








# Tragwerksentwurf I

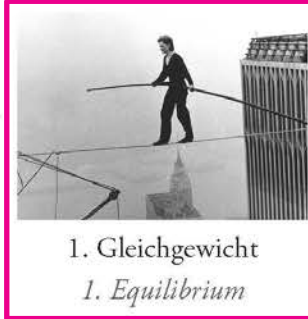
## *Structural Design I*

Philippe Block · Joseph Schwartz

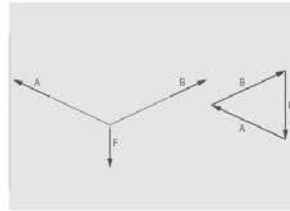
BACHELOR				MASTER			
Structural Design I	Structural Design II	Structural Design III	Structural Design IV	Computational Structural Design I	Computational Structural Design II	Architecture and Structure	Force Material Form
Form and Force	Material	Design Project	Computational Graphic Statics	Form-finding and Fabrication	Design	History and Theory	
							



Tragwerksentwurf  
*Structural Design*



1. Gleichgewicht  
*1. Equilibrium*



2. Graphische Statik  
*2. Graphic statics*



3. Seile  
*3. Cables*



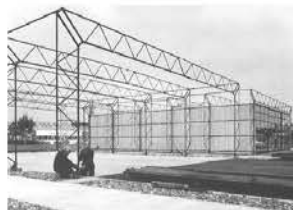
4. Bogen  
*4. Arches*



5. Bogen-Seil  
*5. Arch-cables*

## Tragwerksentwurf I *Structural Design I*

## Tragwerksentwurf II *Structural Design II*



6. Fachwerke  
*6. Trusses*



7. Balken  
*7. Beams*



8. Rahmen  
*8. Frames*



9. Platten  
*9. Plates*



10. Stützen  
*10. Columns*



11. Nachhaltigkeit  
*11. Sustainability*

# Gleichgewicht und grafische Statik

## *Equilibrium and graphic statics*

>> Grafische Statik  
*Graphic Statics*

Kräfte  
*Forces*

Gleichgewicht von zwei Kräften  
*Equilibrium of two forces*

Resultierende von zwei Kräften  
*Resultants of two forces*

Resultierende von drei und mehreren Kräften  
*Resultants of three or more forces*

Gleichgewicht von drei und mehreren Kräften  
*Equilibrium of three or more forces*

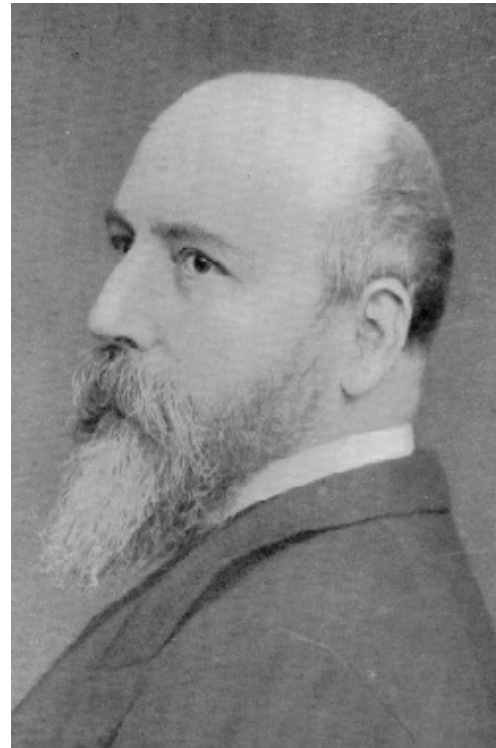
Innere Kräfte  
*Internal forces*



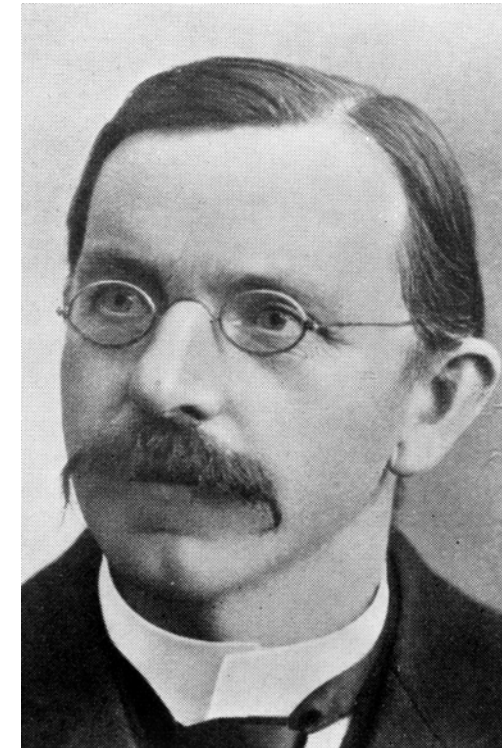
Denkmal für Carl Culmann, ETH Zürich



Carl Culmann  
1821 - 1881

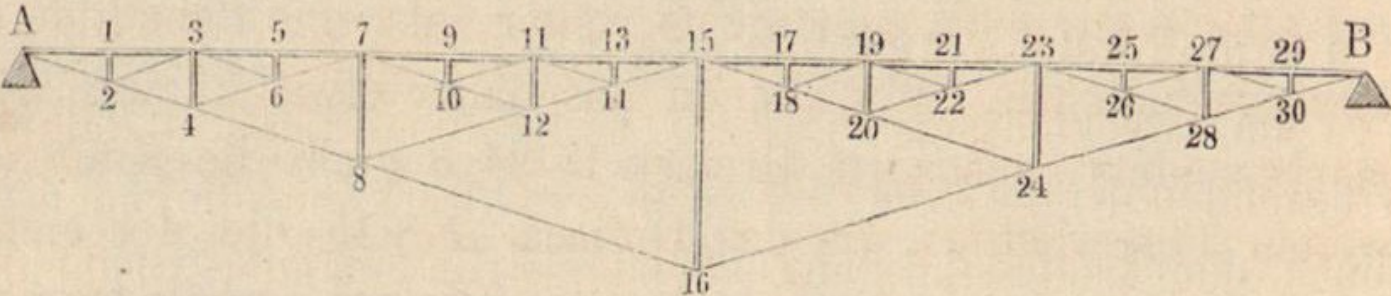


Luigi Cremona  
1830 - 1903



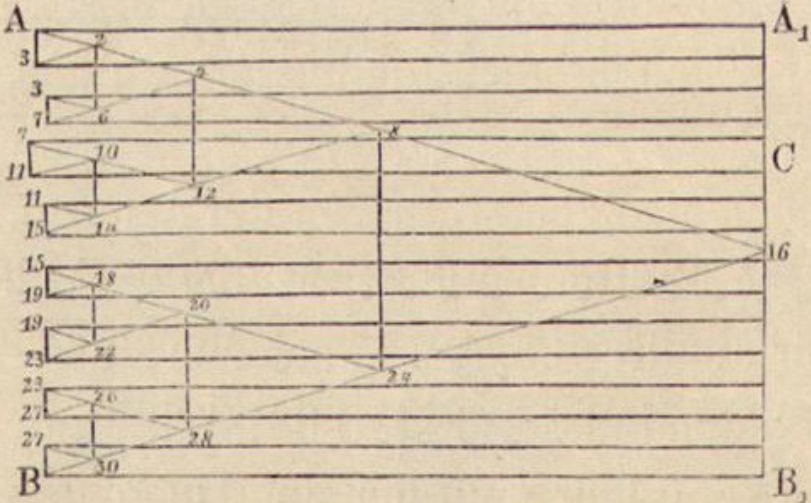
Karl-Wilhelm Ritter  
1847-1905

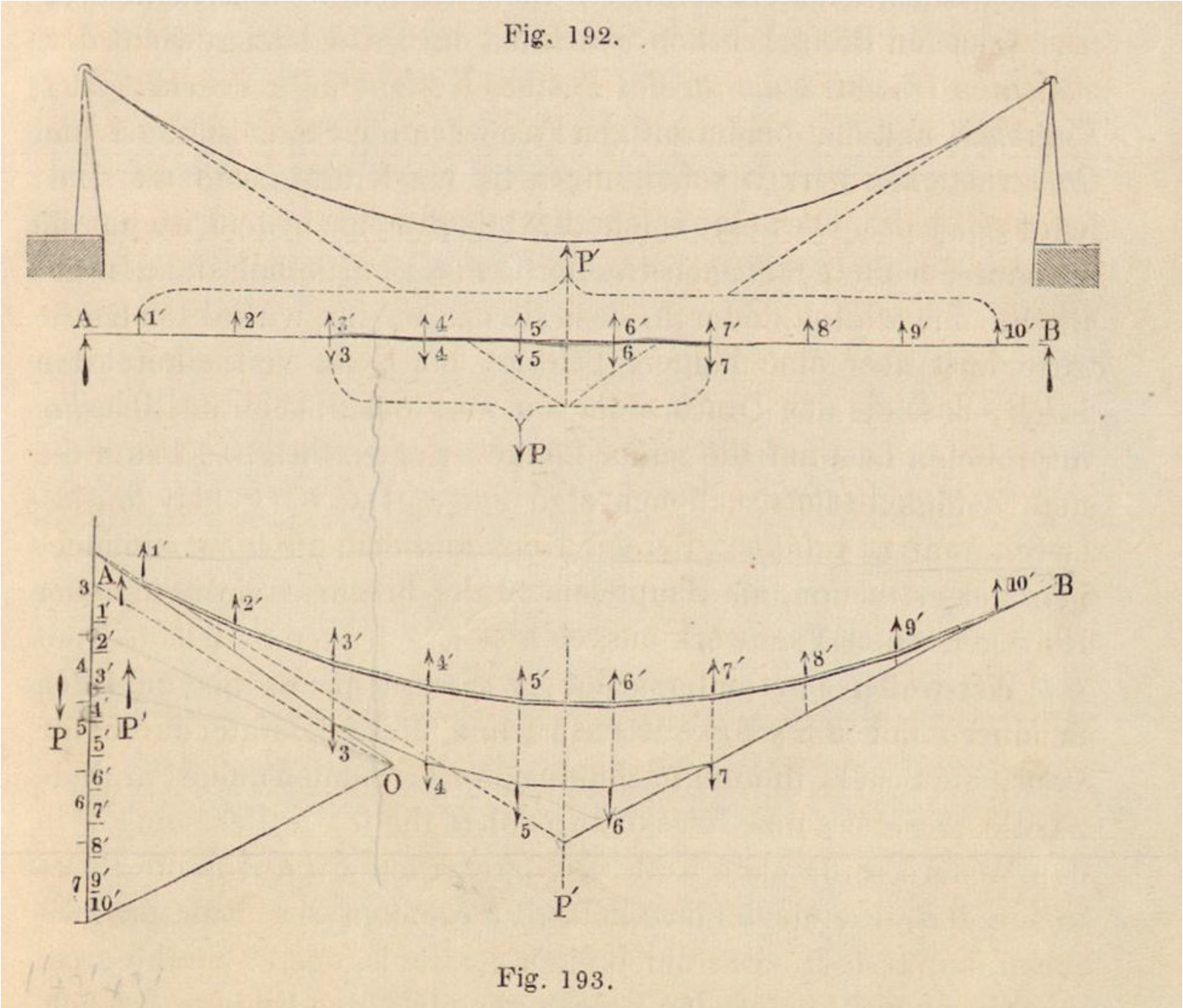
Fig. 168.



tungen 2 4 und 4 6 mittelst des Kräftedreiecks 2 4 6 (Fig. 169) und gibt uns die Spannung 4 6 in der entsprechenden Schlauderstrecke. Diese mit der vom Pfosten 5 6 (Fig. 168) herrührende Spannung

Fig. 169.





Carl Culmann, Die graphische Statik, S. 556



# Gleichgewicht und grafische Statik

## *Equilibrium and graphic statics*

Grafische Statik

*Graphic Statics*

>>

Kräfte

*Forces*

Gleichgewicht von zwei Kräften

*Equilibrium of two forces*

Resultierende von zwei Kräften

*Resultants of two forces*

Resultierende von drei und mehreren Kräften

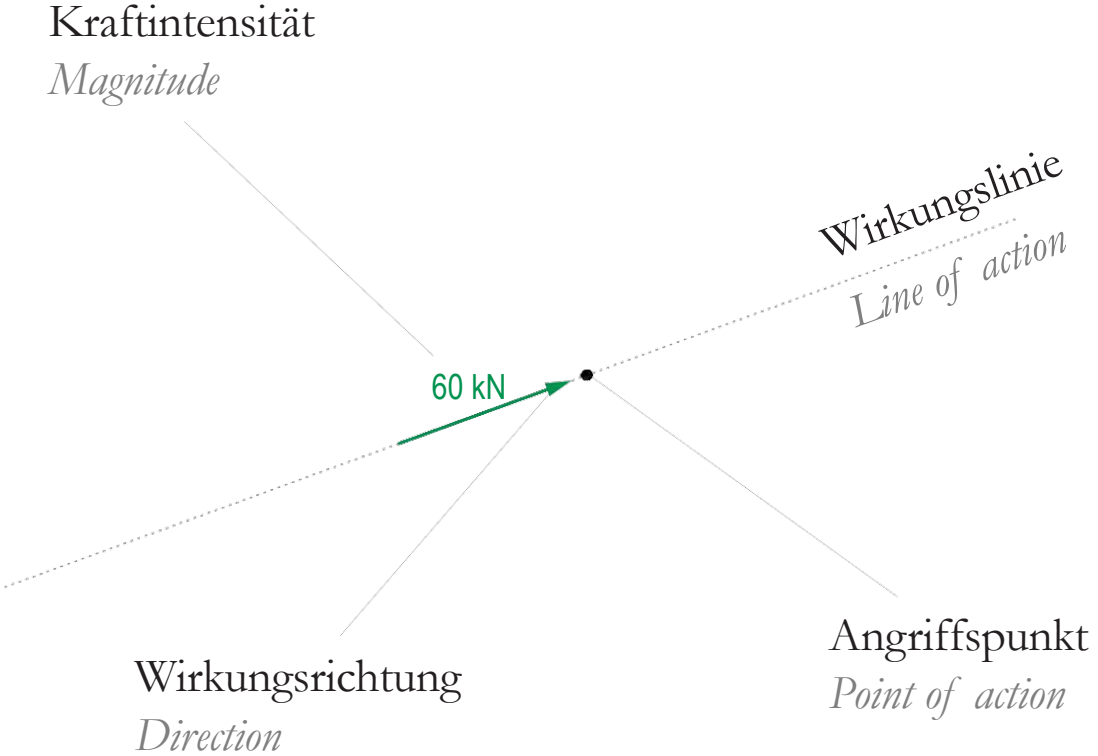
*Resultants of three or more forces*

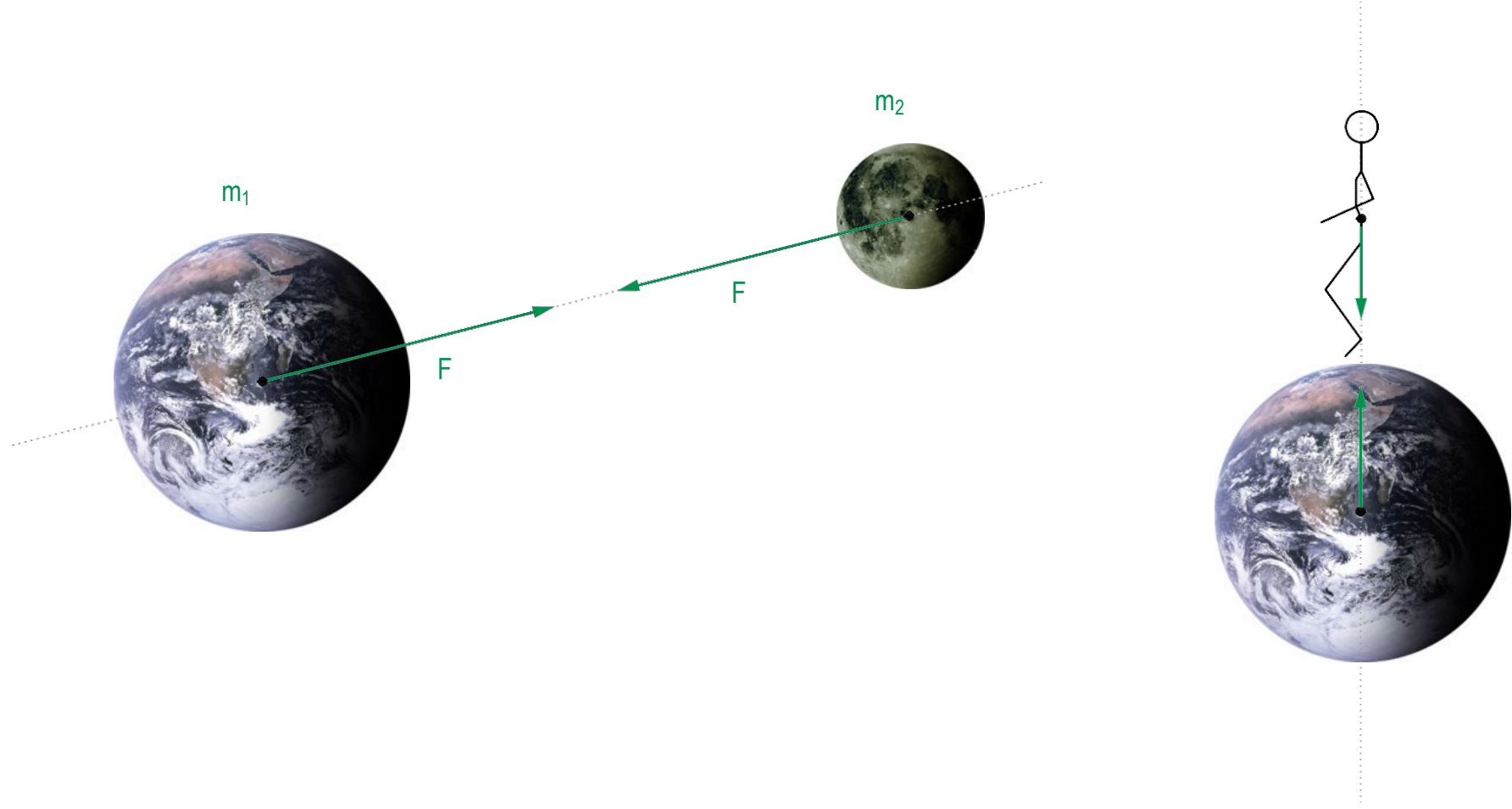
Gleichgewicht von drei und mehreren Kräften

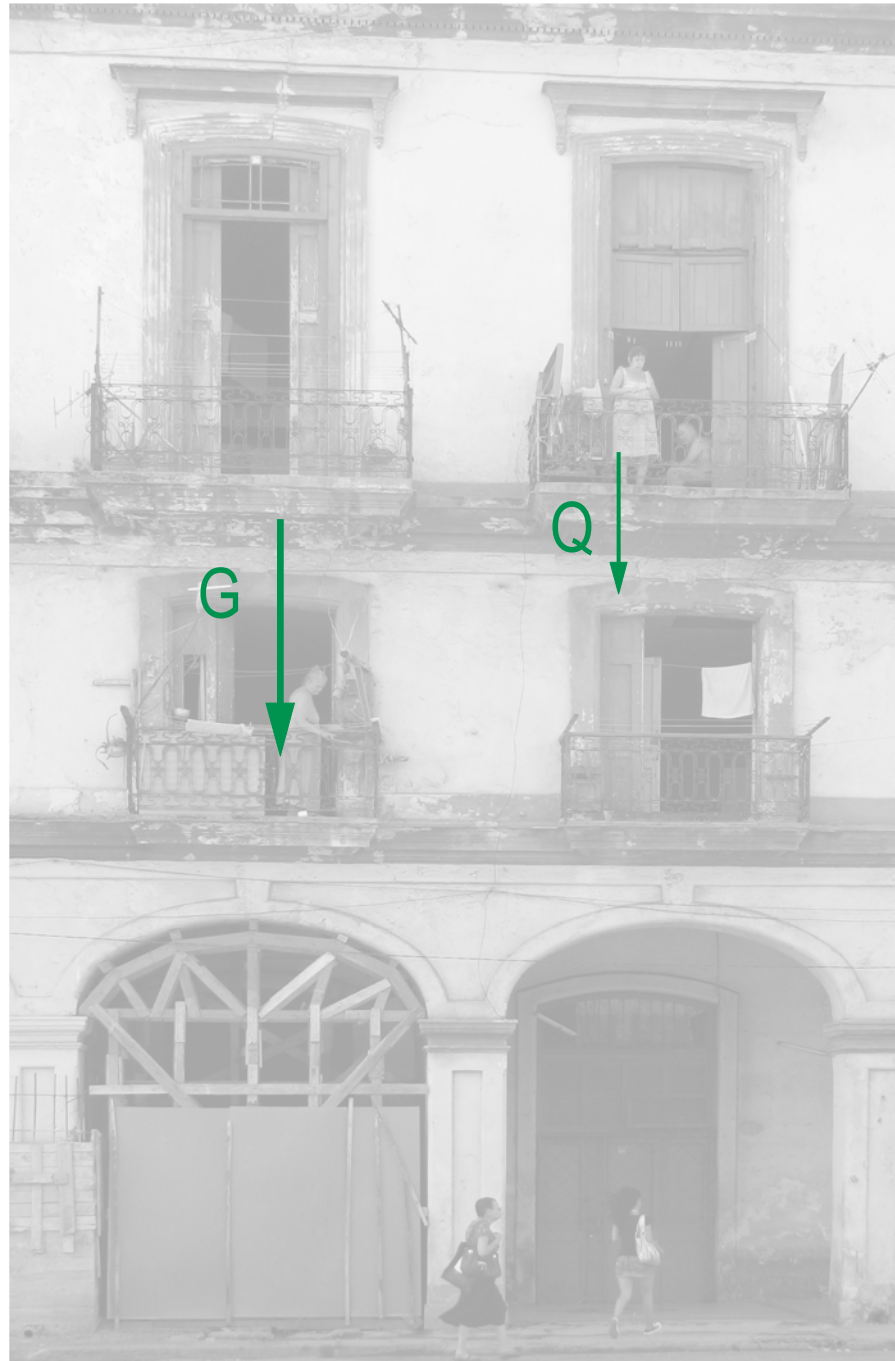
*Equilibrium of three or more forces*

Innere Kräfte

*Internal forces*

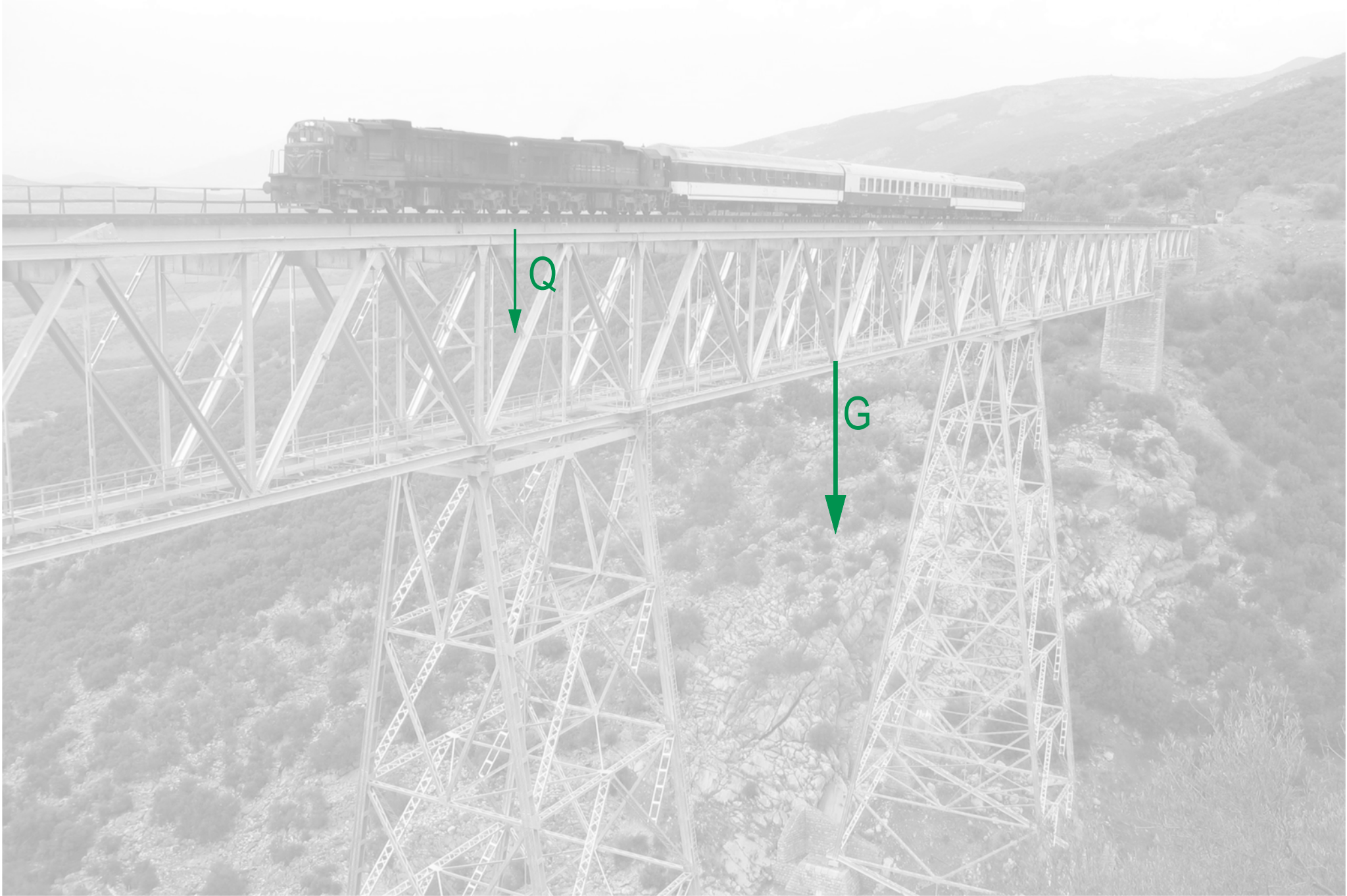


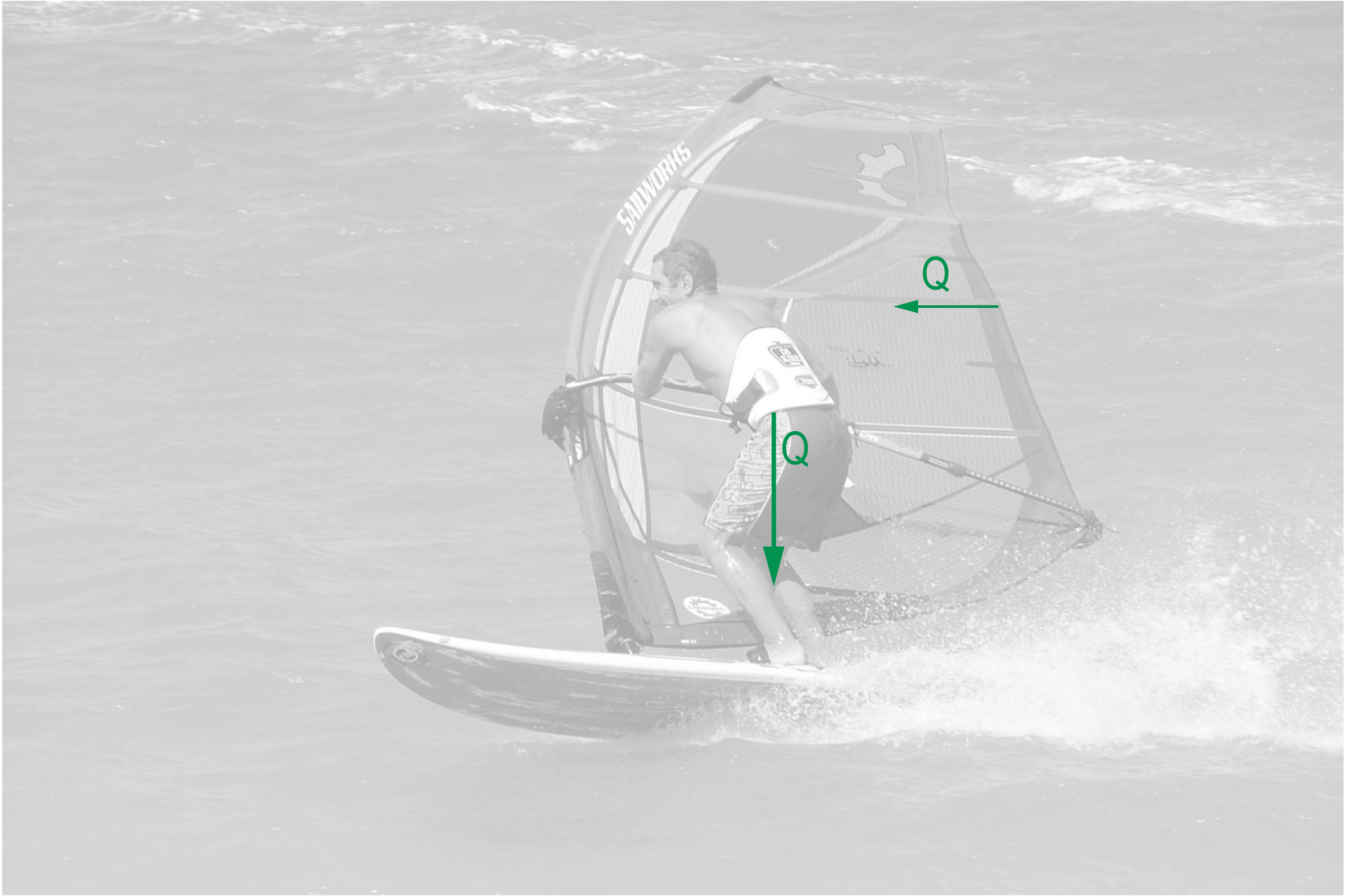




G ständige Last  
*dead load*

Q veränderliche Last  
*live load*











Kräfte

Forces

17

A black and white photograph showing a multi-story building that has been severely damaged and tilted. The building's structure is exposed, with debris scattered around its base. A green arrow labeled 'Q' points horizontally to the right, indicating a lateral force acting on the building. In the foreground, a person is riding a bicycle on a street that is covered in rubble and debris. The background shows another building and utility lines.

Krafteinwirkungen

Types of forces

# Gleichgewicht und grafische Statik

## *Equilibrium and graphic statics*

Grafische Statik

*Graphic Statics*

Kräfte

*Forces*

>>

Gleichgewicht von zwei Kräften

*Equilibrium of two forces*

Resultierende von zwei Kräften

*Resultants of two forces*

Resultierende von drei und mehreren Kräften

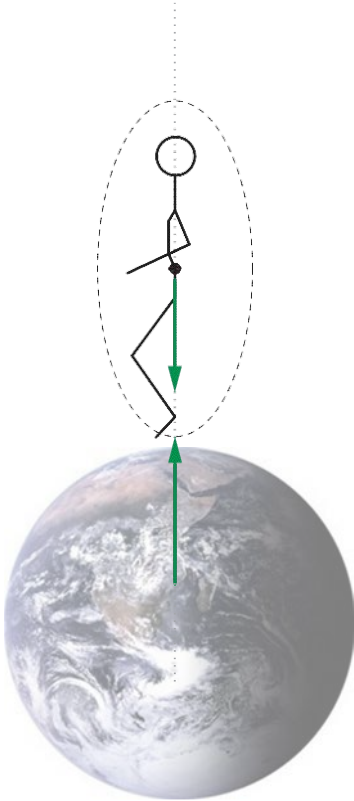
*Resultants of three or more forces*

Gleichgewicht von drei und mehreren Kräften

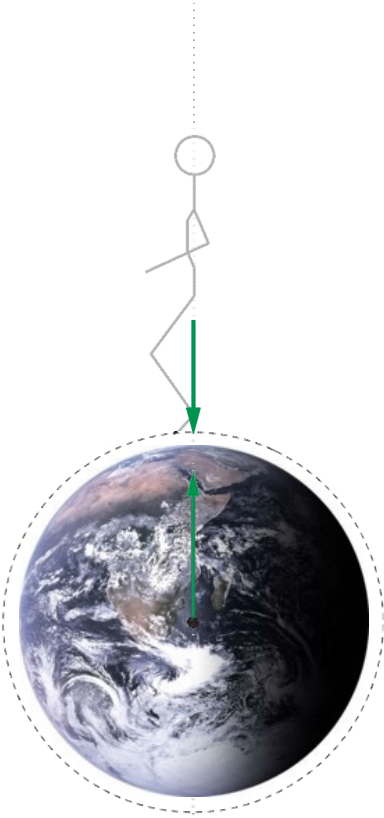
*Equilibrium of three or more forces*

Innere Kräfte

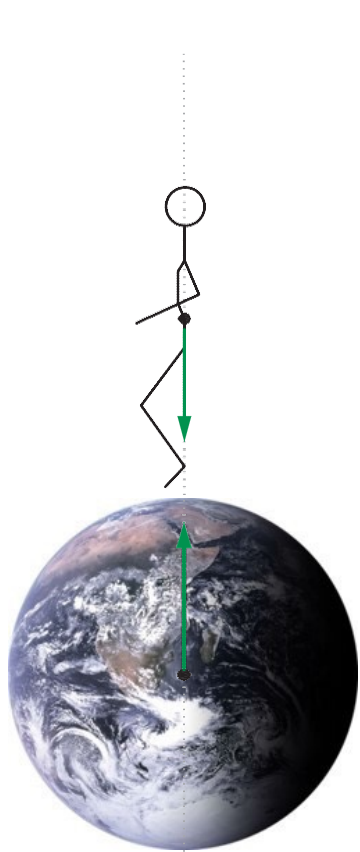
*Internal forces*



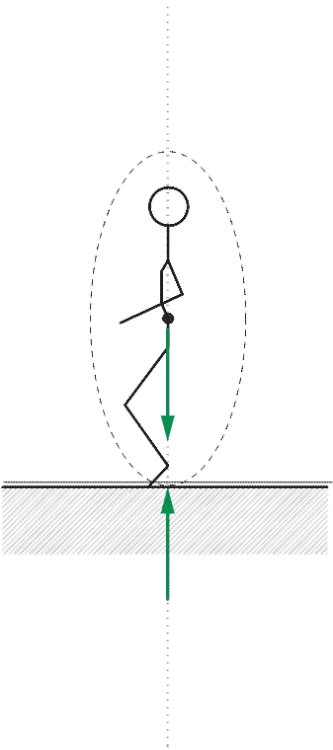
Subsystem Mensch  
*Subsystem body*



Subsystem Erde  
*Subsystem earth*



Gesamtsystem  
*Global system*



Lageplan  
*Form diagram*

Masstab 1:10  
*Scale 1:100*

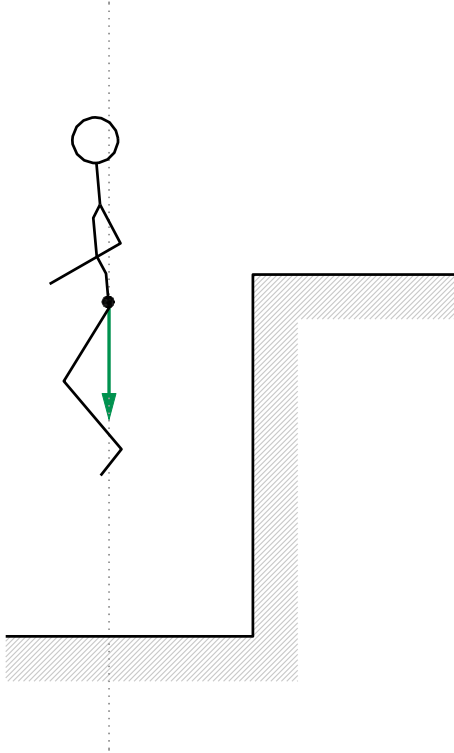


Kräfteplan  
*Force diagram*

Masstab 1cm ≅ 10 kN  
*Scale 1cm ≅ 10 kN*

- Gleiche Wirkungslinie
- Gleiche Intensität, unterschiedliche Richtung
- *same line of action*
- *same magnitude, different direction*

Übersetzung  
*Translation*

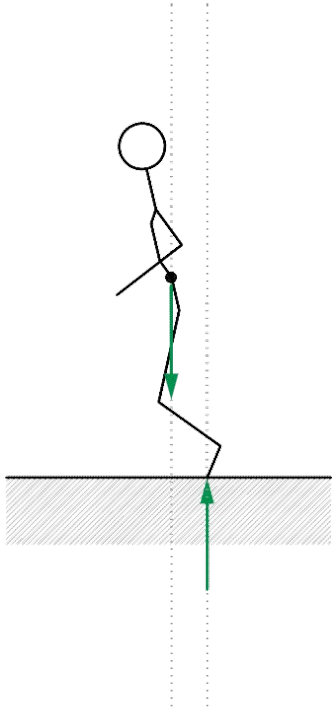


Lageplan  
*Form diagram*



Kräfteplan  
*Force diagram*

Rotation  
*Rotation*

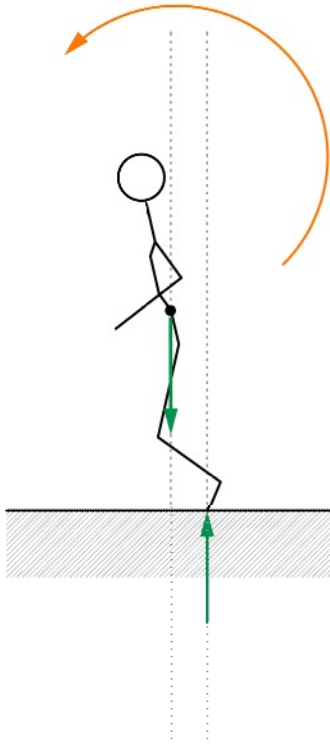


Lageplan  
*Form diagram*



Kräfteplan  
*Force diagram*

Rotation  
*Rotation*



Lageplan  
*Form diagram*

Kräfteplan  
*Force diagram*

# Gleichgewicht und grafische Statik

## *Equilibrium and graphic statics*

Grafische Statik

*Graphic Statics*

Kräfte

*Forces*

Gleichgewicht von zwei Kräften

*Equilibrium of two forces*

>>

Resultierende von zwei Kräften

*Resultants of two forces*

Resultierende von drei und mehreren Kräften

*Resultants of three or more forces*

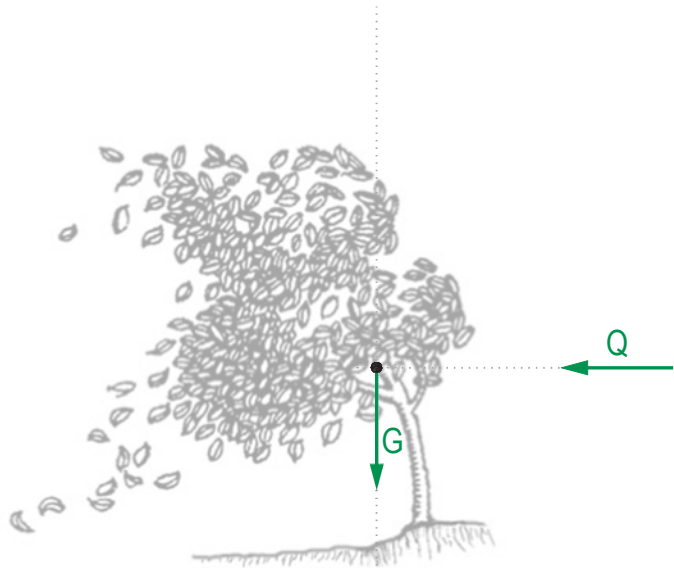
Gleichgewicht von drei und mehreren Kräften

*Equilibrium of three or more forces*

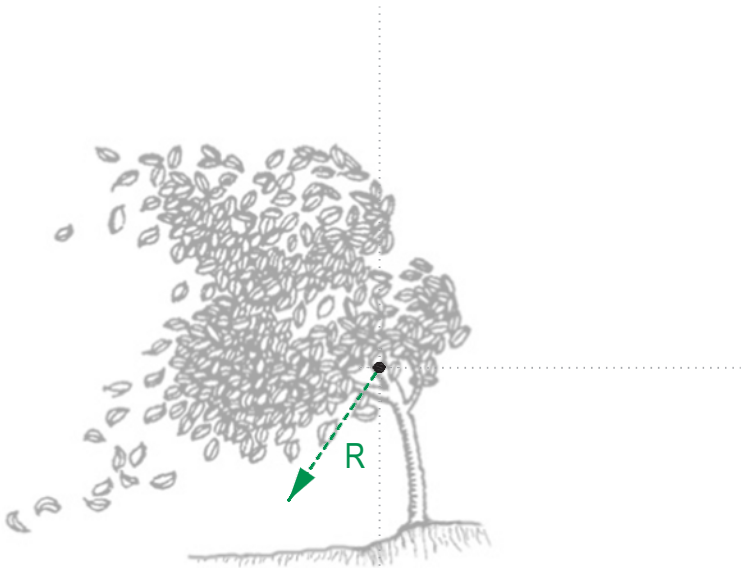
Innere Kräfte

*Internal forces*

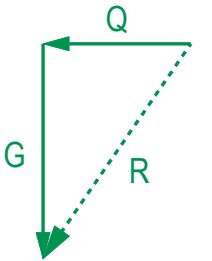




Lageplan  
*Form diagram*

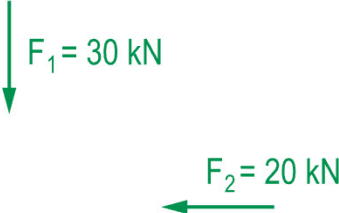


Lageplan  
*Form diagram*



Kräfteplan  
*Force diagram*

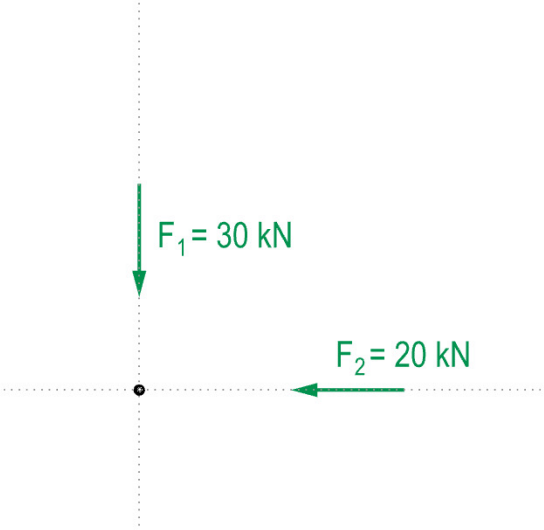
*Resultant of two forces*



Lageplan 1:100

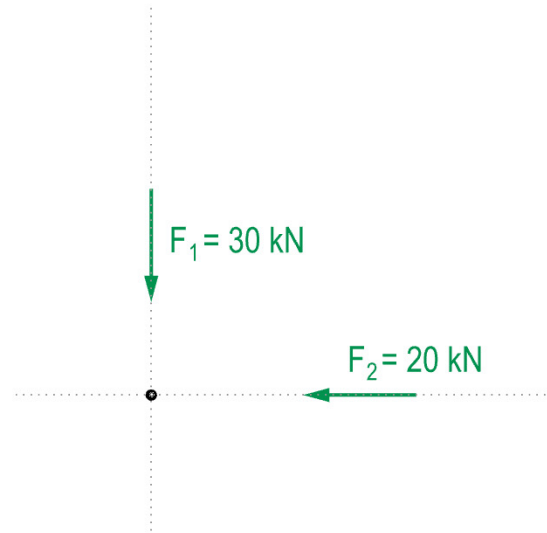
*Form diagram 1:100*

*Resultant of two forces*



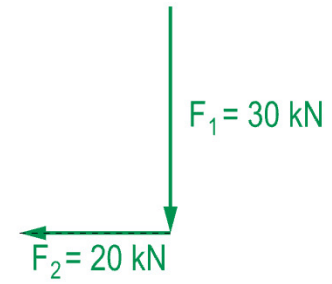
Lageplan 1:100

*Form diagram 1:100*



Lageplan 1:100

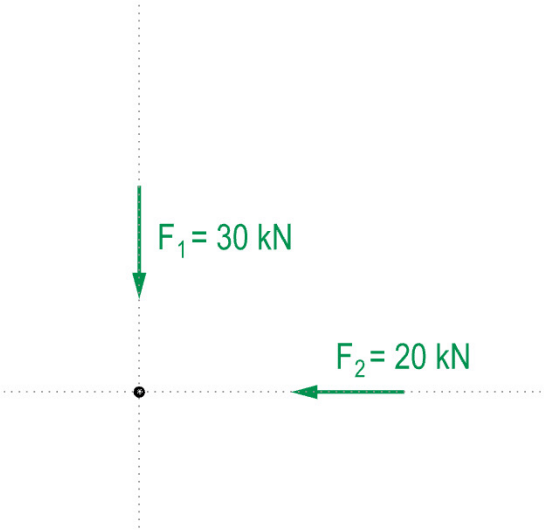
*Form diagram 1:100*



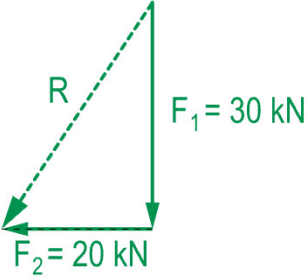
Kräfteplan 1 cm  $\hat{=}$  1 kN

*Force diagram 1 cm  $\hat{=}$  1 kN*

*Resultant of two forces*

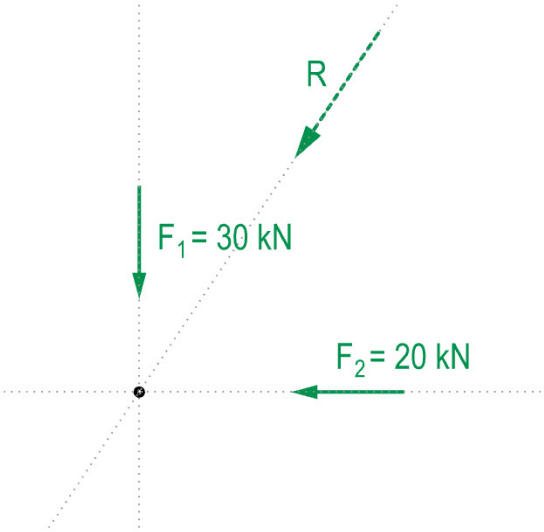


Lageplan 1:100  
*Form diagram 1:100*

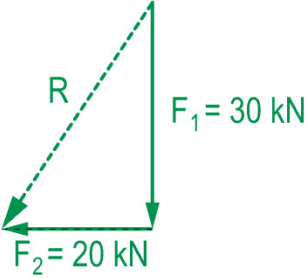


Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of two forces*



Lageplan 1:100  
*Form diagram 1:100*



Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of two forces*

$F_1 = 30 \text{ kN}$

$F_2 = 20 \text{ kN}$



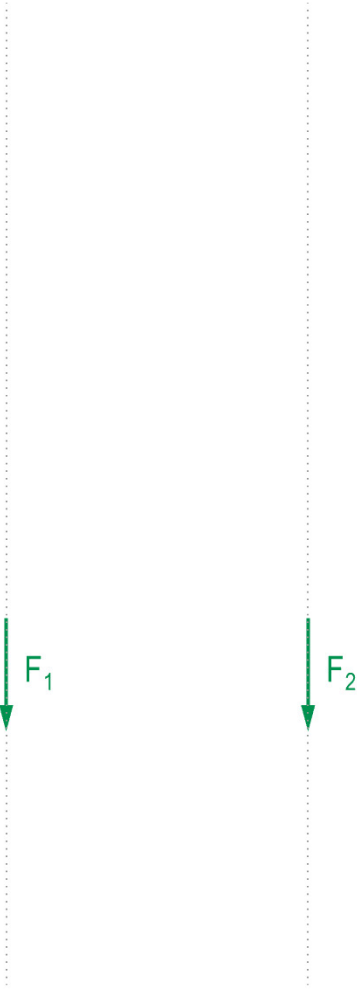
Lageplan 1:100

*Form diagram 1:100*

*Resultant of two forces*

$F_1 = 30 \text{ kN}$

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Lageplan 1:100

*Form diagram 1:100*



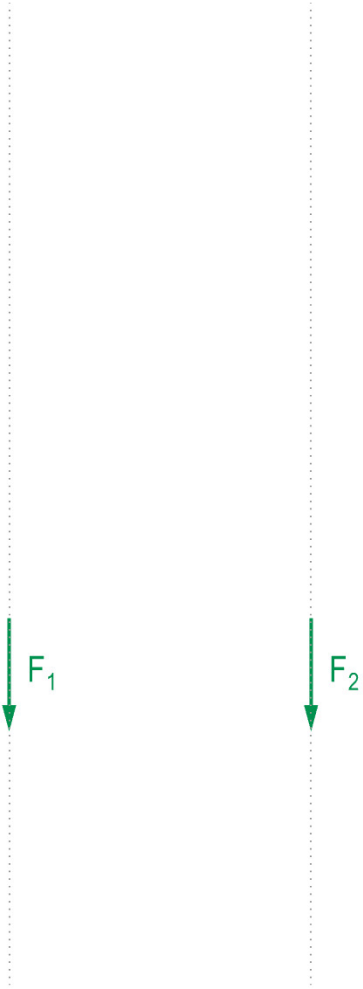
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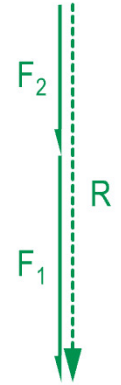


*Resultant of two forces*

$F_1 = 30 \text{ kN}$   
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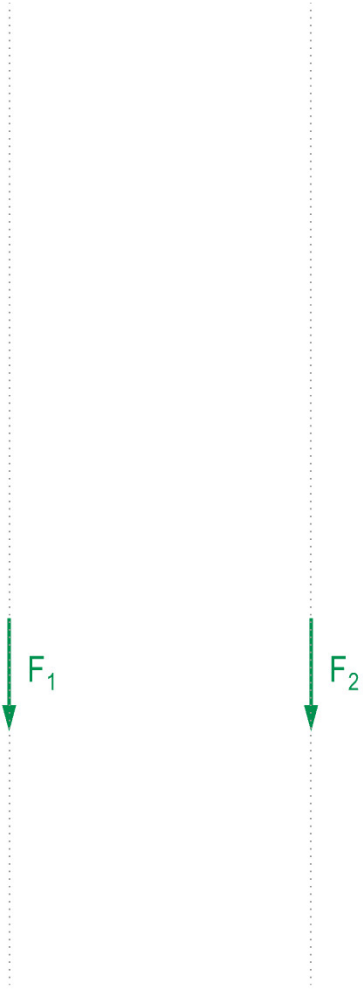
Lageplan 1:100  
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Kräfteplan 1 cm  $\cong$  1 kN  
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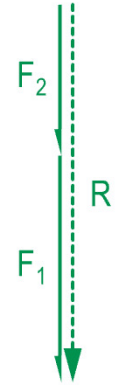
$F_1 = 30 \text{ kN}$   
 $F_2 = 20 \text{ kN}$



Lageplan 1:100  
*Form diagram 1:100*

Pol  
*Pole*

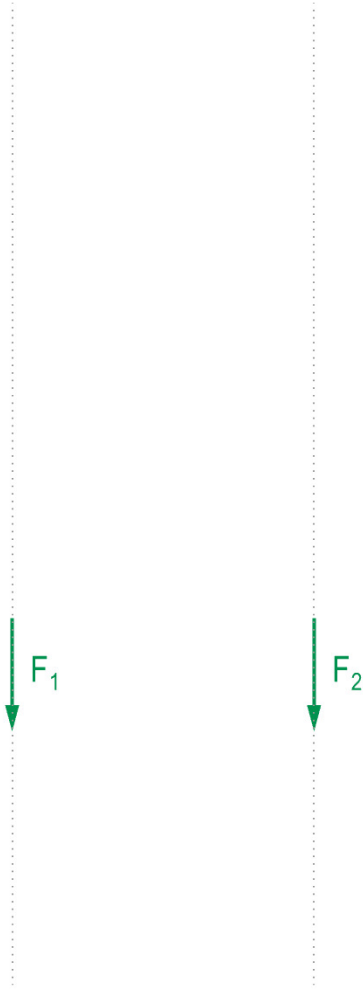
o •



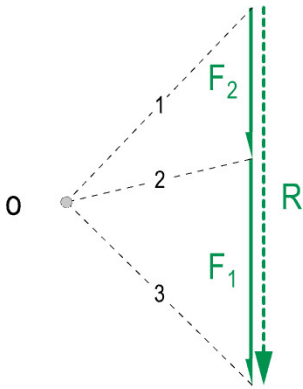
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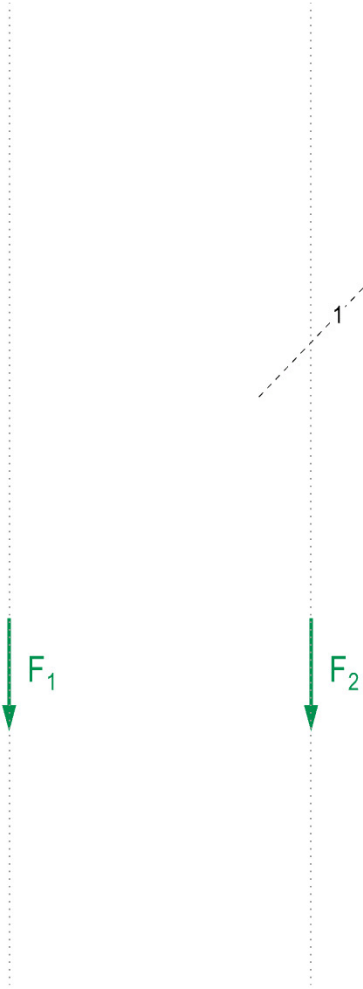
Lageplan 1:100  
*Form diagram 1:100*



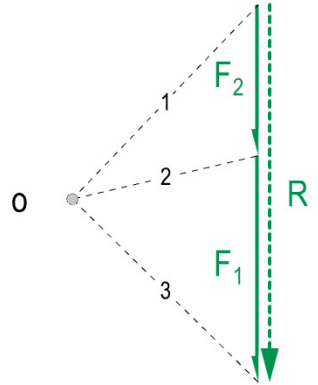
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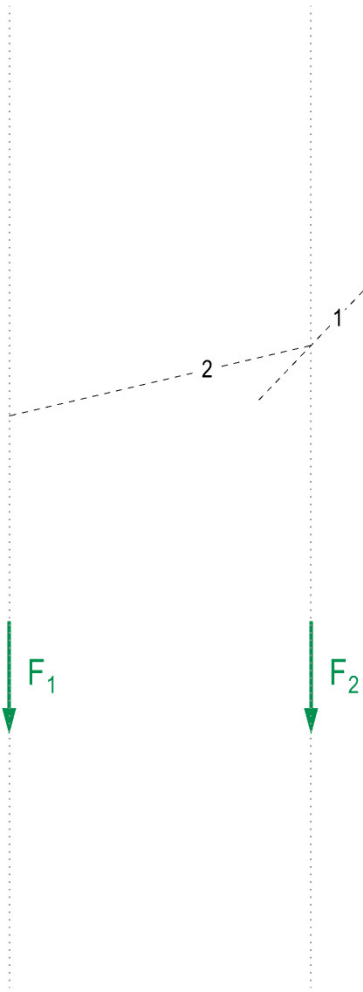
Lageplan 1:100  
*Form diagram 1:100*



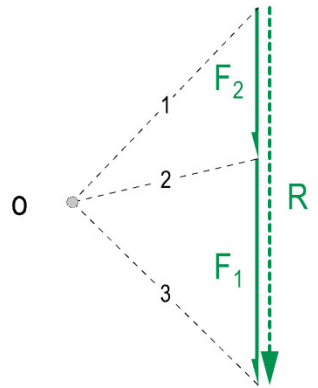
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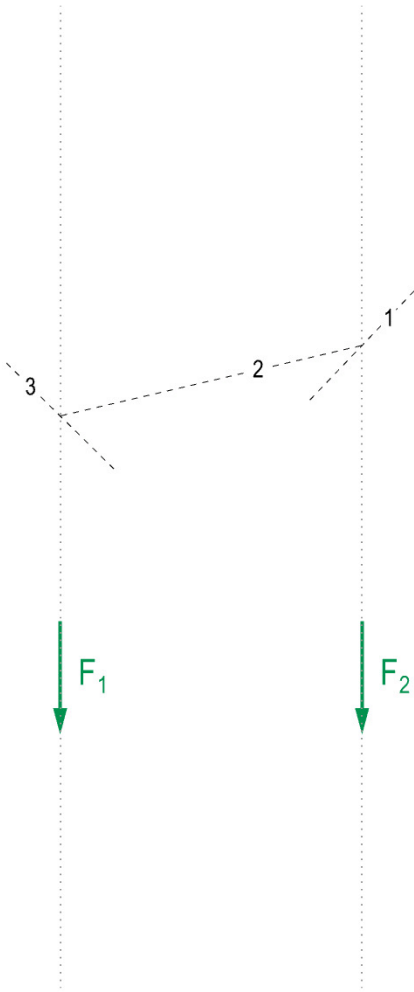
Lageplan 1:100  
*Form diagram 1:100*



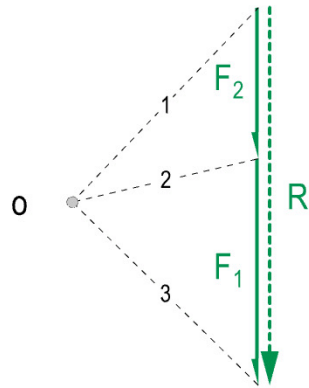
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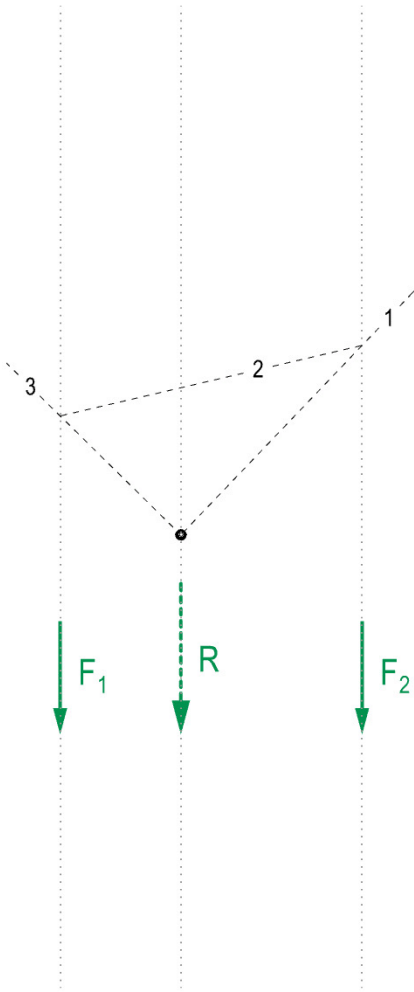
Lageplan 1:100  
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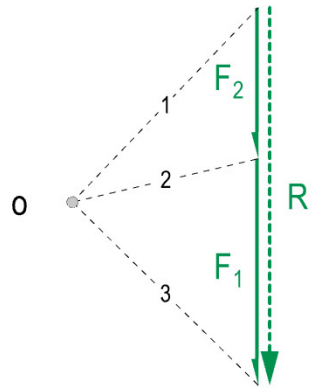
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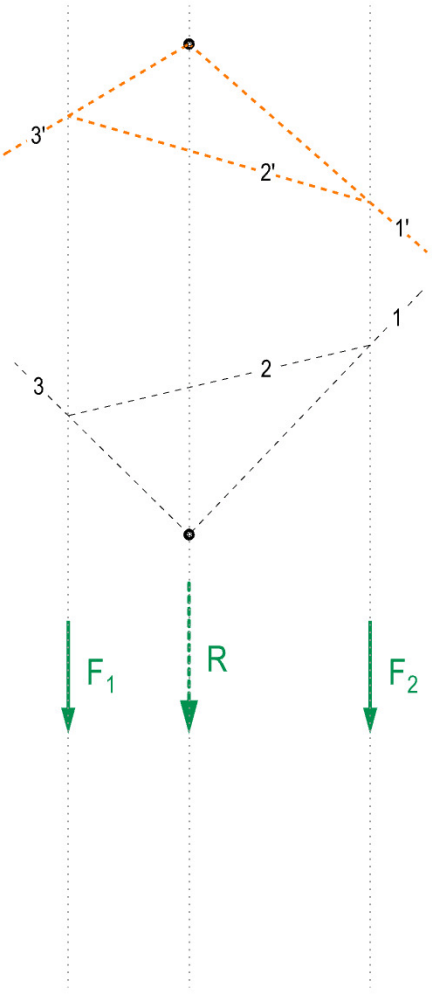
Lageplan 1:100  
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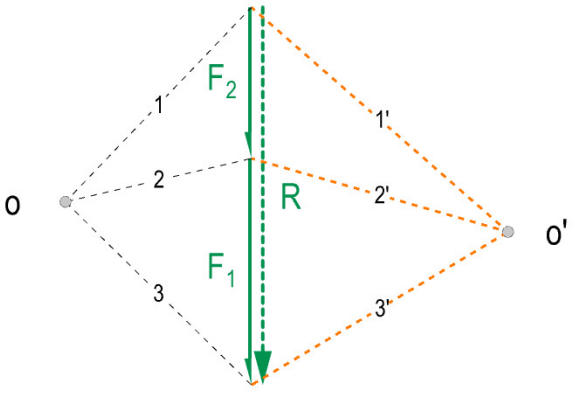
Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of two forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 20 \text{ kN}$



Lageplan 1:100  
*Form diagram 1:100*



Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*



# Gleichgewicht und grafische Statik

## *Equilibrium and graphic statics*

Grafische Statik

*Graphic Statics*

Kräfte

*Forces*

Gleichgewicht von zwei Kräften

*Equilibrium of two forces*

Resultierende von zwei Kräften

*Resultants of two forces*

>> Resultierende von drei und mehreren Kräften

*Resultants of three or more forces*

Gleichgewicht von drei und mehreren Kräften

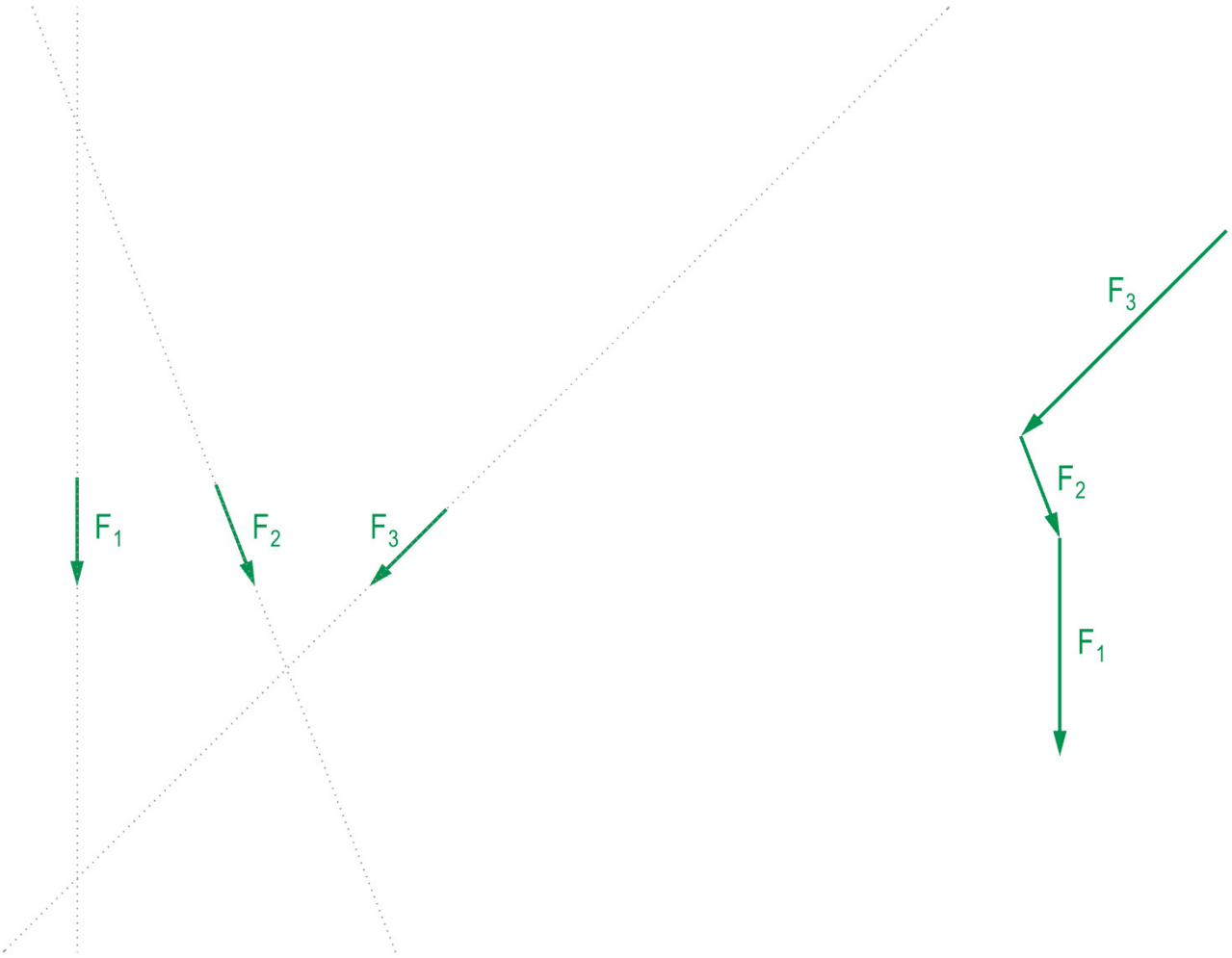
*Equilibrium of three or more forces*

Innere Kräfte

*Internal forces*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 15 \text{ kN}$   
 $F_3 = 40 \text{ kN}$

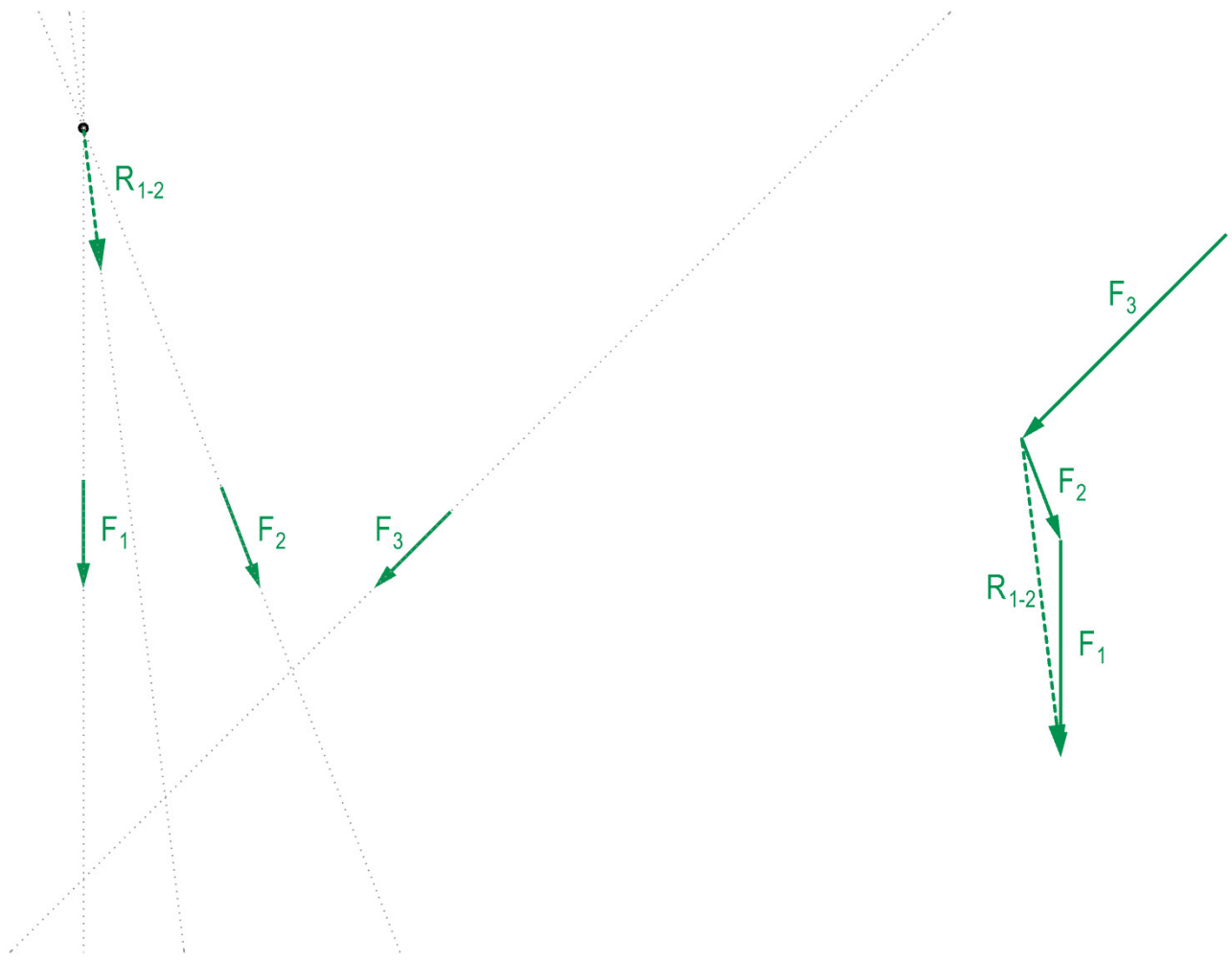


Lageplan 1:100  
*Form diagram 1:100*

Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

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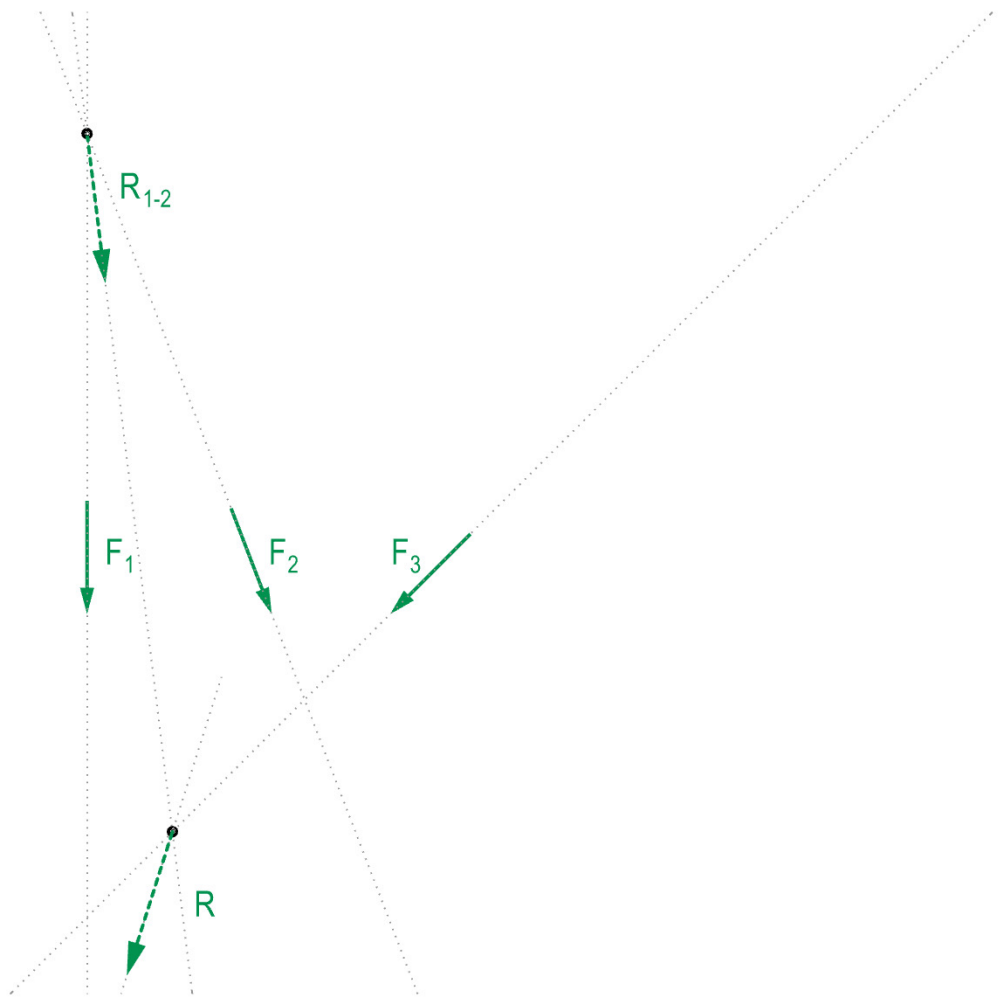


Lageplan 1:100  
*Form diagram 1:100*

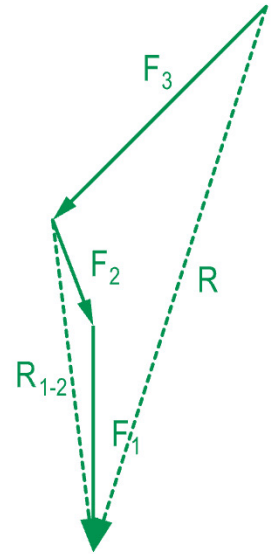
Kräfteplan 1 cm  $\cong$  1 kN  
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*Resultant of three and more forces*

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Lageplan 1:100  
*Form diagram 1:100*



Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$

$F_2 = 10 \text{ kN}$

$F_3 = 20 \text{ kN}$



Lageplan 1:100

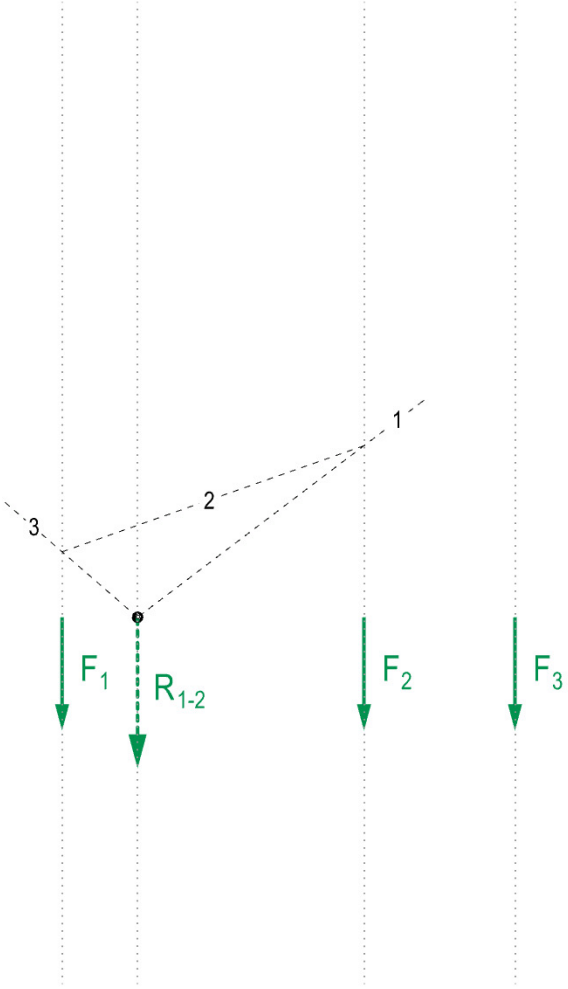
*Form diagram 1:100*

Kräfteplan 1 cm  $\cong$  1 kN

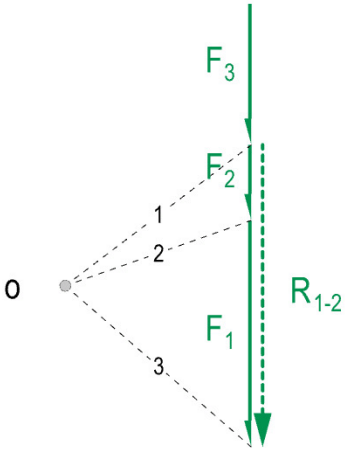
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

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 $F_3 = 20 \text{ kN}$



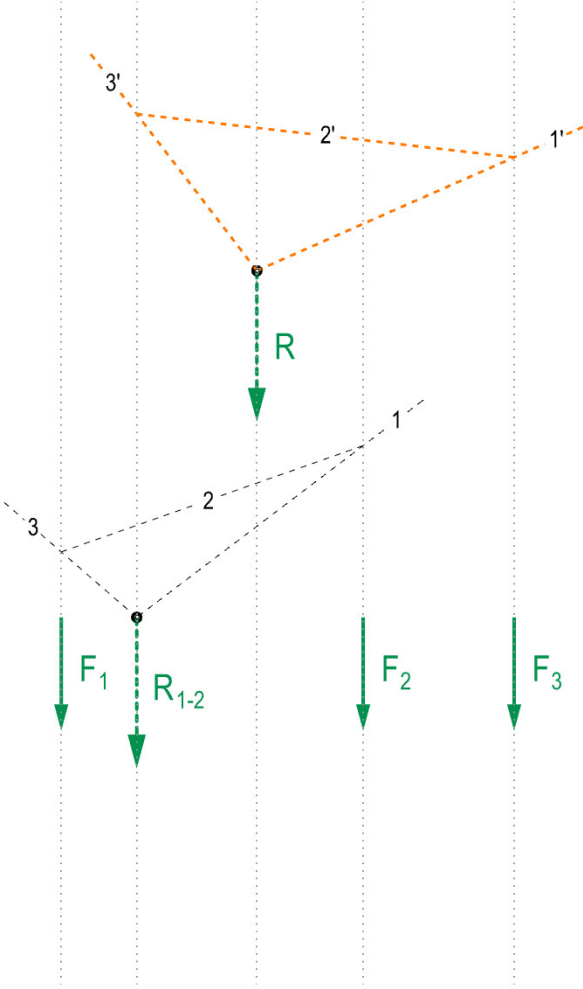
Lageplan 1:100  
*Form diagram 1:100*



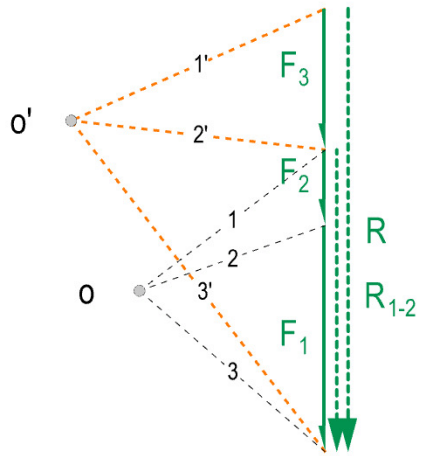
Kräfteplan 1 cm  $\cong$  1 kN  
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*Resultant of three and more forces*

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Lageplan 1:100  
*Form diagram 1:100*



Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 10 \text{ kN}$   
 $F_3 = 20 \text{ kN}$



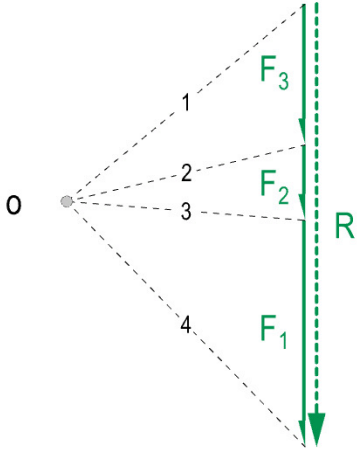
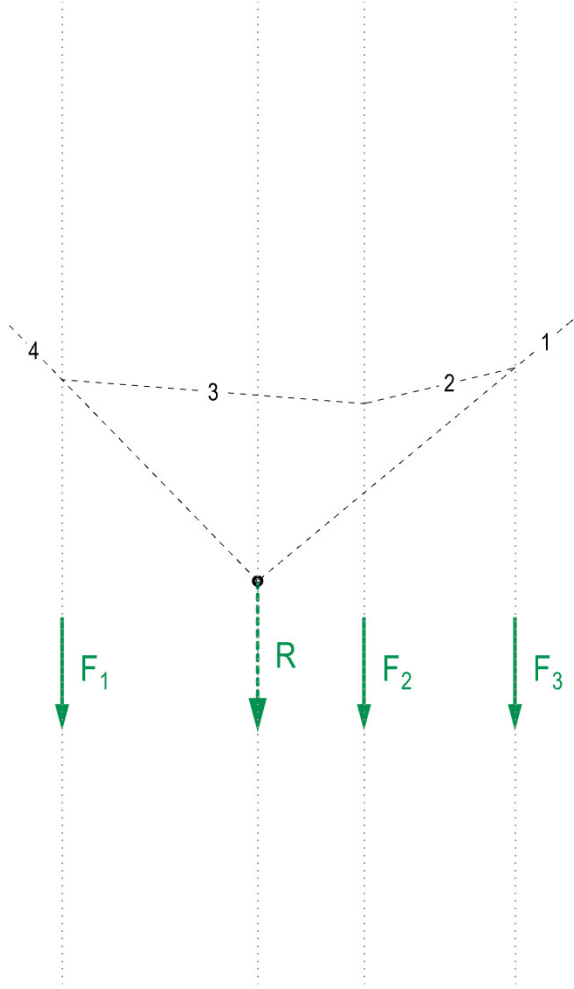
Lageplan 1:100  
*Form diagram 1:100*

Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*



*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 10 \text{ kN}$   
 $F_3 = 20 \text{ kN}$

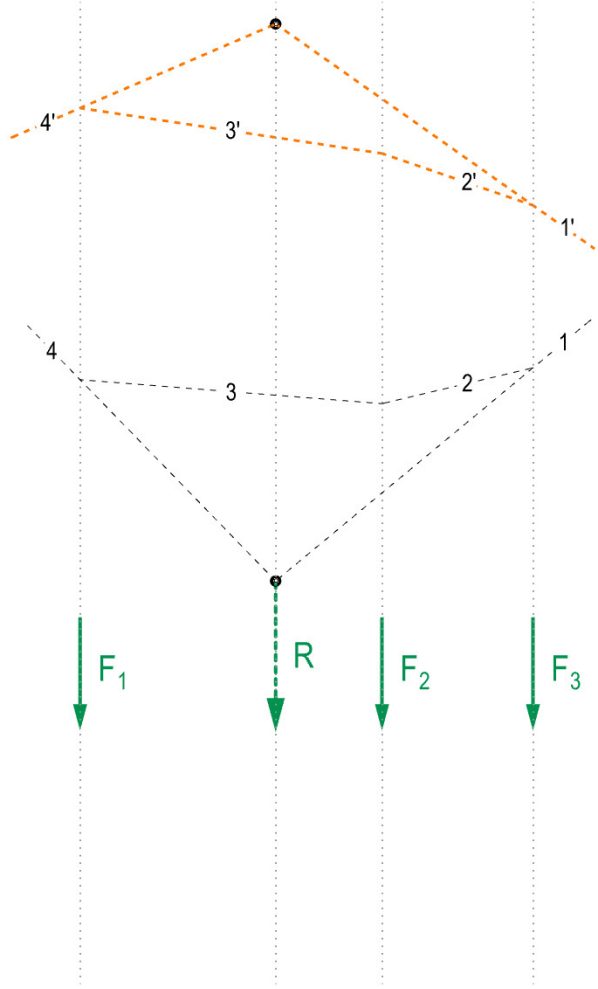


Lageplan 1:100  
*Form diagram 1:100*

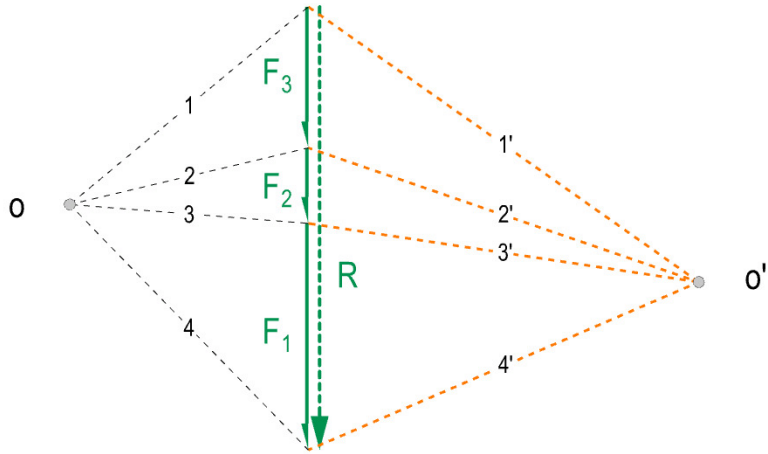
Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 10 \text{ kN}$   
 $F_3 = 20 \text{ kN}$



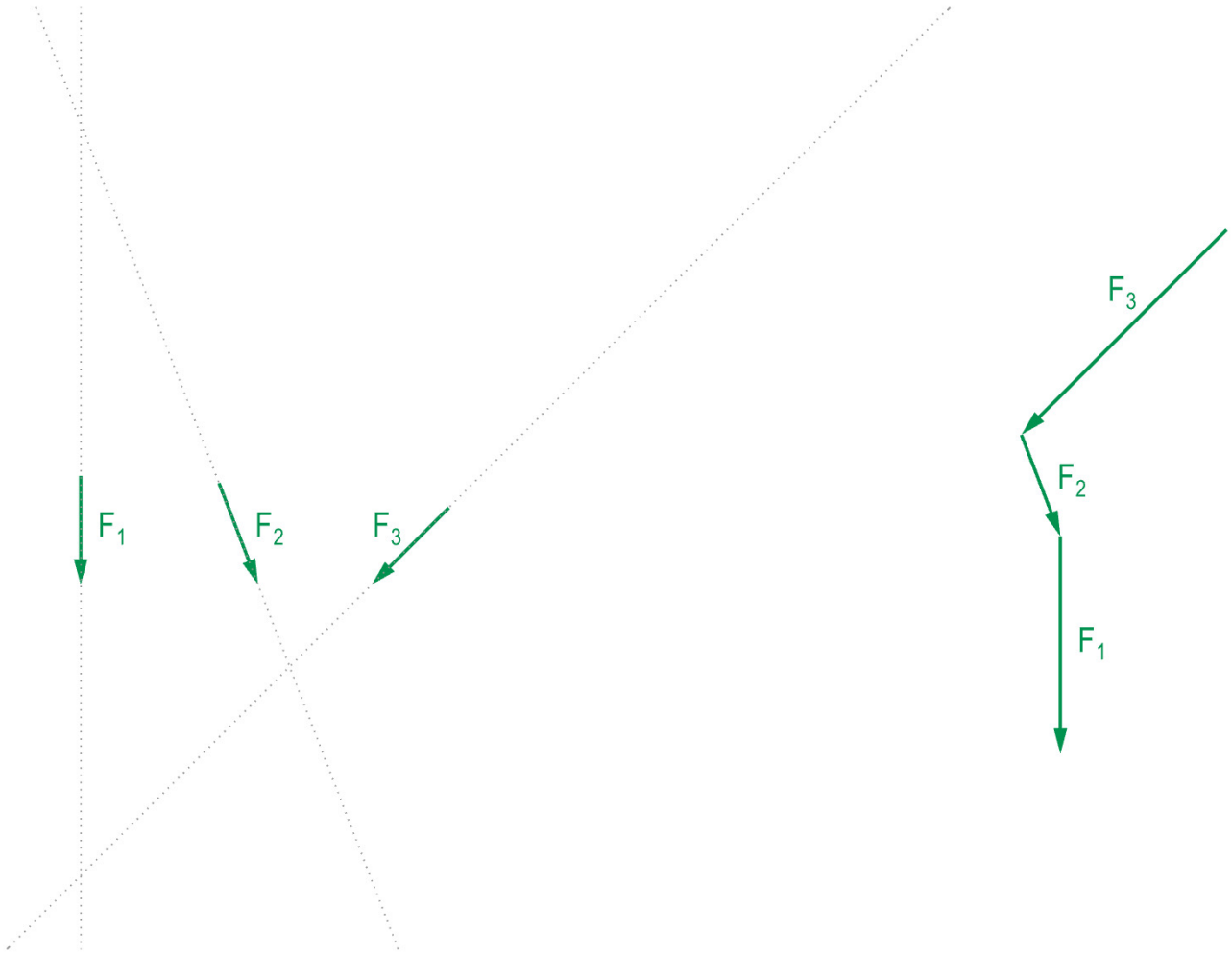
Lageplan 1:100  
*Form diagram 1:100*



Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 15 \text{ kN}$   
 $F_3 = 40 \text{ kN}$



Lageplan 1:100  
*Form diagram 1:100*

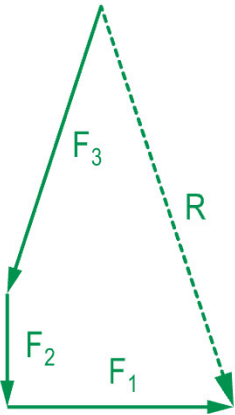
Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 15 \text{ kN}$   
 $F_3 = 40 \text{ kN}$



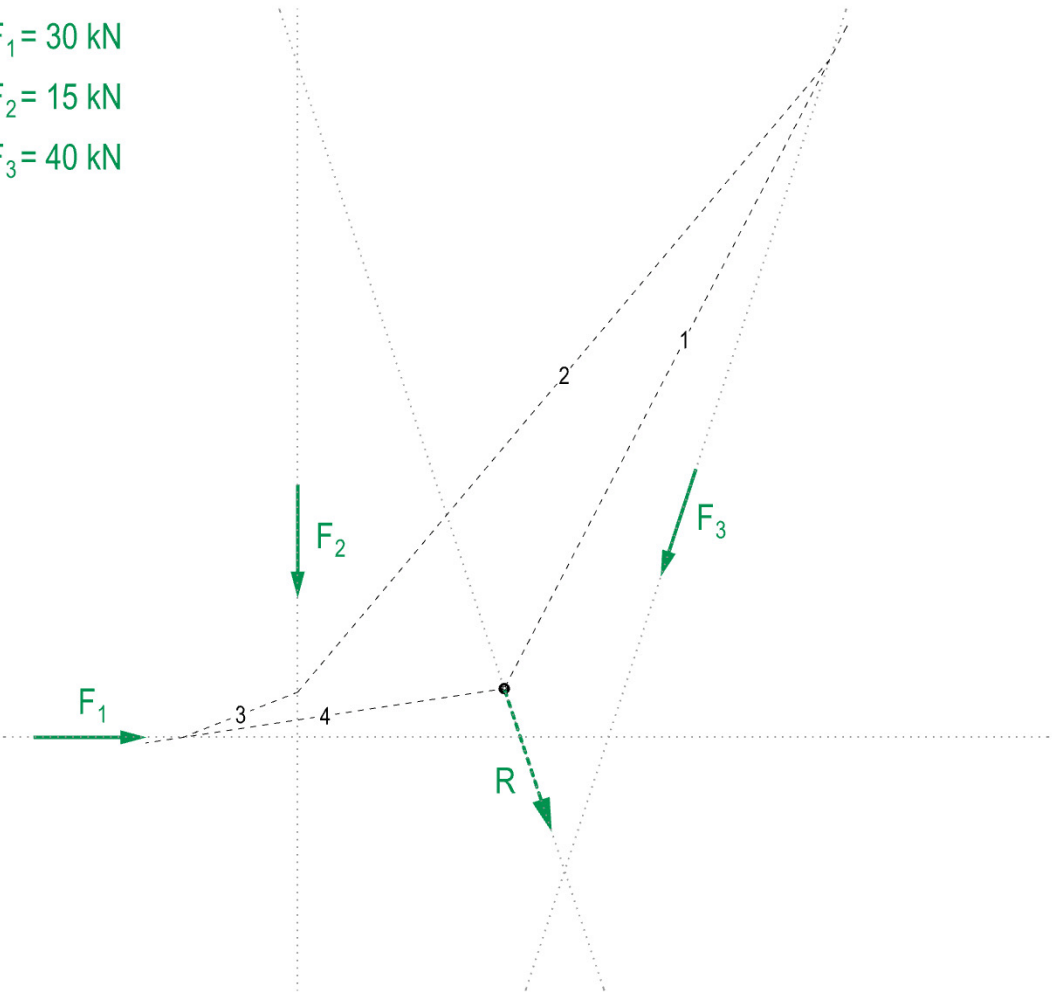
Lageplan 1:100  
*Form diagram 1:100*



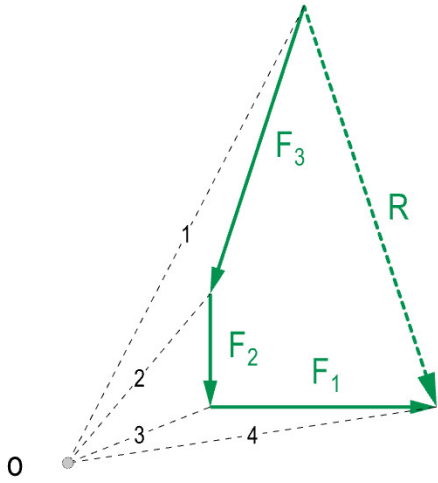
Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 15 \text{ kN}$   
 $F_3 = 40 \text{ kN}$



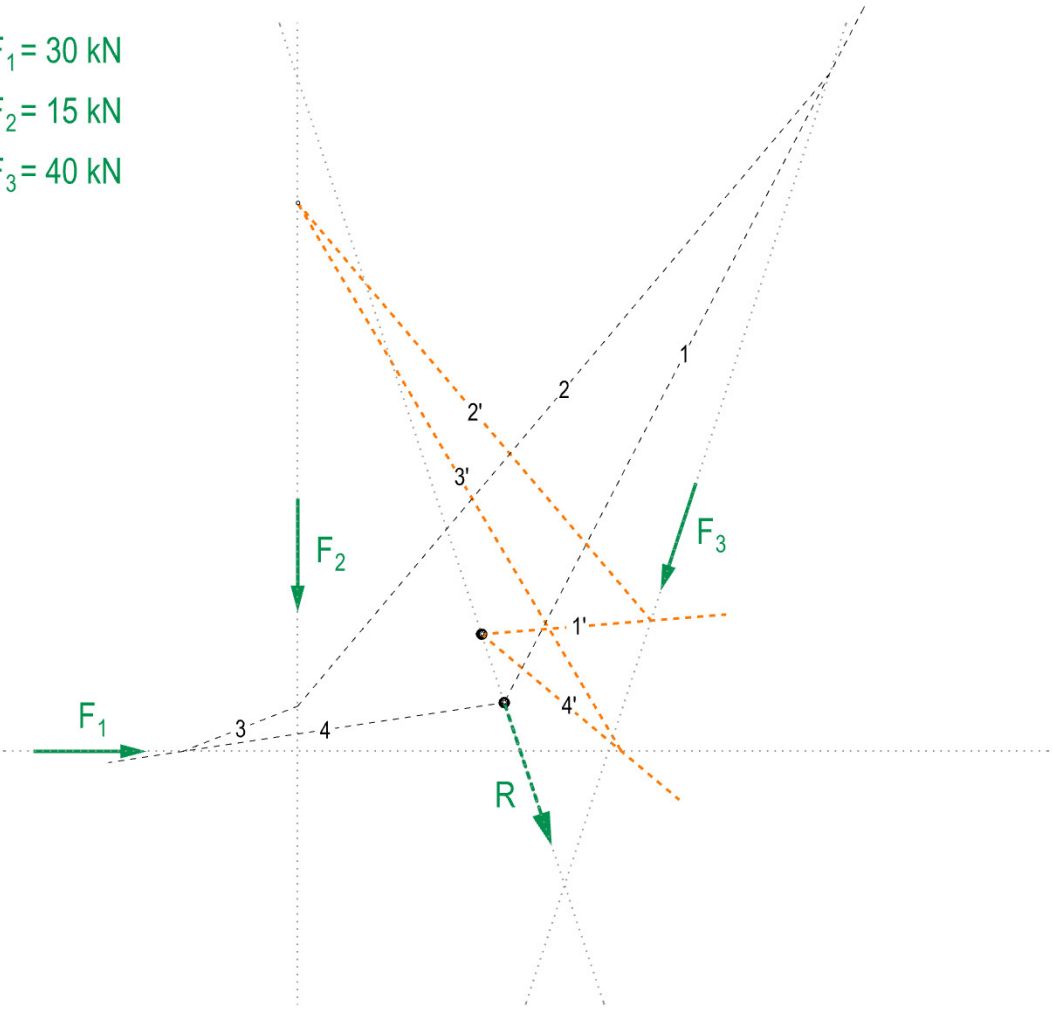
Lageplan 1:100  
*Form diagram 1:100*



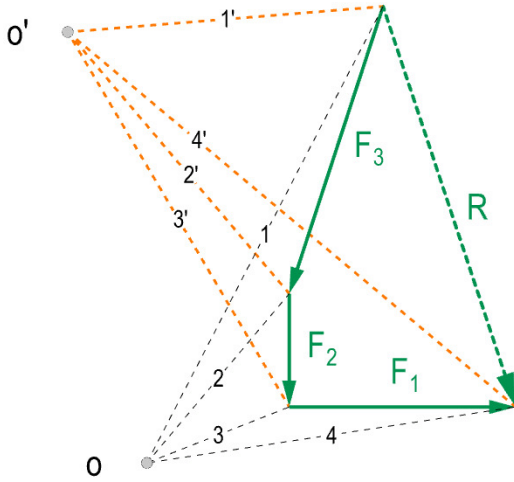
Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

*Resultant of three and more forces*

$F_1 = 30 \text{ kN}$   
 $F_2 = 15 \text{ kN}$   
 $F_3 = 40 \text{ kN}$

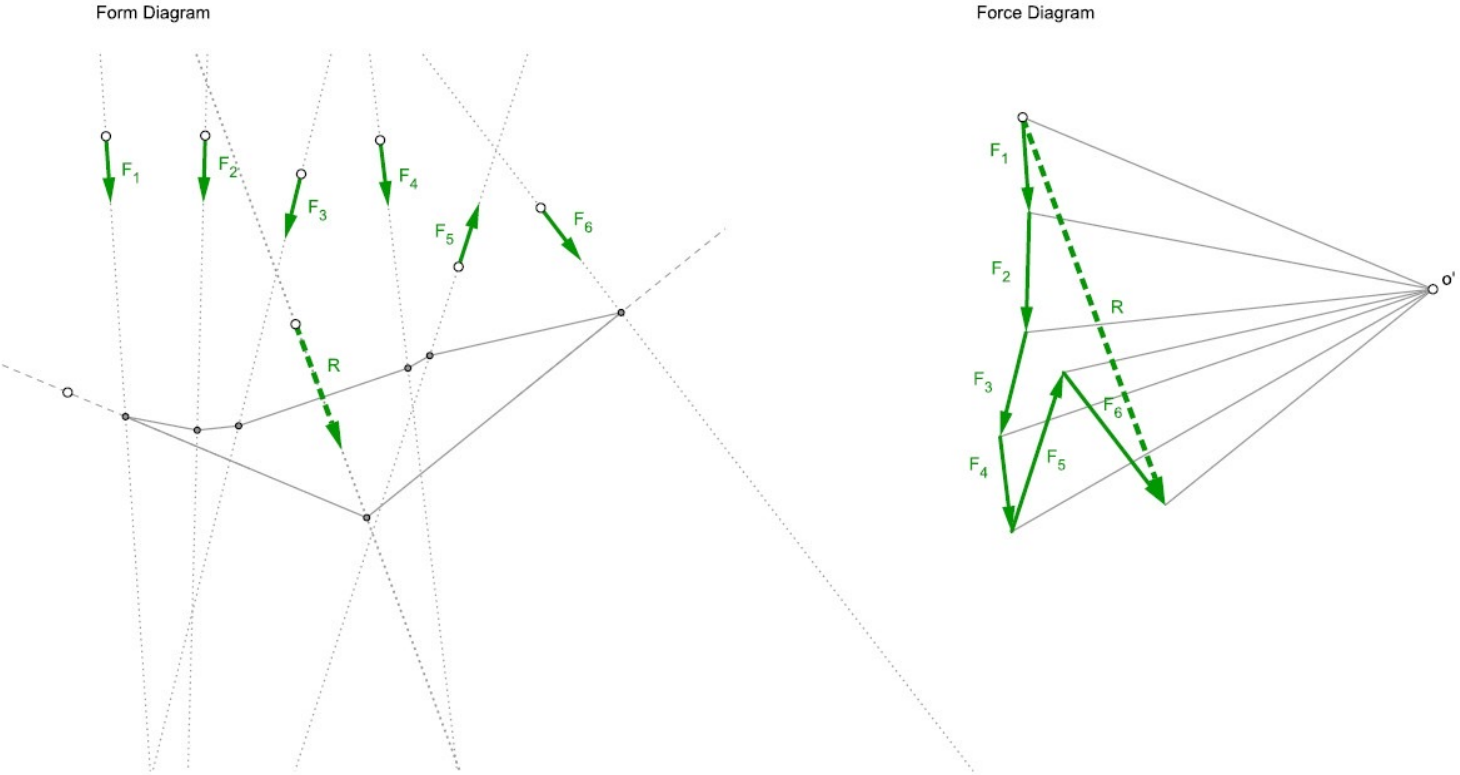


Lageplan 1:100  
*Form diagram 1:100*



Kräfteplan 1 cm  $\cong$  1 kN  
*Force diagram 1 cm  $\cong$  1 kN*

eQ: Resultierende von drei und mehreren Kräften



# Gleichgewicht und grafische Statik

## *Equilibrium and graphic statics*

Grafische Statik

*Graphic Statics*

Kräfte

*Forces*

Gleichgewicht von zwei Kräften

*Equilibrium of two forces*

Resultierende von zwei Kräften

*Resultants of two forces*

Resultierende von drei und mehreren Kräften

*Resultants of three or more forces*

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Gleichgewicht von drei und mehreren Kräften

*Equilibrium of three or more forces*

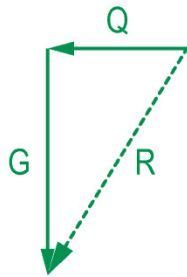
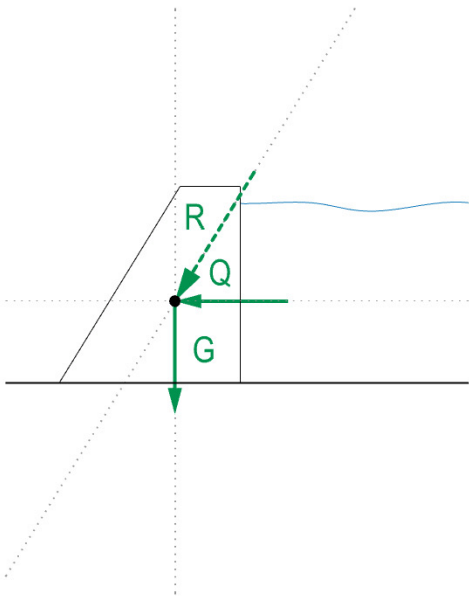
Innere Kräfte

*Internal forces*

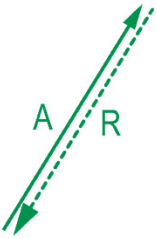
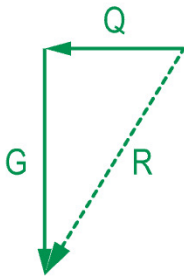
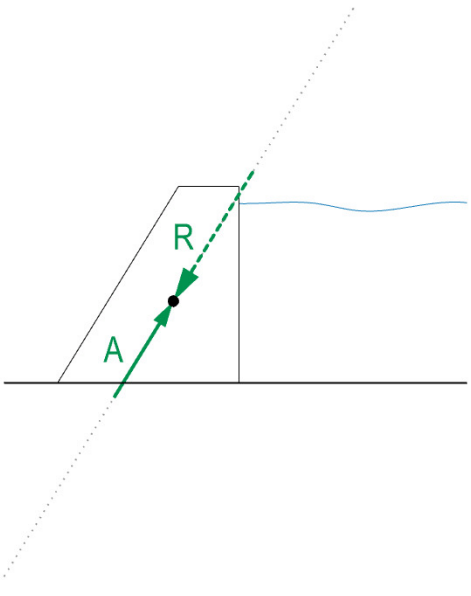
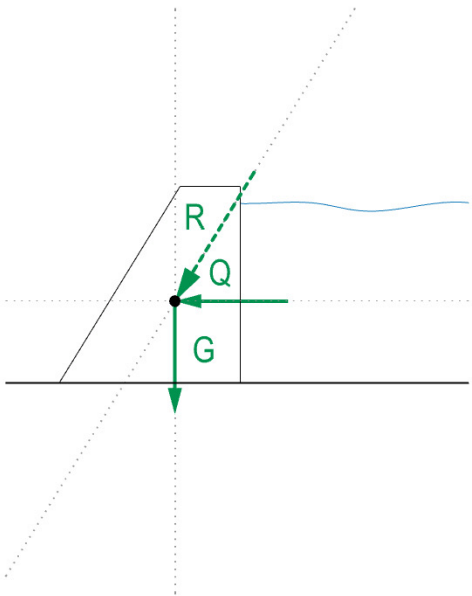




Grande Dixence Damm, Kanton Wallis, Schweiz

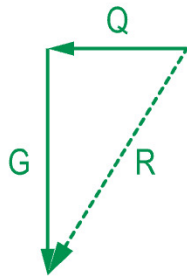
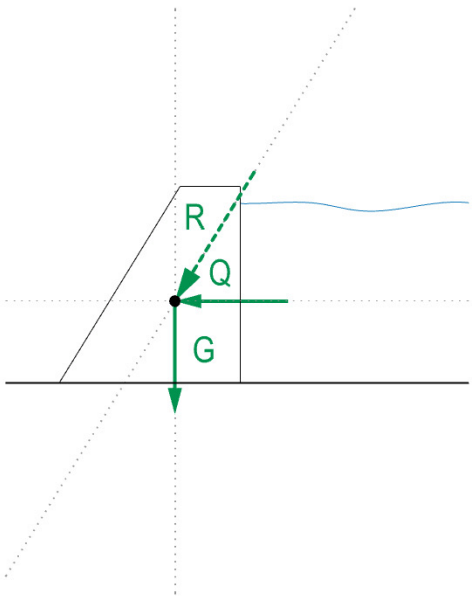


Resultierende  
*Resultant*

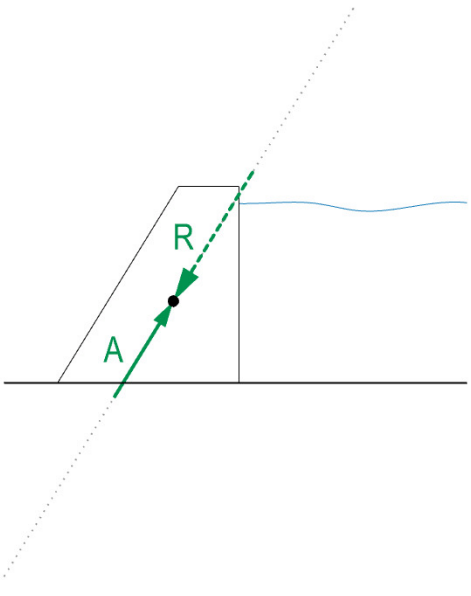


Resultierende  
*Resultant*

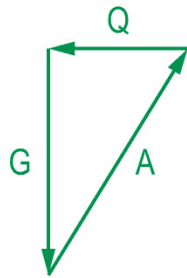
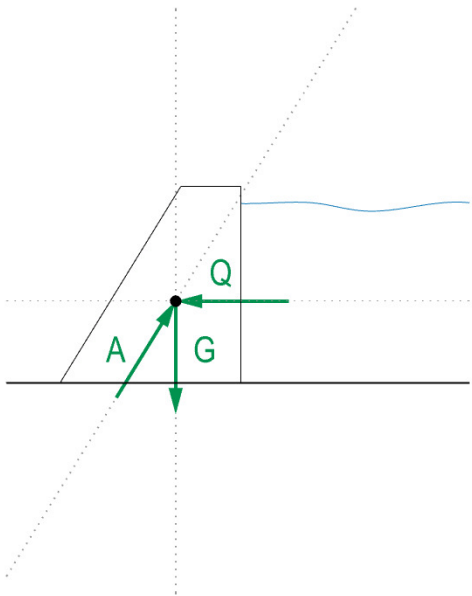
Gleichgewicht  
*Equilibrium*



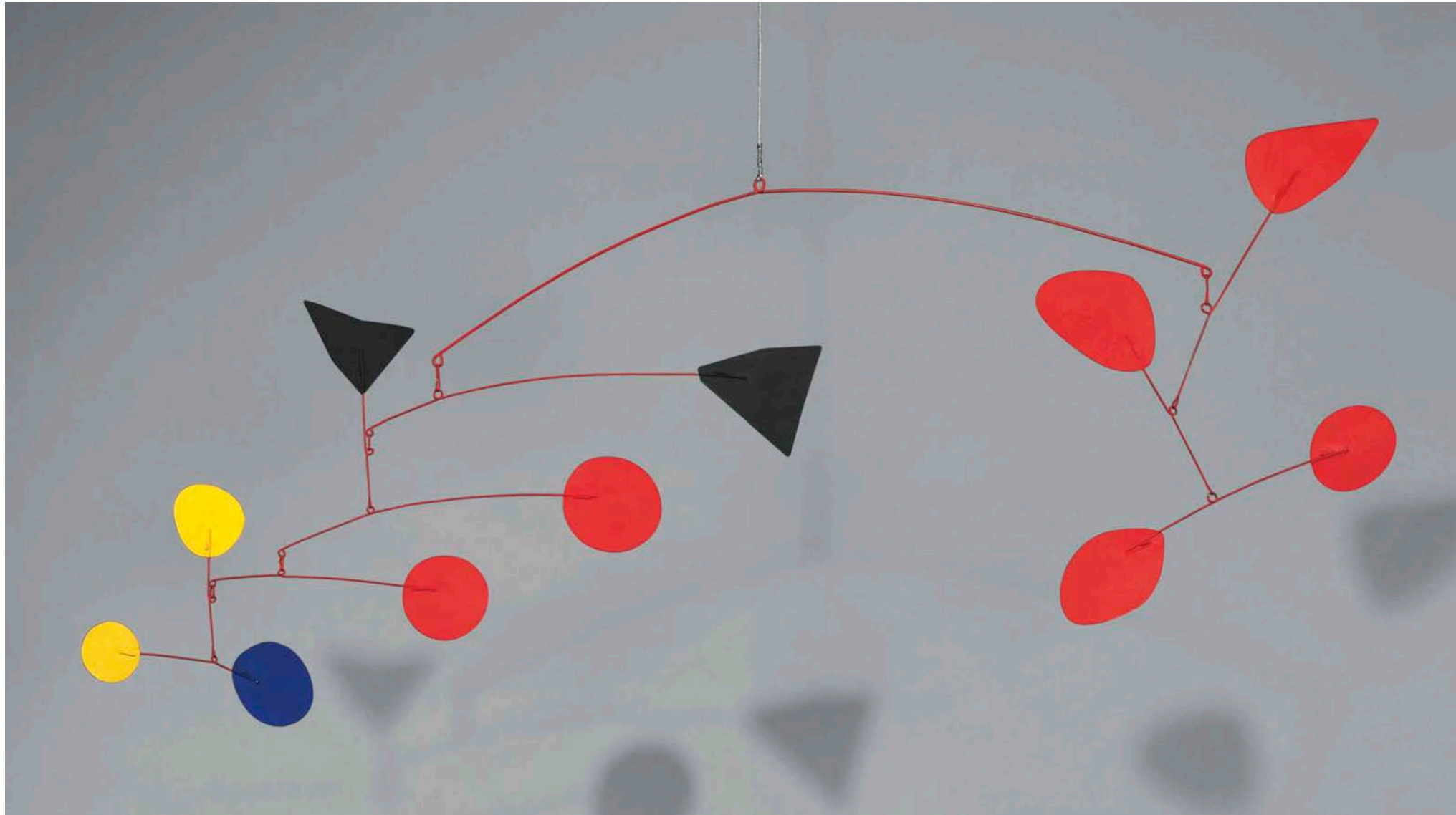
Resultierende  
*Resultant*



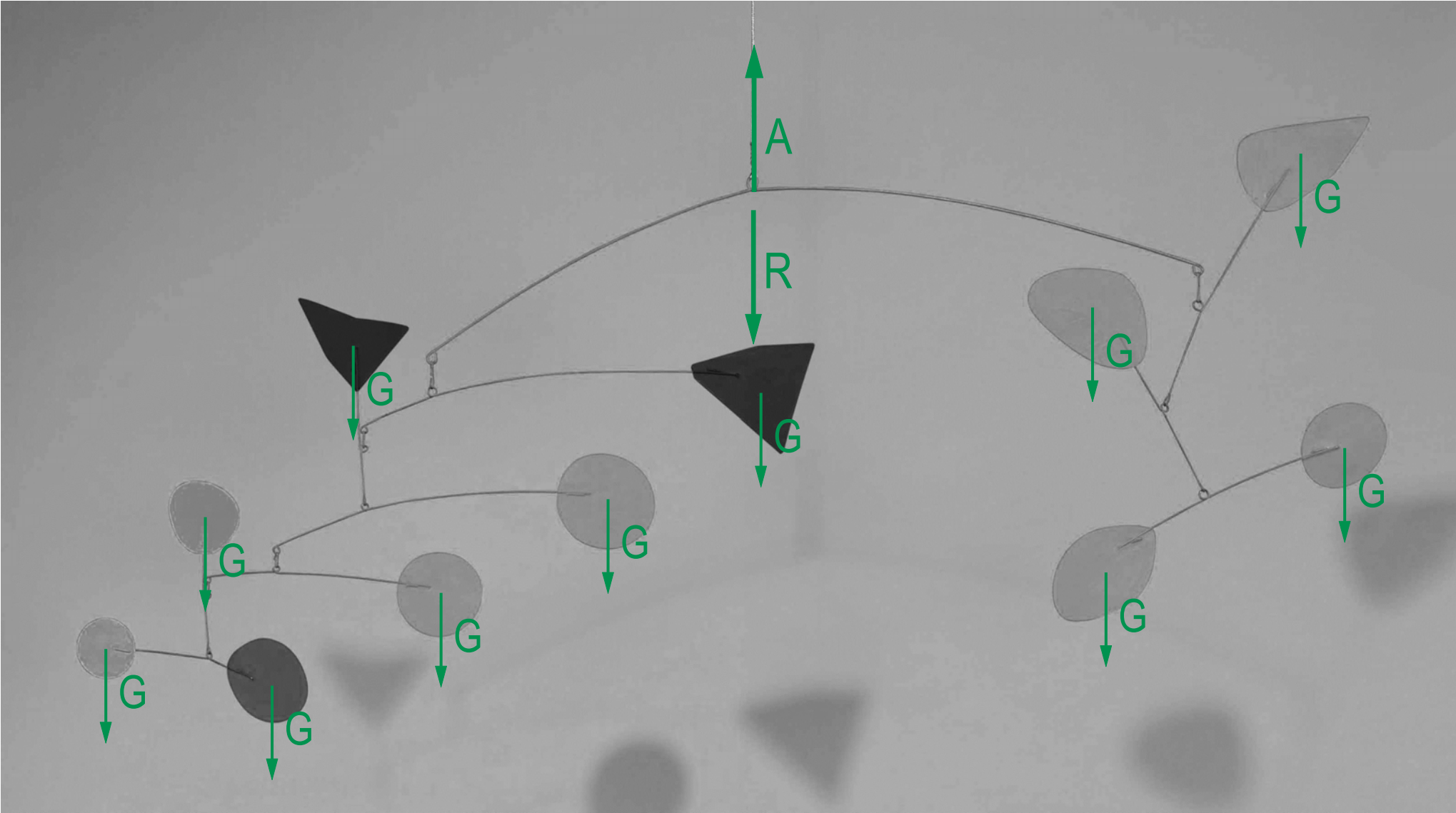
Gleichgewicht  
*Equilibrium*



Gleichgewicht direkt  
*Equilibrium directly*

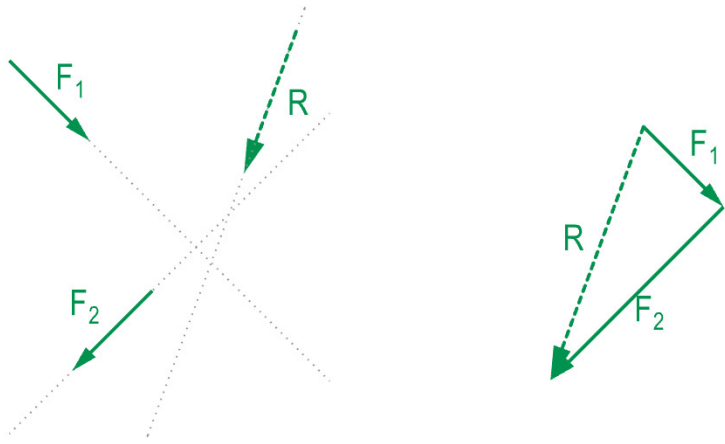


Skulptur von Alexander Calder

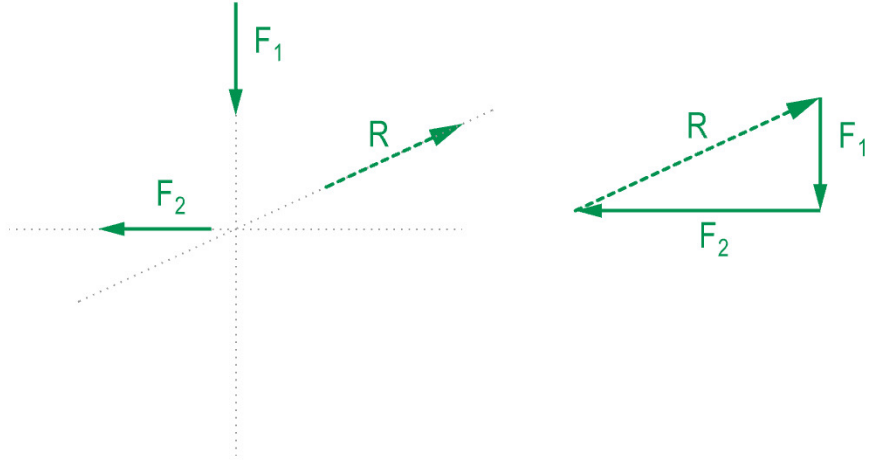


Skulptur von Alexander Calder

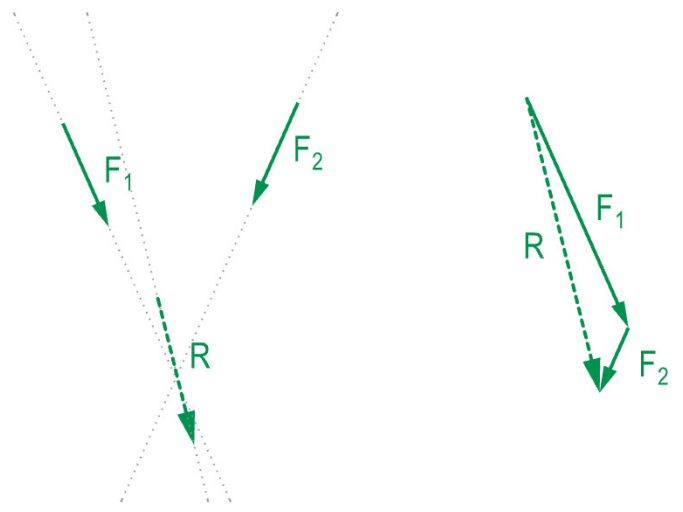
a)



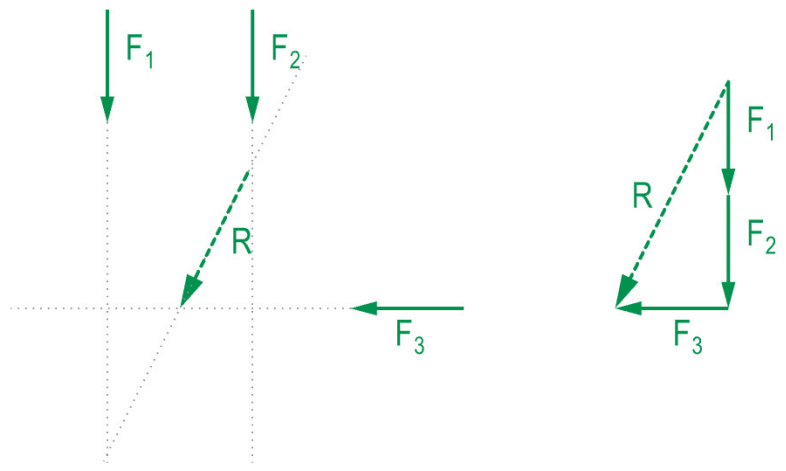
b)



c)



d)



Quiz

# Gleichgewicht und grafische Statik

## *Equilibrium and graphic statics*

Grafische Statik

*Graphic Statics*

Kräfte

*Forces*

Gleichgewicht von zwei Kräften

*Equilibrium of two forces*

Resultierende von zwei Kräften

*Resultants of two forces*

Resultierende von drei und mehreren Kräften

*Resultants of three or more forces*

Gleichgewicht von drei und mehreren Kräften

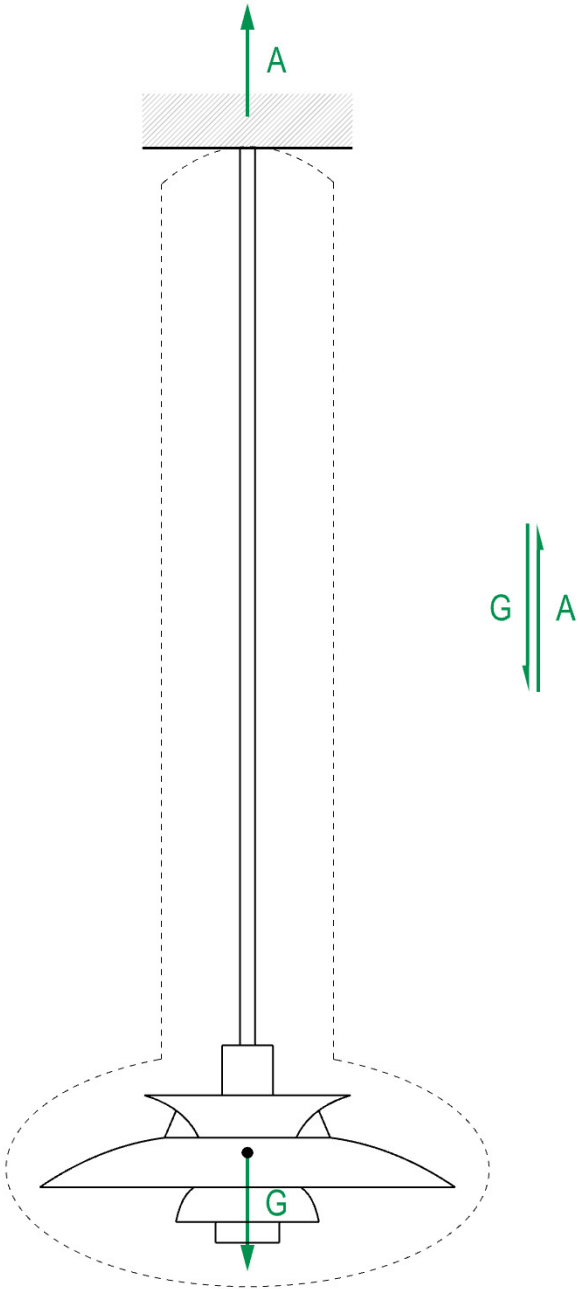
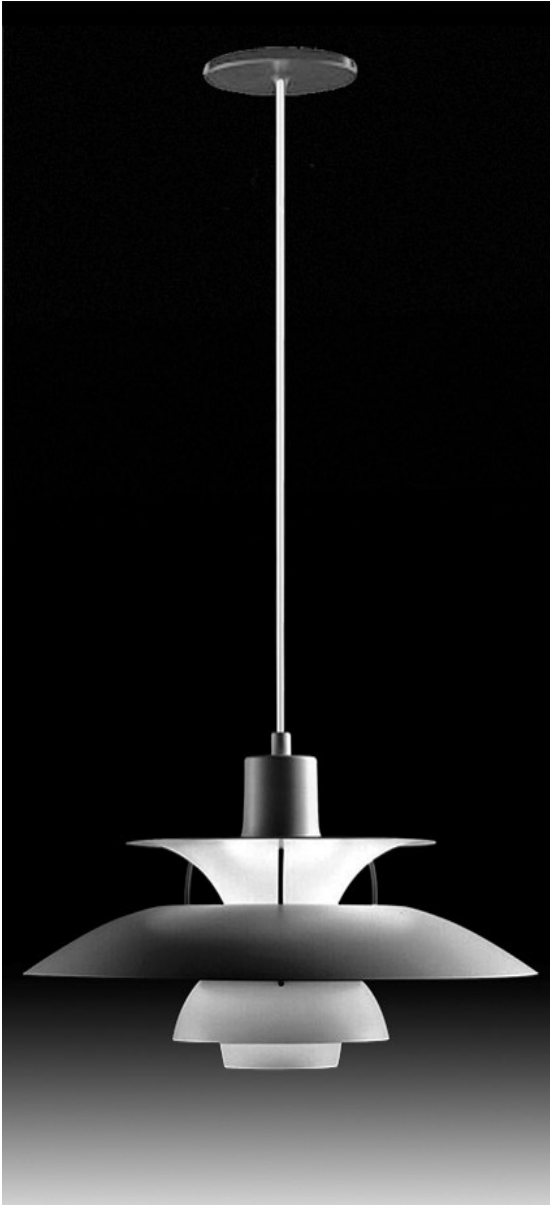
*Equilibrium of three or more forces*

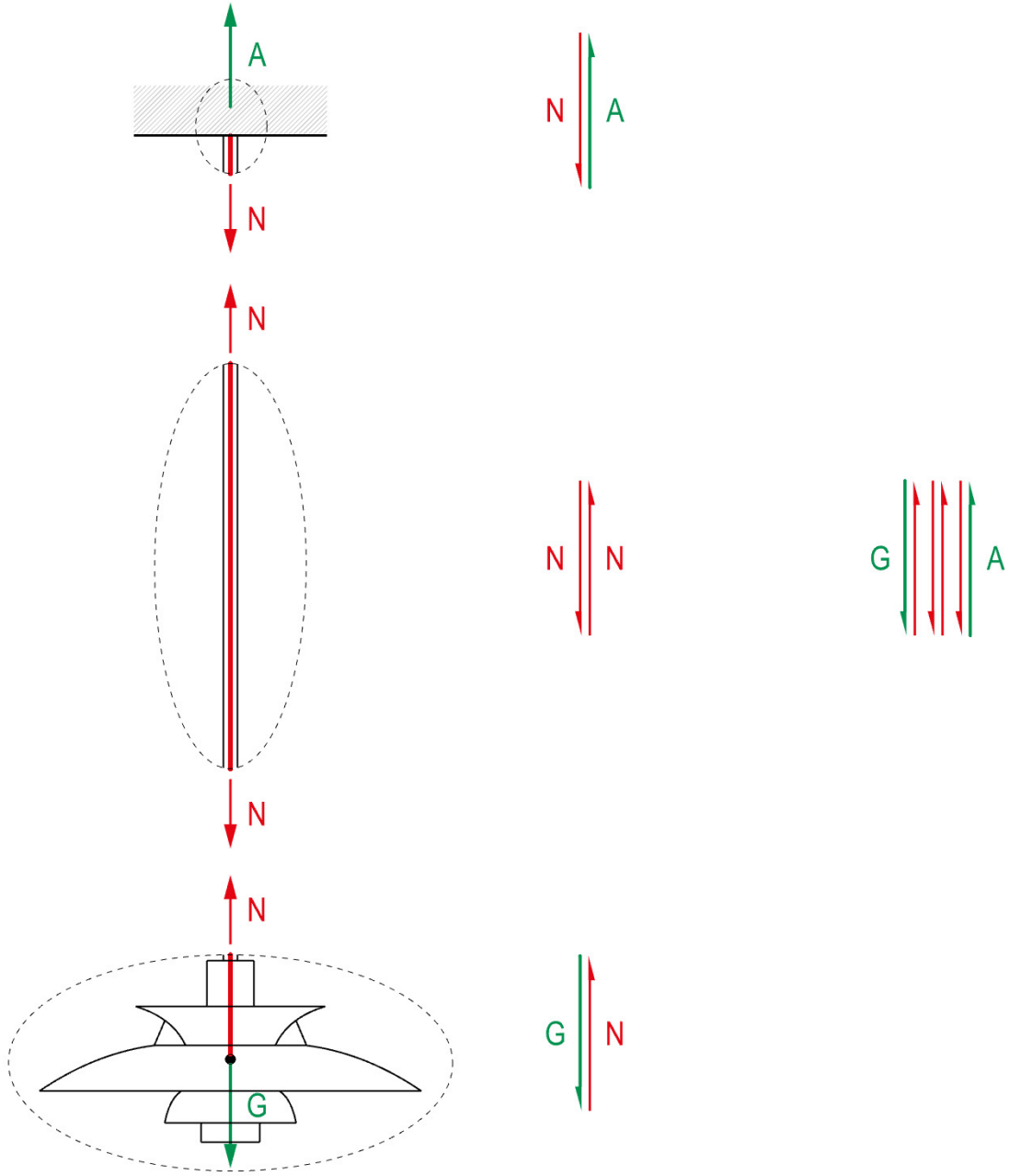
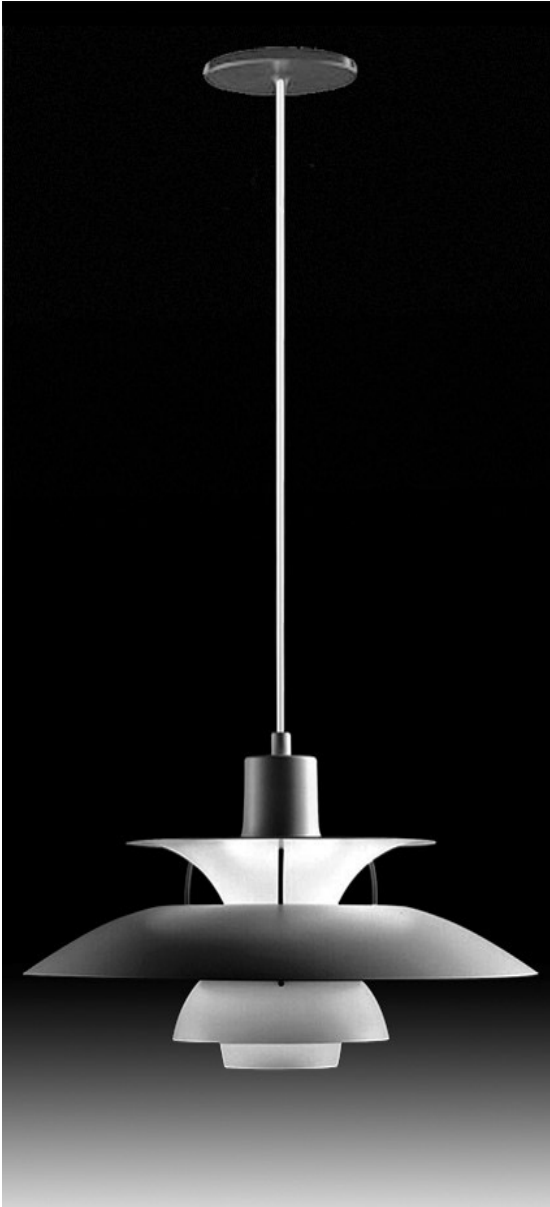
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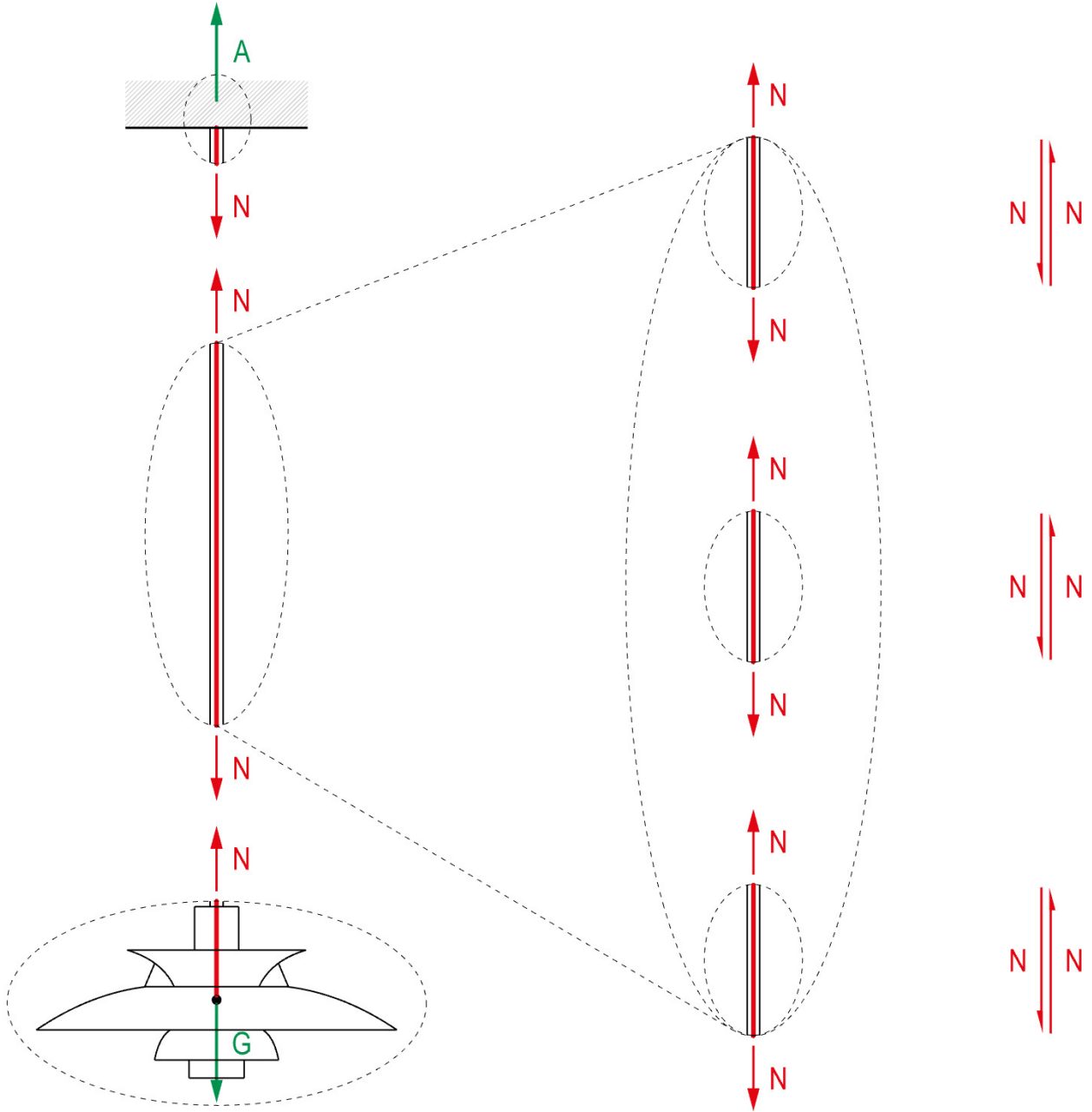
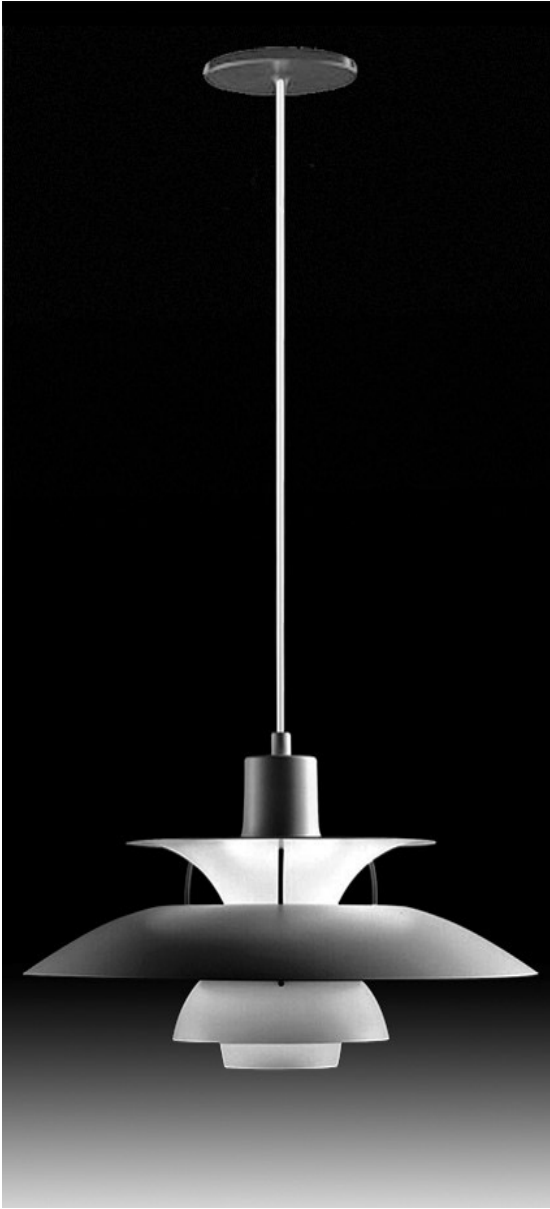
Innere Kräfte

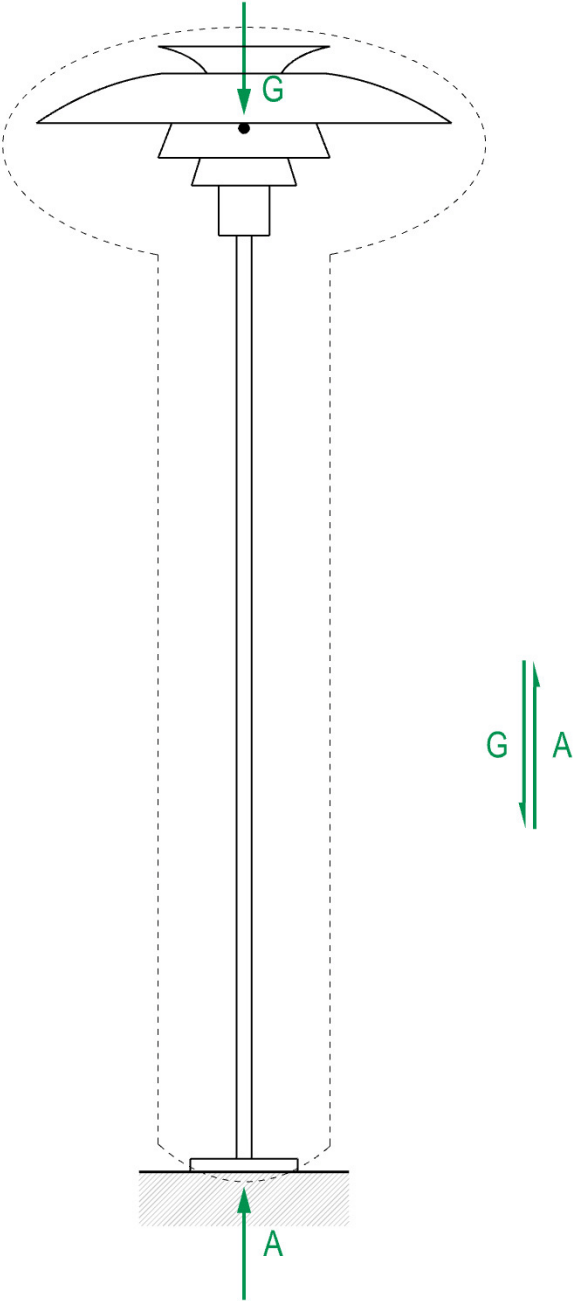
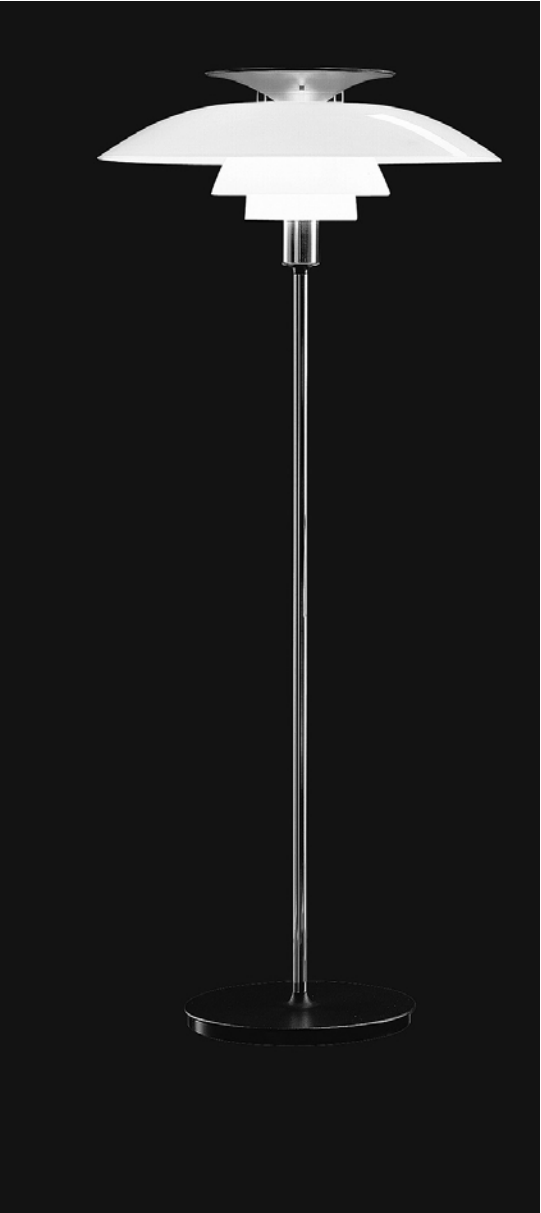
*Internal forces*

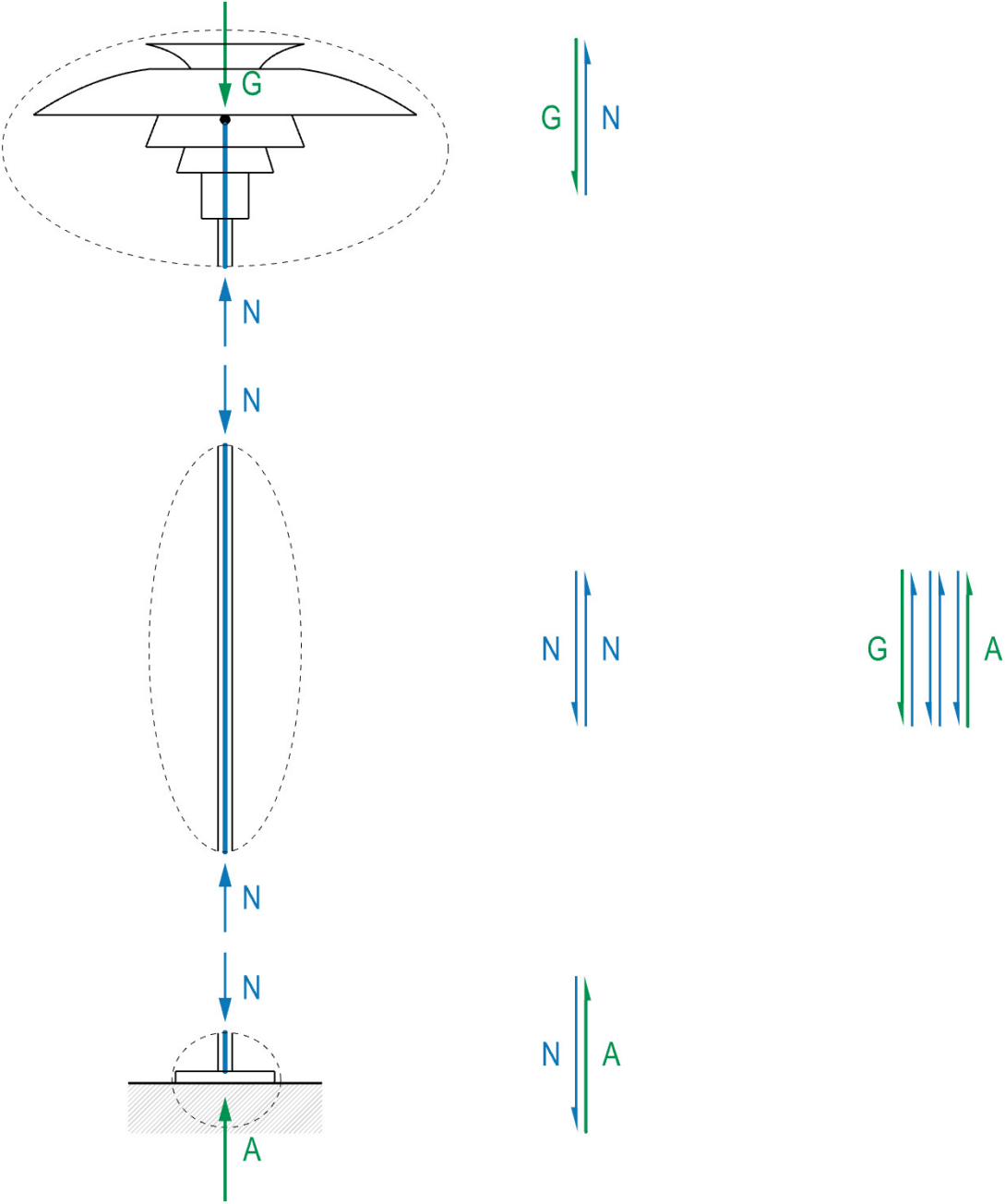
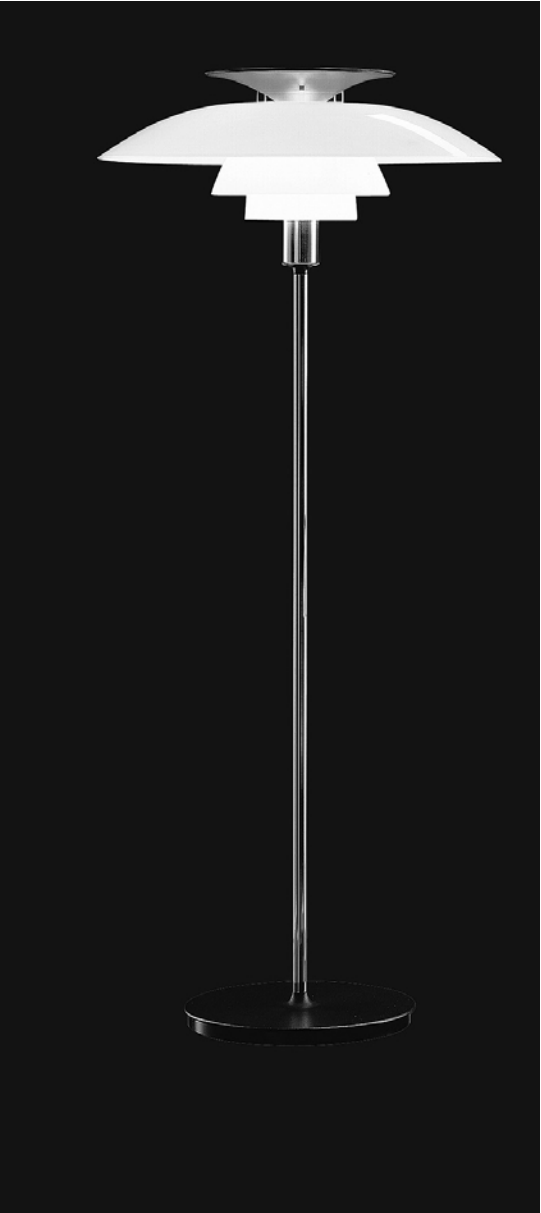


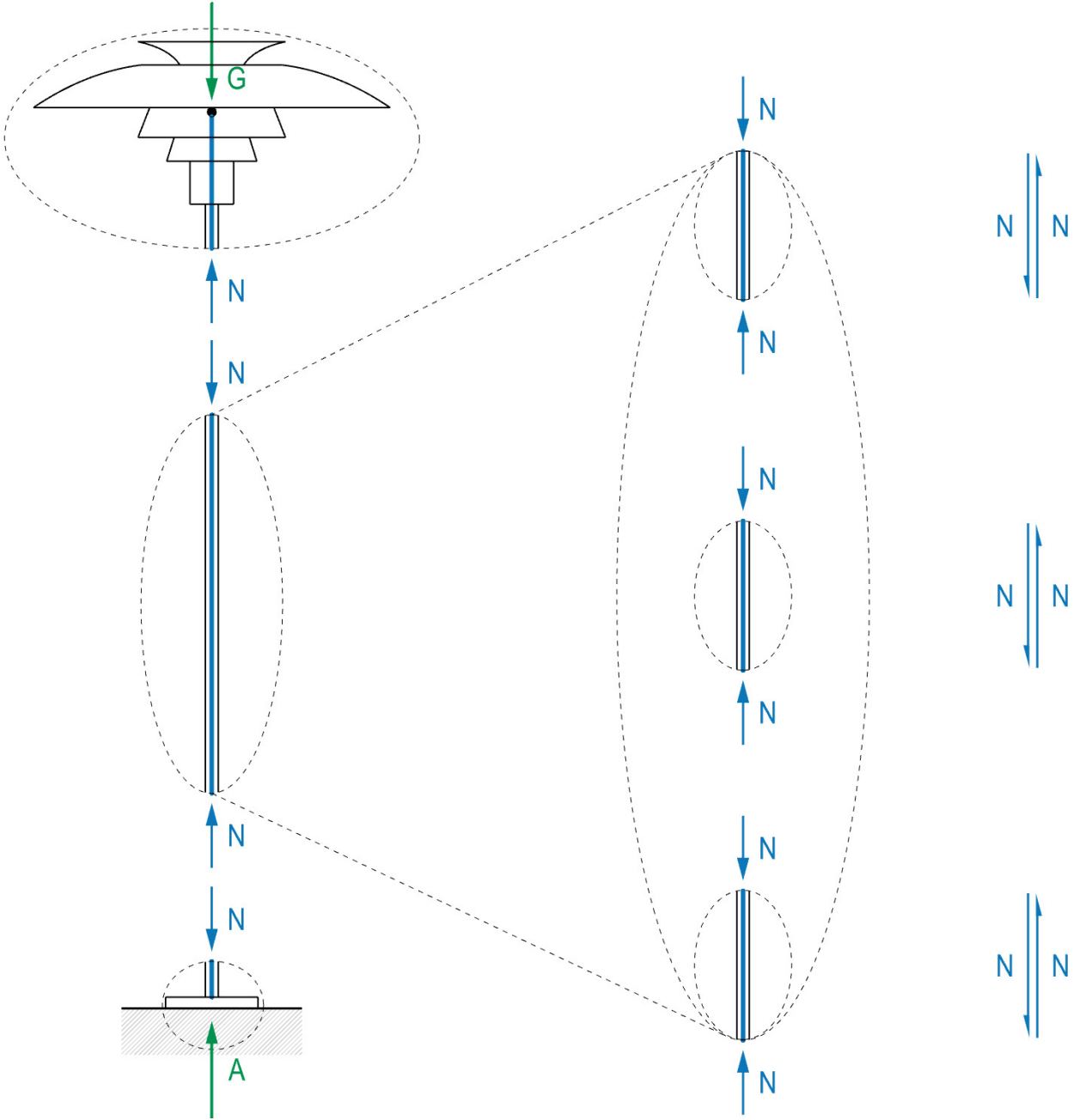
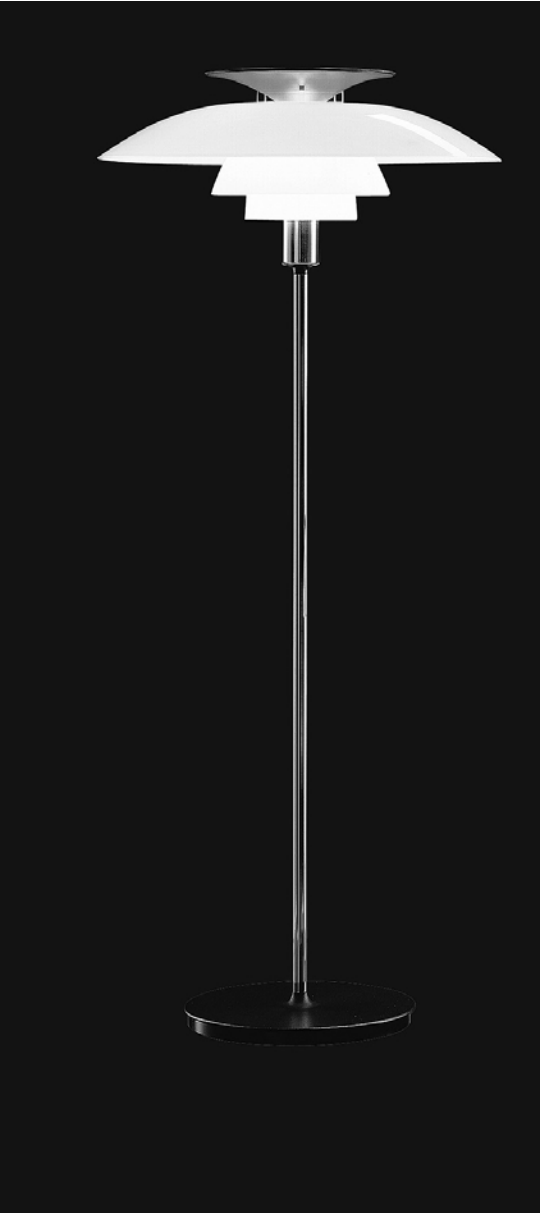


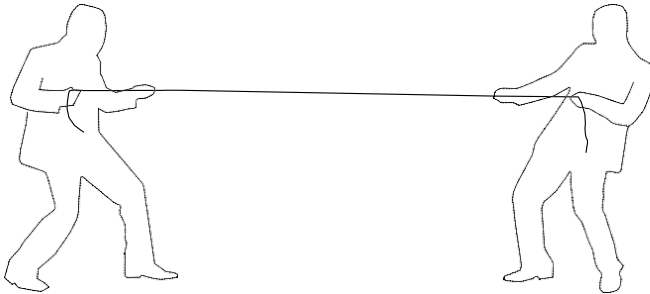


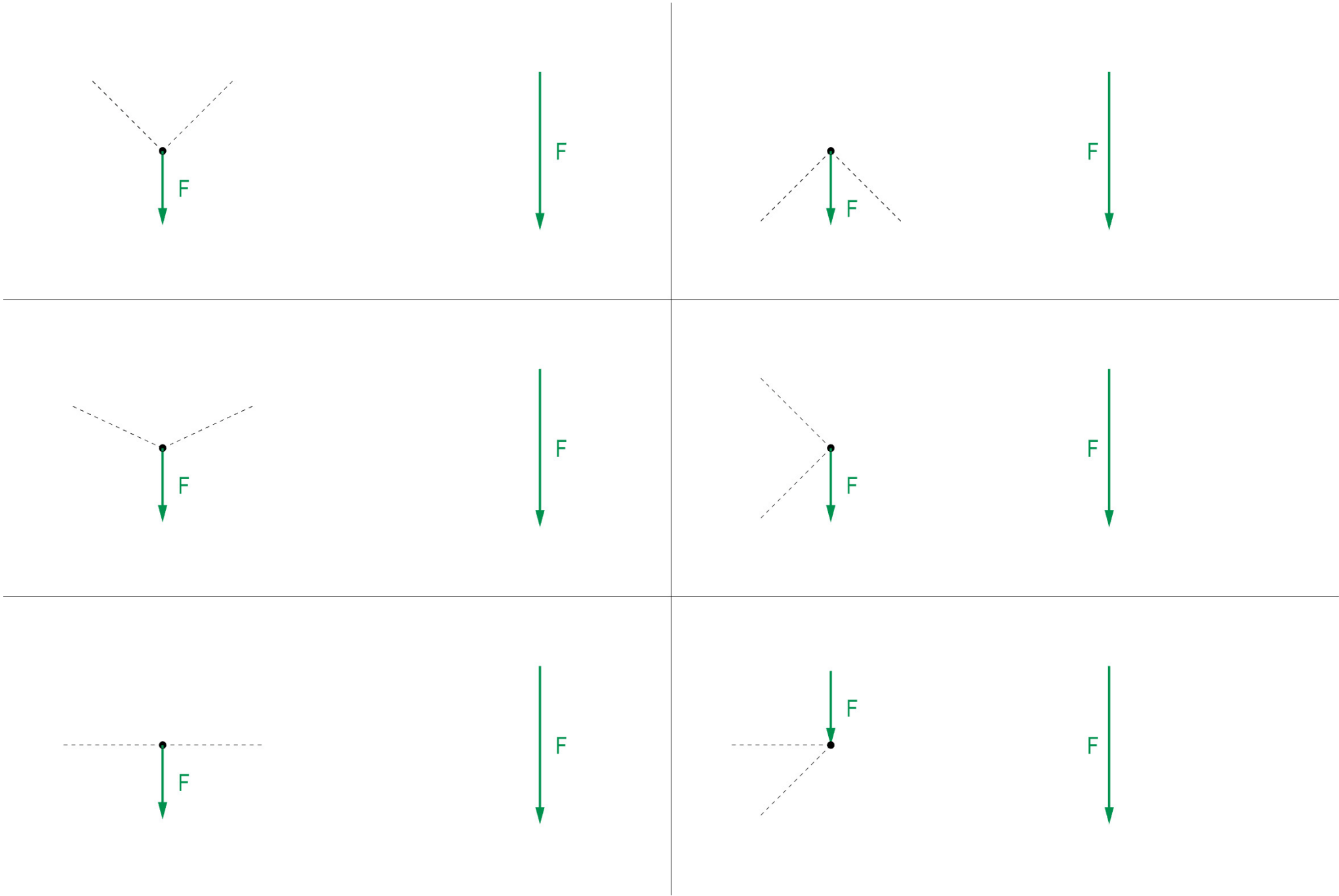




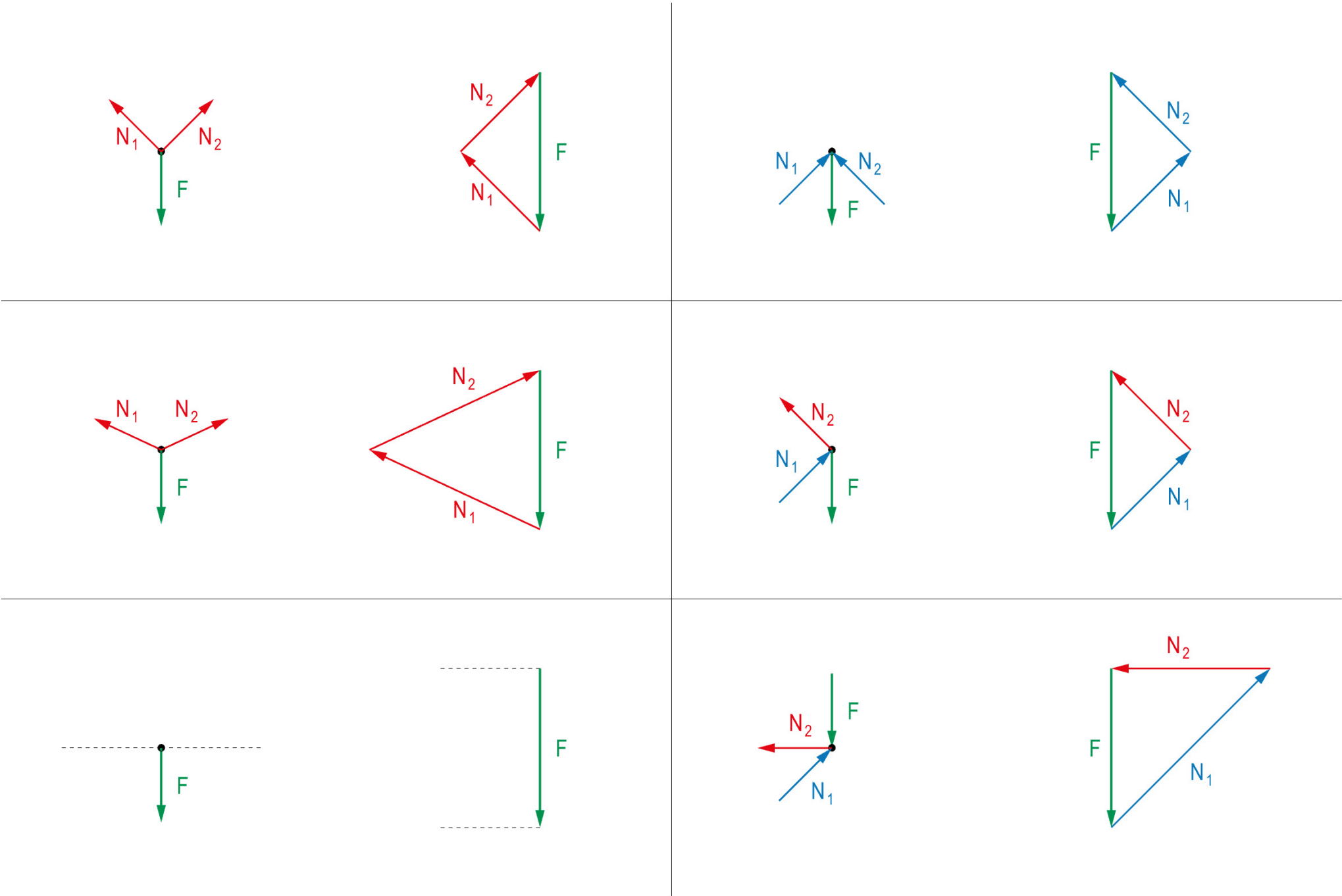


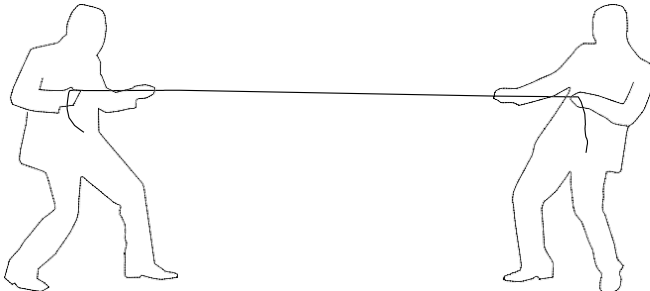






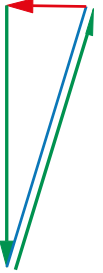
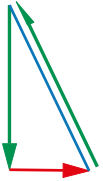
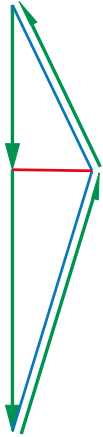
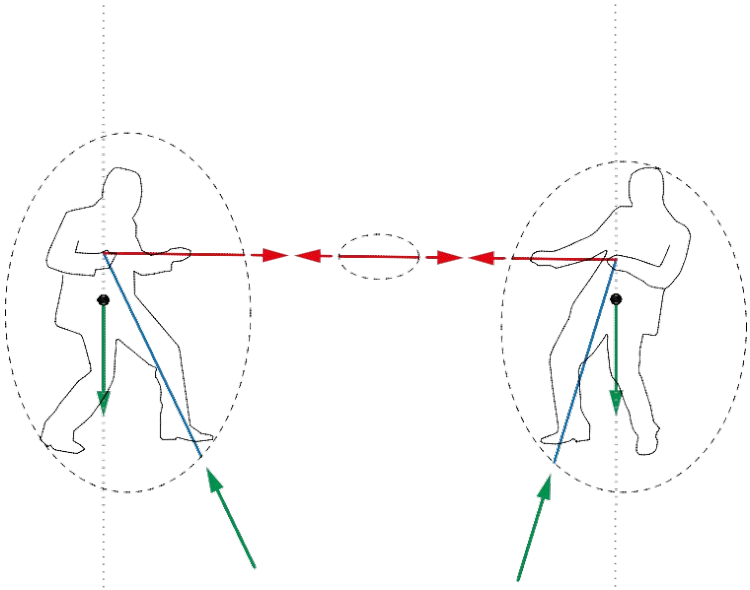






Lageplan  
*Form diagram*

Kräfteplan  
*Force diagram*



Lageplan  
*Form diagram*

Kräfteplan  
*Force diagram*



Tauzieh-Team aus Engelberg