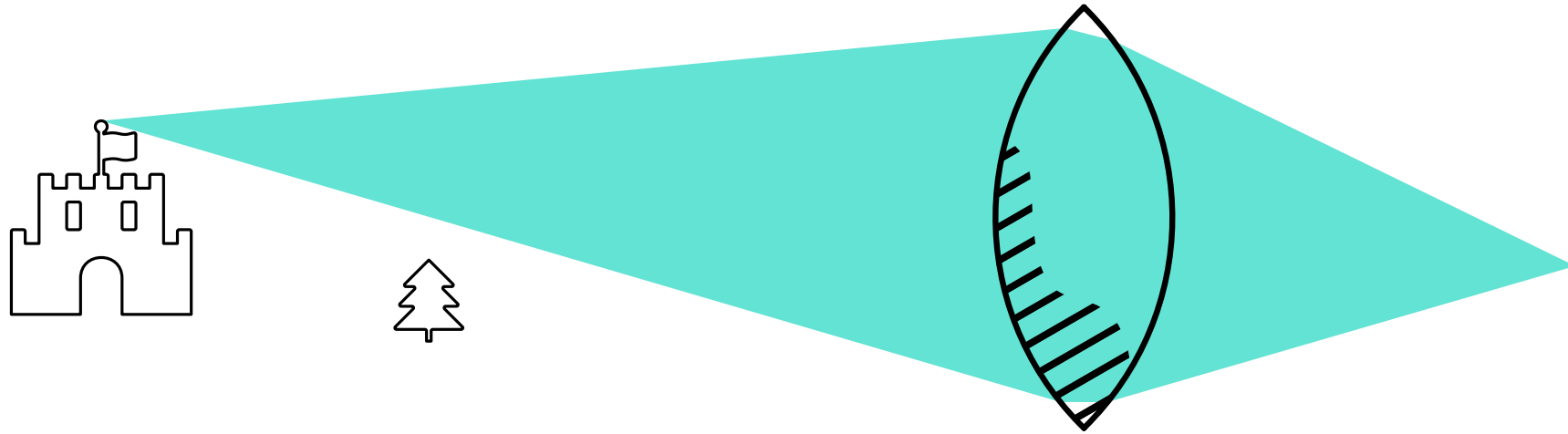
# Schärfentiefe



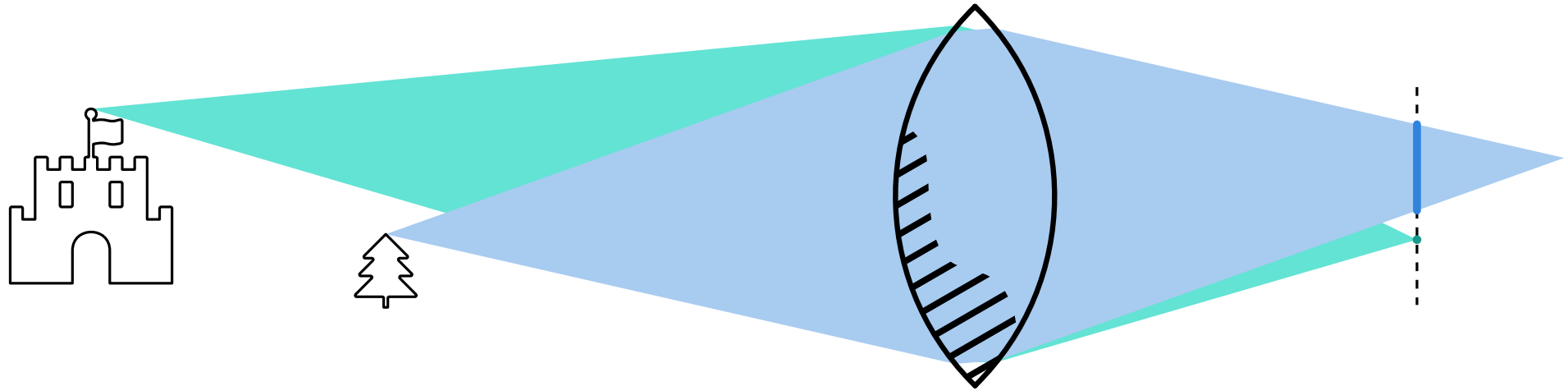
# Schärfentiefe



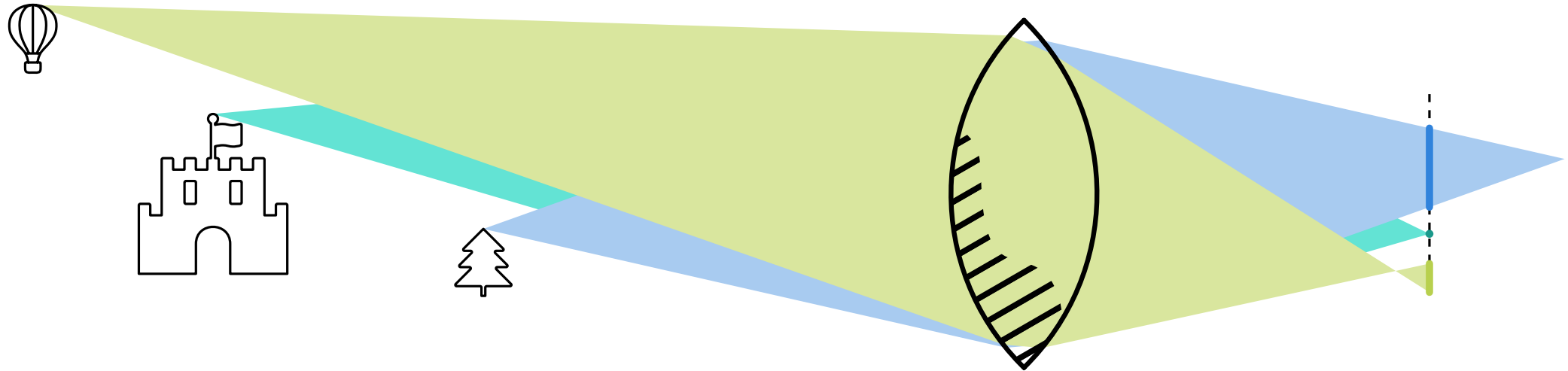
# Schärfentiefe



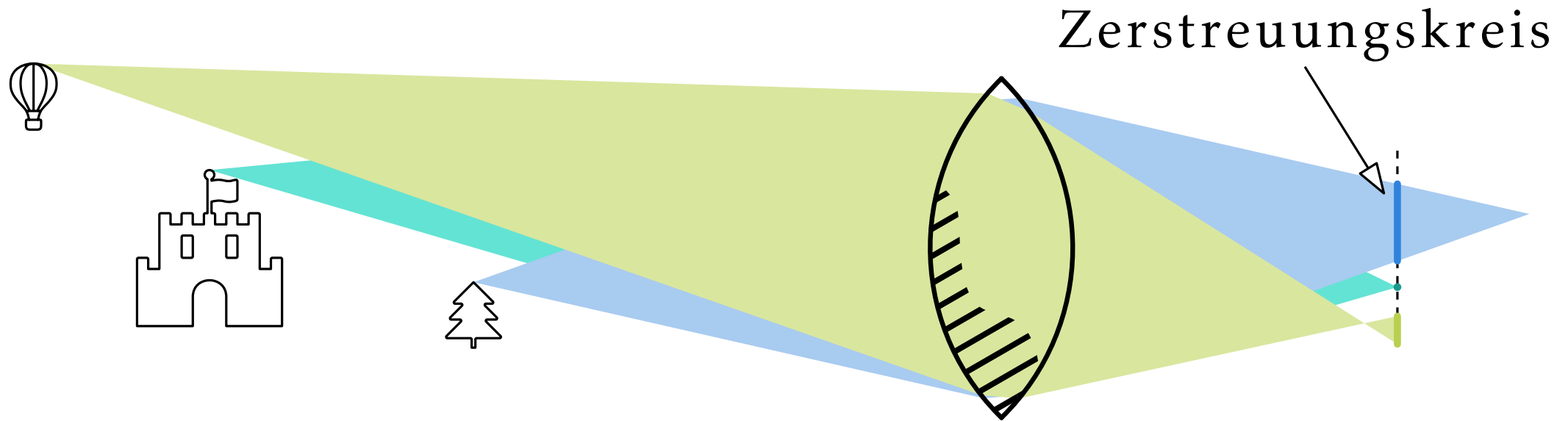
# Schärfentiefe



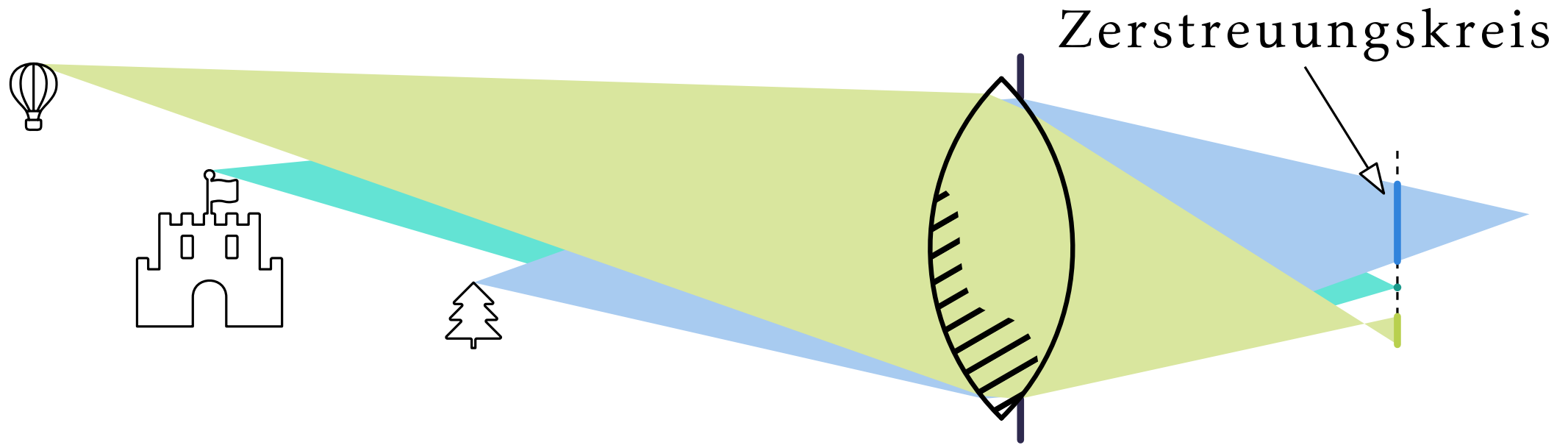
# Schärfentiefe



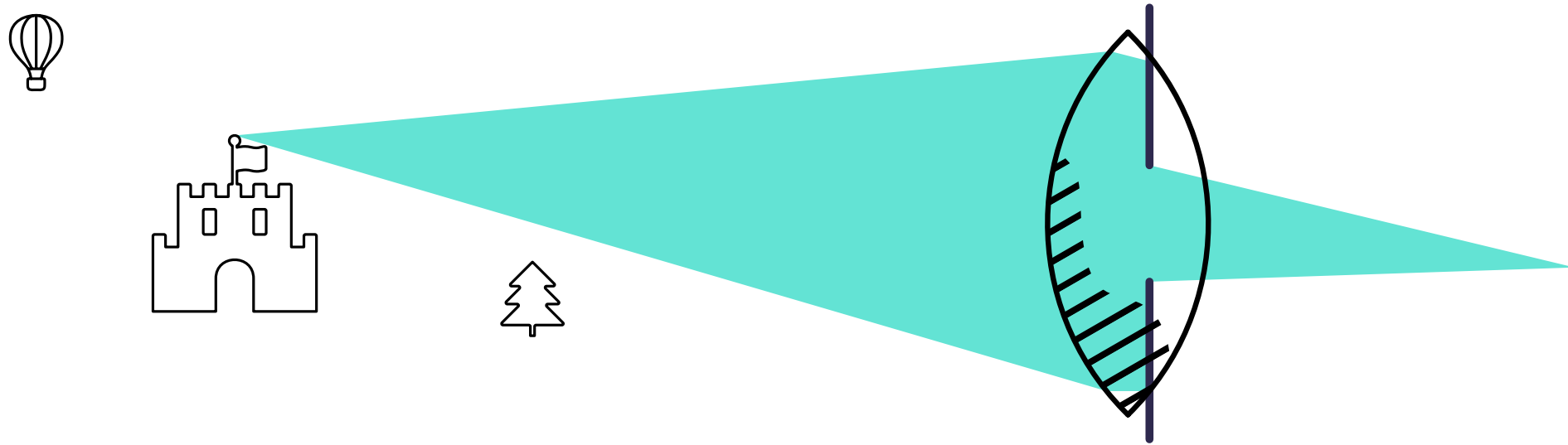
# Schärfentiefe



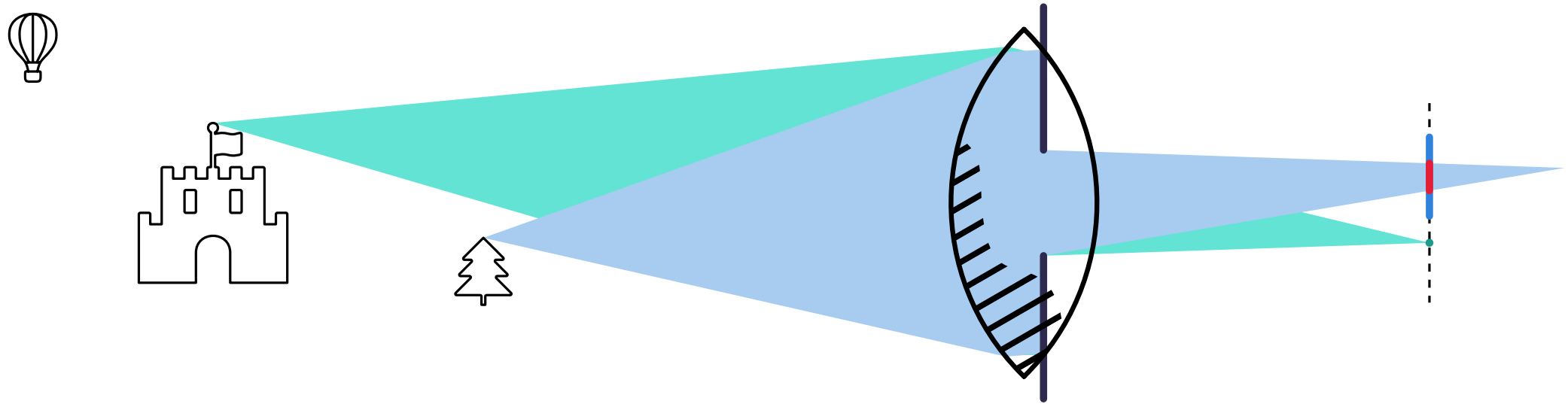
# Schärfentiefe



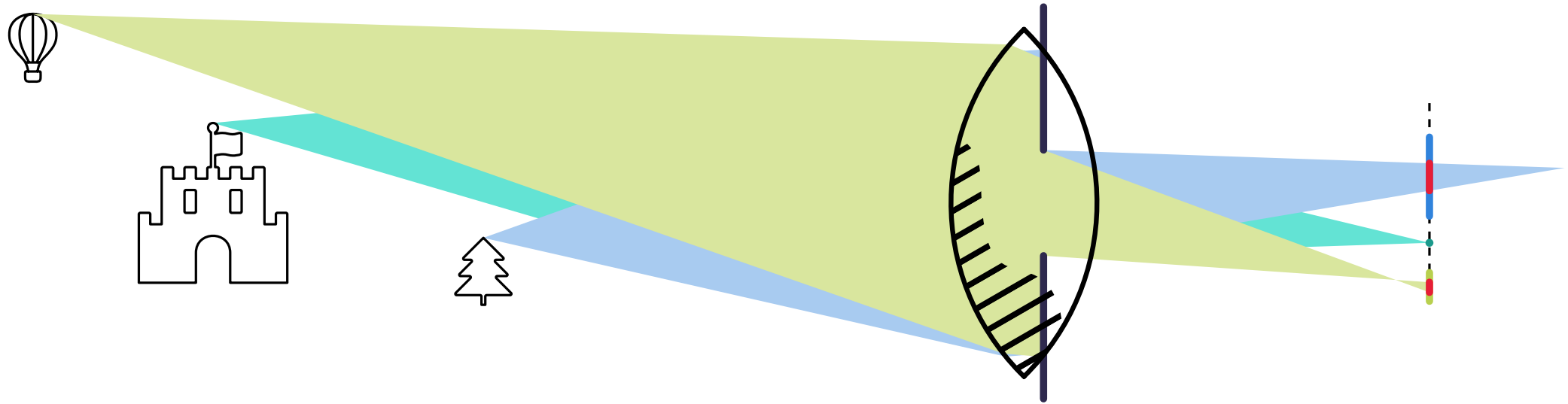
# Schärfentiefe



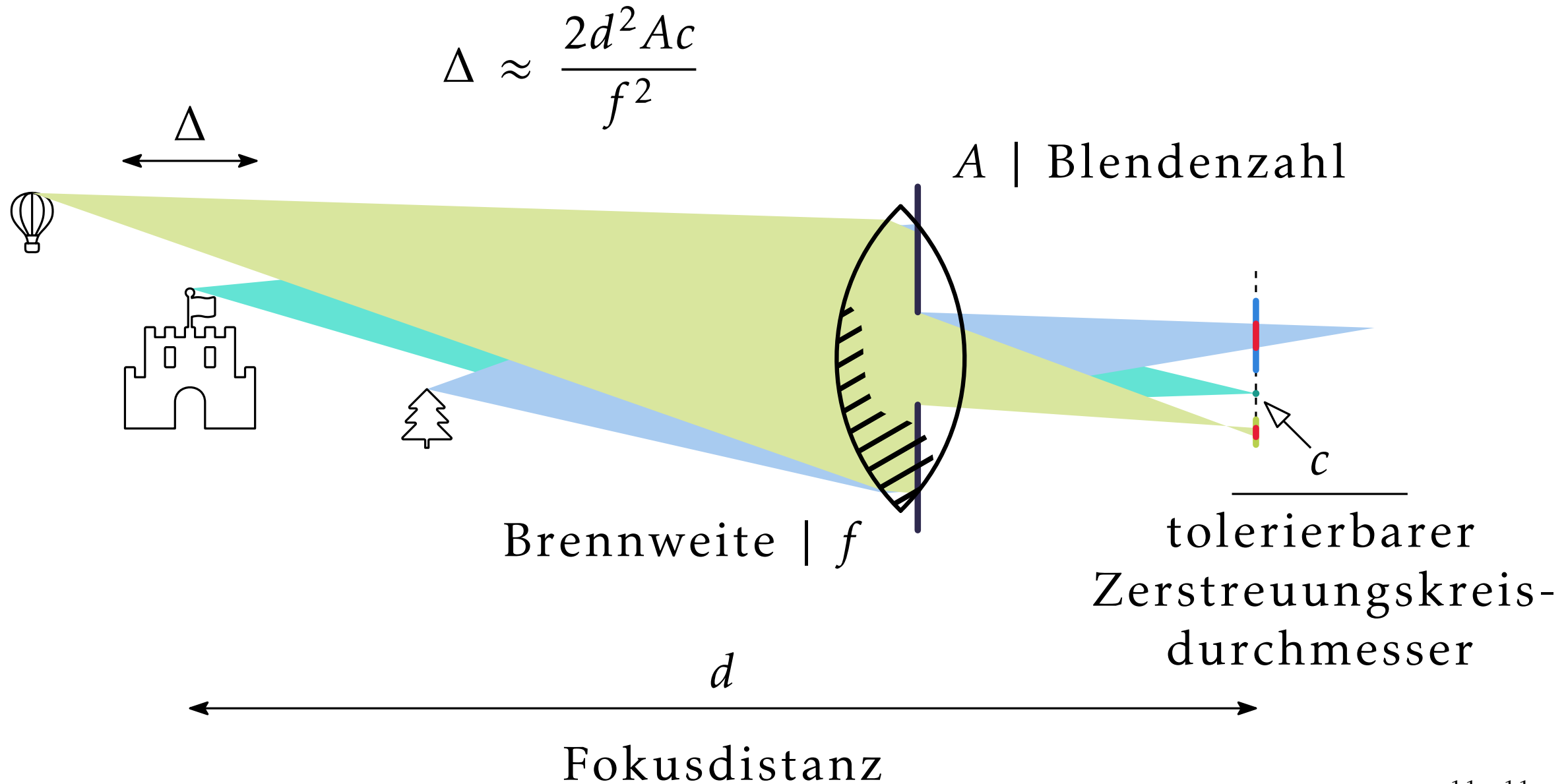
# Schärfentiefe



# Schärfentiefe



# Schärfentiefe

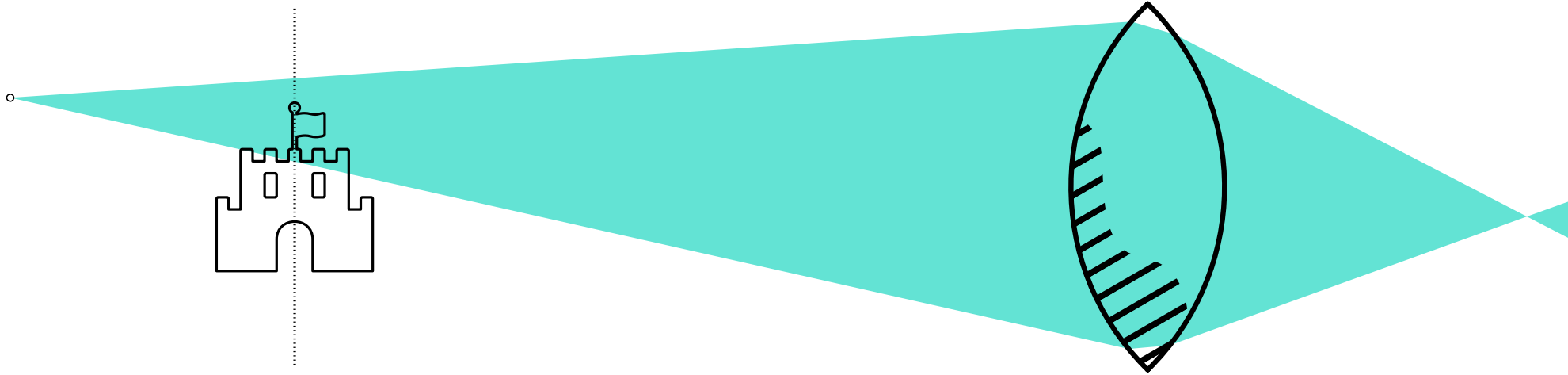


# Bokeh 暈け



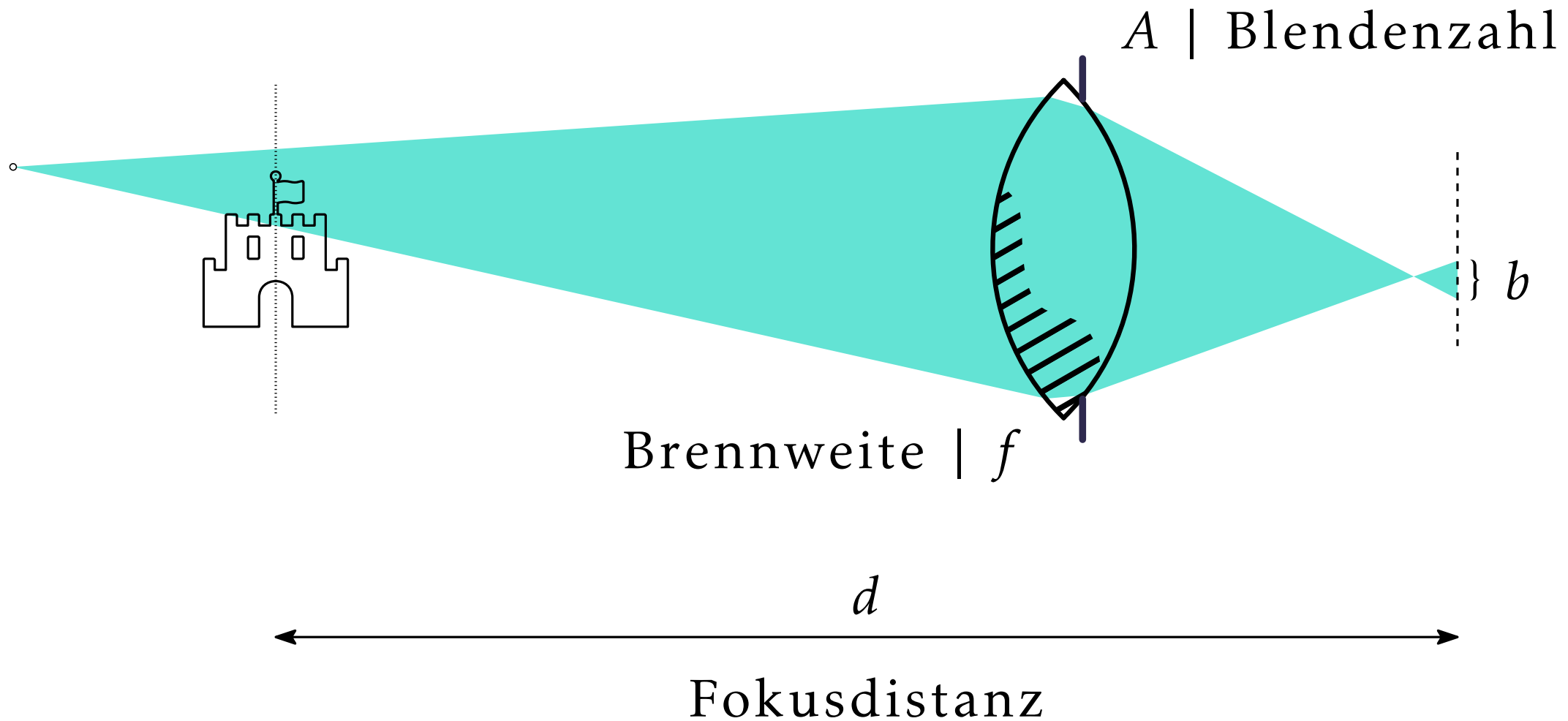
50mm  
 $f/1,7$   
1/1250 s  
ISO 100

# Bokeh 暈け



# Bokeh 暈け

$$b \approx \frac{f^2}{Ad}$$



# Bokeh 暈け

$$\frac{b}{D} \approx \frac{f^2}{AdD}$$

