SEM0104 - Aula 2

Graus de Liberdade e Cadeias Cinemáticas

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USP - EESC - SEM

LabRoM

Sumário da Aula

- **Introdução**
- Graus de Liberdade
- Cadeias Cinemáticas
- Exercícios Recomendados
- Bibliografia Recomendada

Introdução

- O que são mecanismos?

- O que são Máquinas?

Sumário da Aula

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- **Graus de Liberdade**
- Cadeias Cinemáticas
- Exercícios Recomendados
- Bibliografia Recomendada

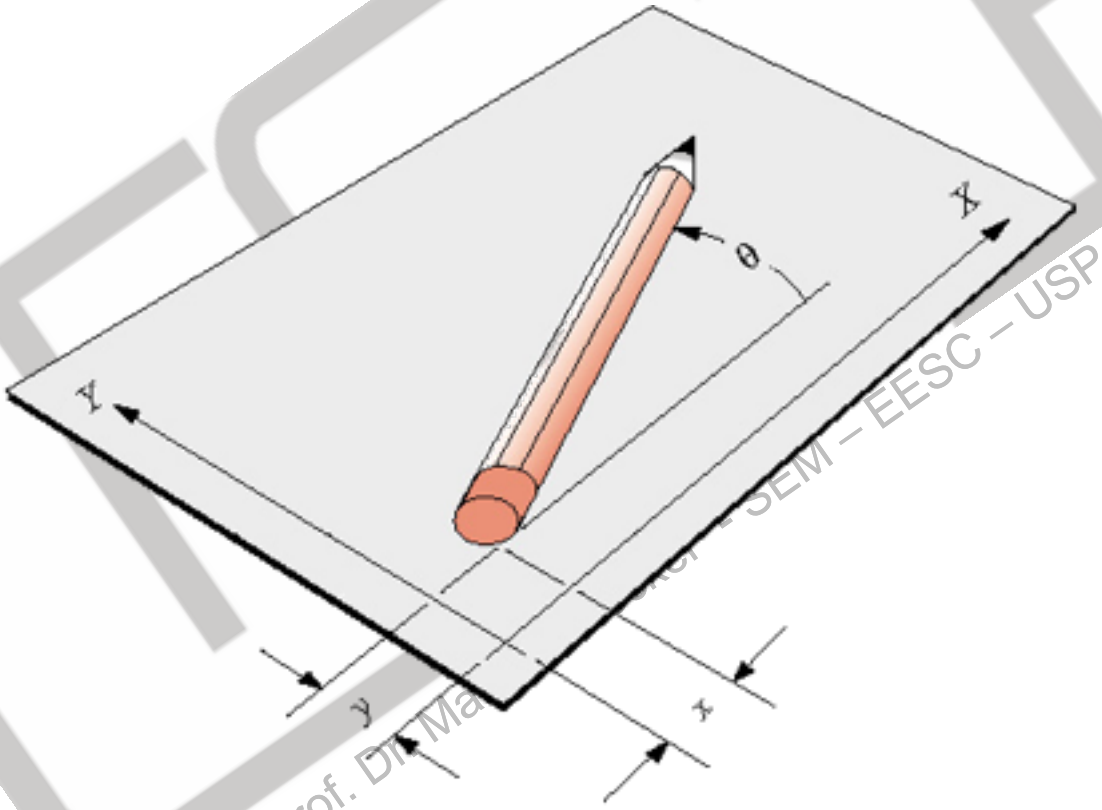
Graus de Liberdade

- GDL ou DOF (*Degree Of Freedom*)
- O que significa Grau de Liberdade?

Definição: é o número de parâmetros independentes que são necessários para se definir a posição de um corpo no espaço em qualquer instante.

Graus de Liberdade

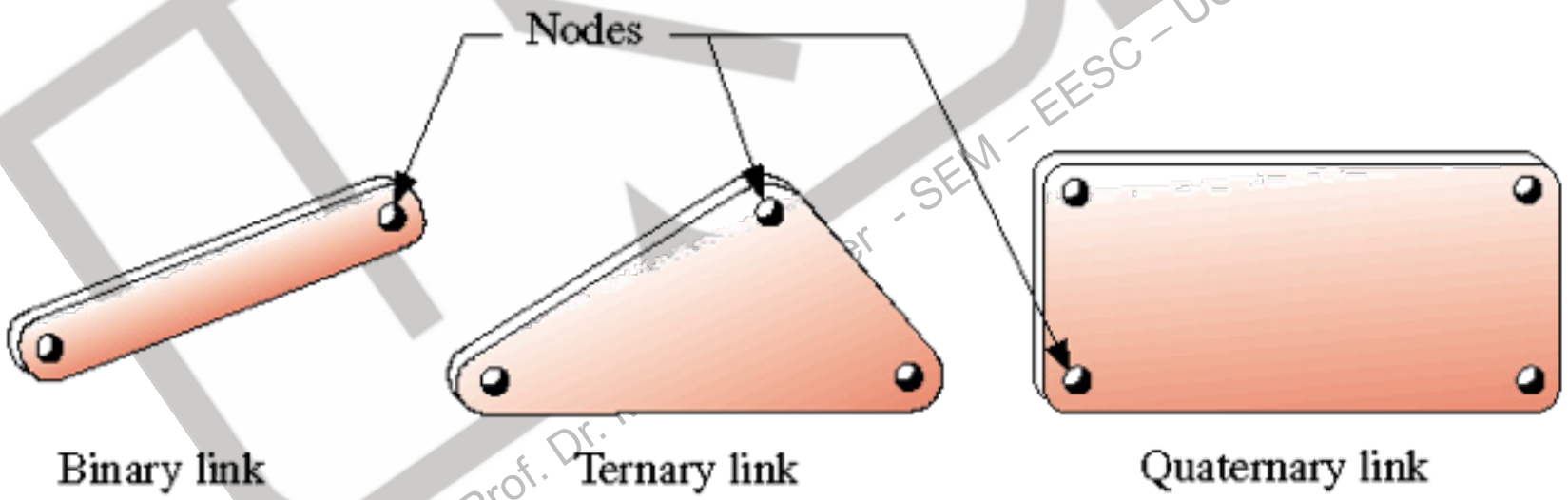
- No Plano: 3 GDL



Graus de Liberdade

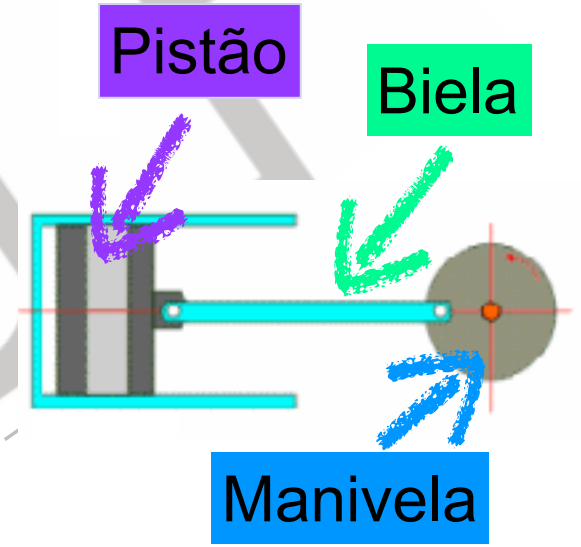
- Corpo Rígido ou Link

Definição: Corpo que não sofre deformações em nenhuma de suas direções e une 2 ou mais juntas



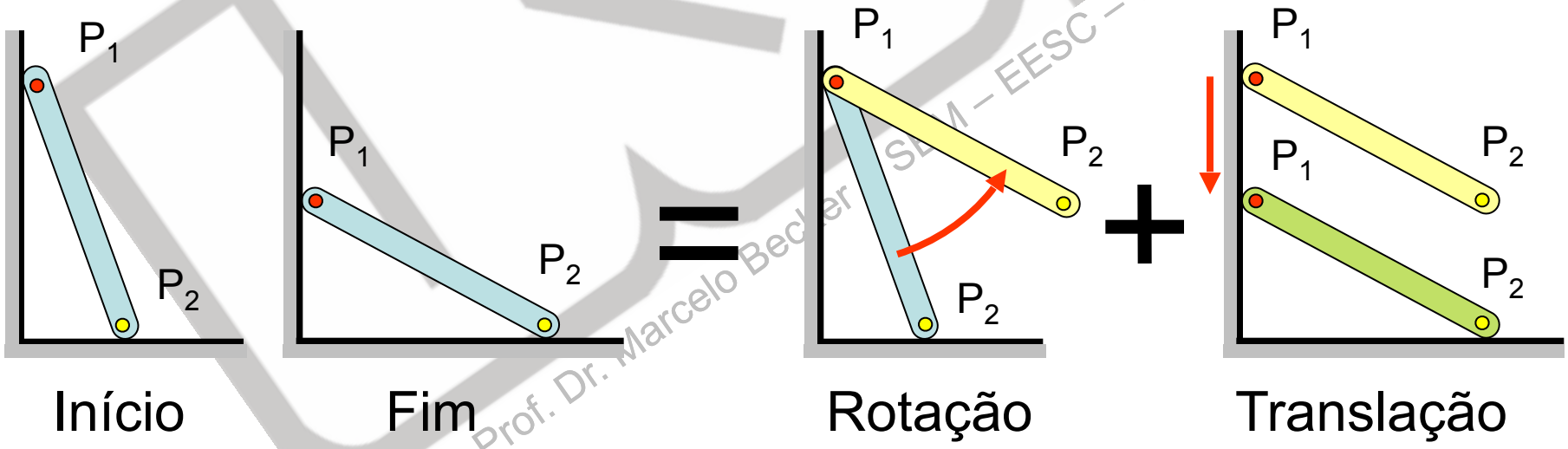
Graus de Liberdade

- Tipos de Movimento
  - Rotação Pura
  - Translação Pura
  - Movimento Complexo
    - Rotação + Translação



Graus de Liberdade

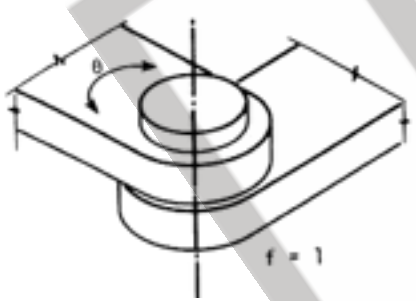
- Movimento Complexo
  - Pode ser descrito como a combinação de rotação e translação



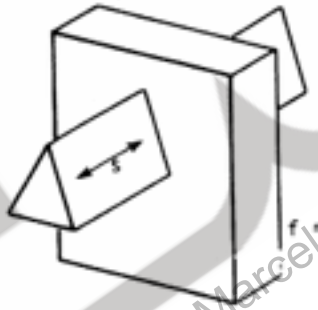
Graus de Liberdade

- Juntas *(Joints)*

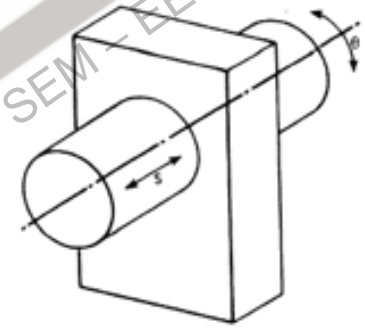
Definição: elemento que conecta 2 corpos e que permite a transmissão de força ou torque. Atuam como restrições geométricas.



Rotacional



Prismática



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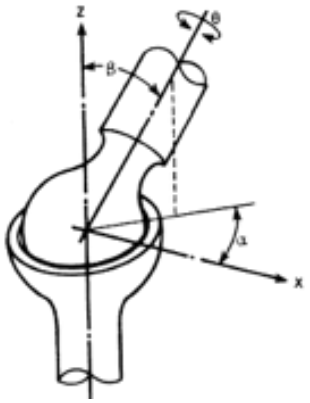
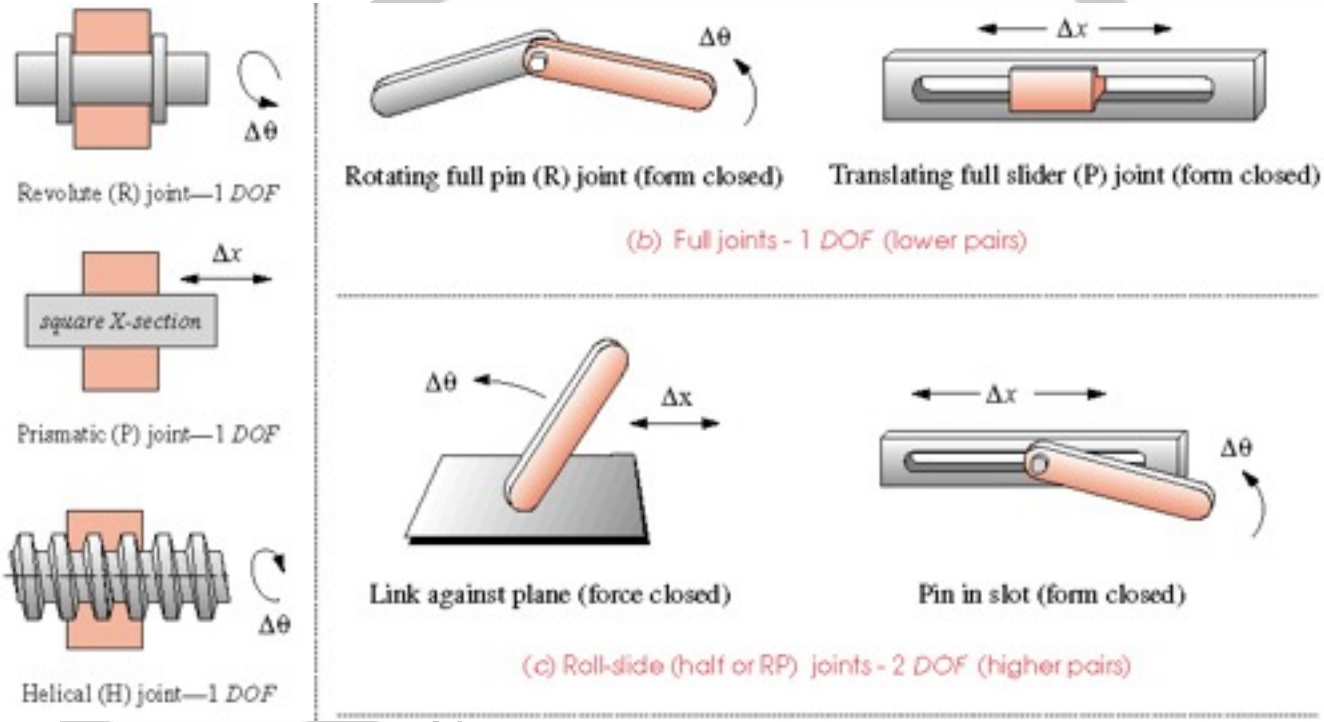


Esférica

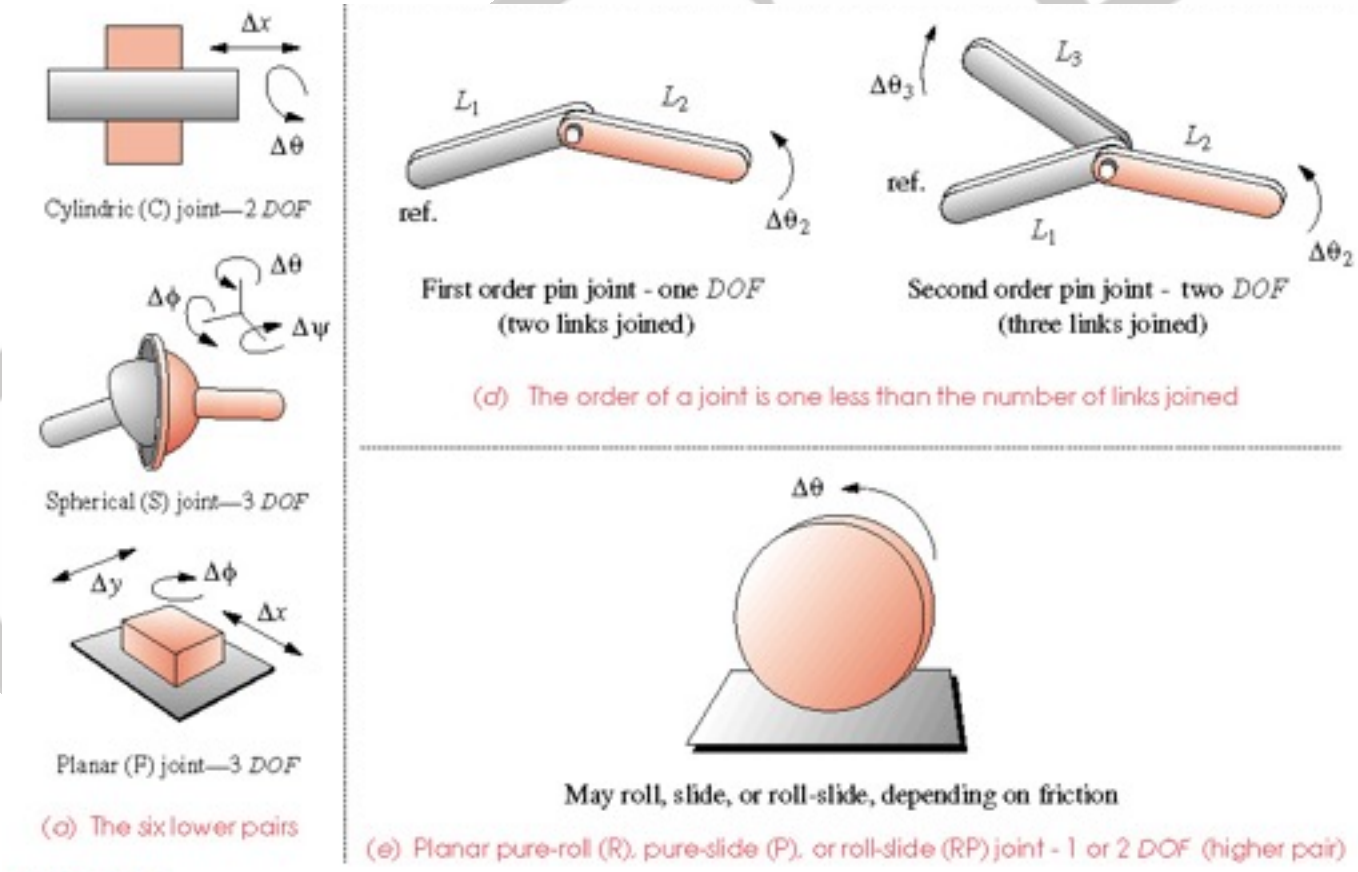
Graus de Liberdade

- Juntas *(Joints)*



Graus de Liberdade

- Juntas *(Joints)*



Graus de Liberdade
Mecanismos Planares

- Critério de Kutzbach

$$N = 3.(B-1) - 2.n_{J1} - n_{J2}$$

- Onde:

N: Número de GDLs

B: Número de Total de Corpos (incluindo o solo)

n_{J1}: Número de Juntas com 1 GDL

n_{J2}: Número de Juntas com 2 GDLs

Graus de Liberdade
Mecanismos Planares

- Critério de Kutzbach

$$N = 3.(B-1) - 2.n_{J1} - n_{J2}$$

- Se:

  N = 0 : Sistema Estático

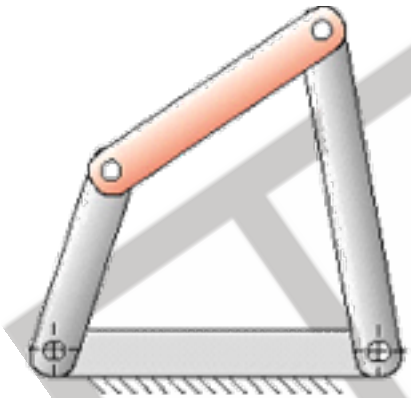
  N > 0 : Sistema com "N" graus de liberdade

  N < 0 : Sistema Hiperestático

Graus de Liberdade
Mecanismos Planares

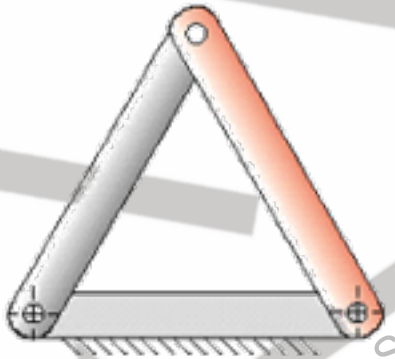
- Critério de Kutzbach

$$N = 3.(B-1) - 2.n_{J1} - n_{J2}$$



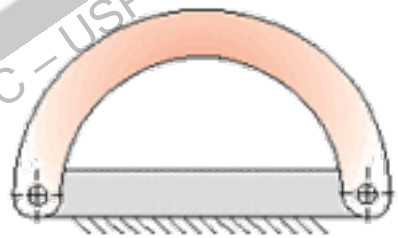
N = 1

Mecanismo



N = 0

Estrutura



N = -1

Estrutura Pré-carregada

Graus de Liberdade

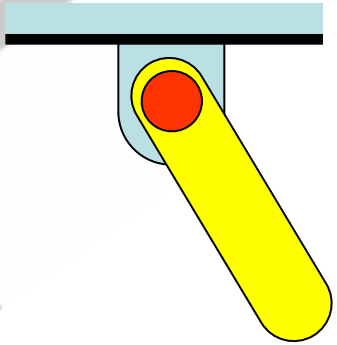
Mecanismos Planares - Exemplos

- Pêndulo Simples

$N = 3.(B-1) - 2.n_{J1} - n_{J2}$

$B = 2 \quad n_{J1} = 1 \quad n_{J2} = 0$

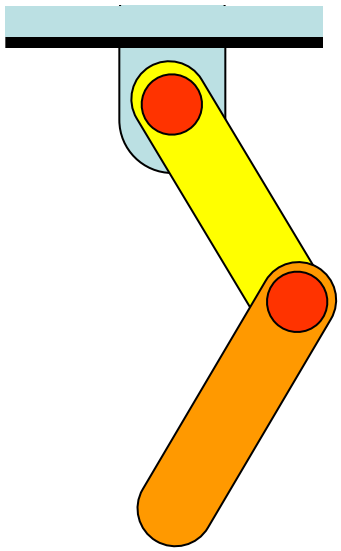
$N = 3.(2-1) - 2.(1) - (0) =$ 1 GDL



- Pêndulo Duplo

$B = 3 \quad n_{J1} = 2 \quad n_{J2} = 0$

$N = 3.(3-1) - 2.(2) - (0) =$ 2 GDL

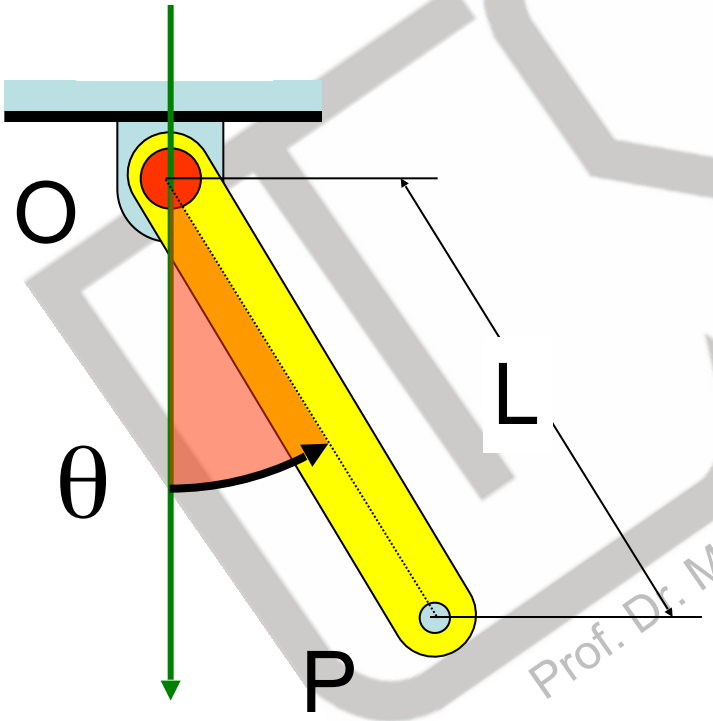


Graus de Liberdade

Mecanismos Planares – Pêndulo Simples

- Equações de Posição:

1 GDL



$$\overrightarrow{P} = L.e^{i\theta}$$

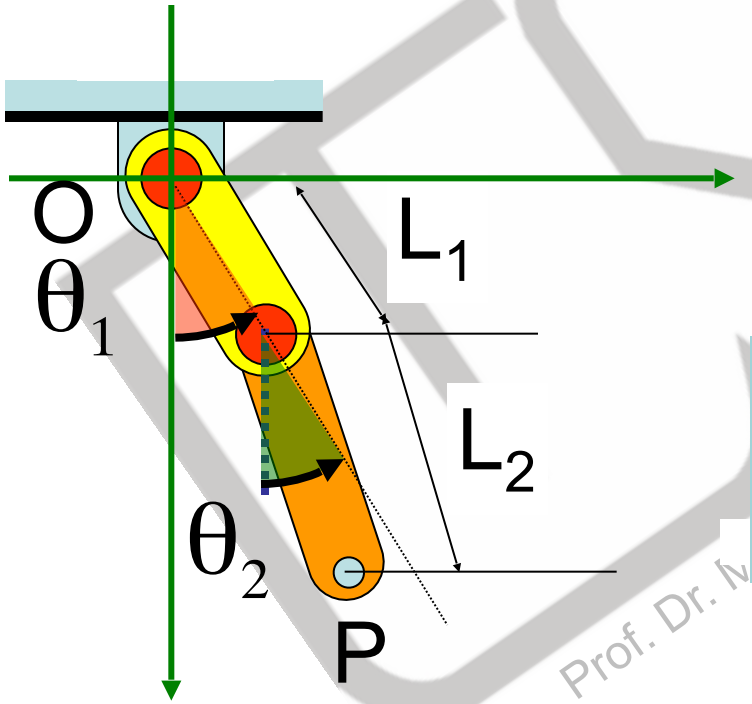
$$\overrightarrow{P} = L.(\sin\theta\,\vec{i} + \cos\theta\,\vec{j})$$

Graus de Liberdade

Mecanismos Planares – Pêndulo Duplo

- Equações de Posição:

2 GDL



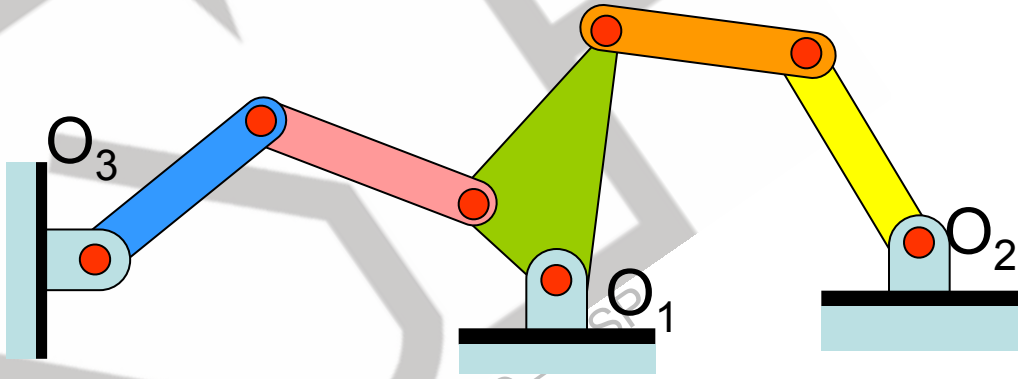
$$\overrightarrow{P} = L_1.e^{i\theta_1} + L_2.e^{i\theta_2}$$

$$\overrightarrow{P} = L_1.(\sin\theta_1\,\vec{i} + \cos\theta_1\,\vec{j}) + L_2.(\sin\theta_2\,\vec{i} + \cos\theta_2\,\vec{j})$$

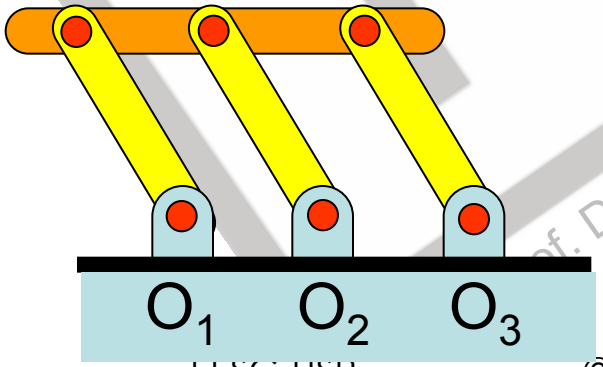
Graus de Liberdade

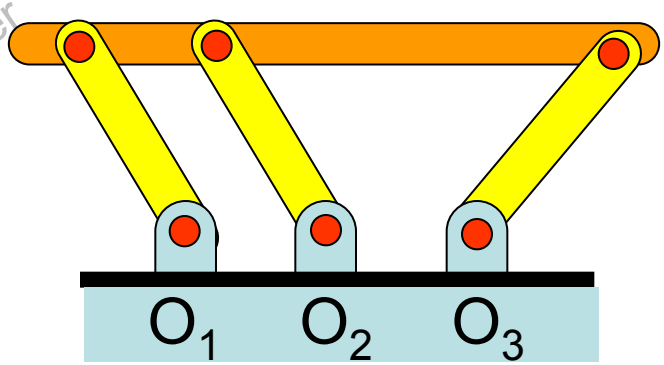
Mecanismos Planares – Observações

(1) Contagem do solo



(2) Existem exceções ao Critério de Kutzbach

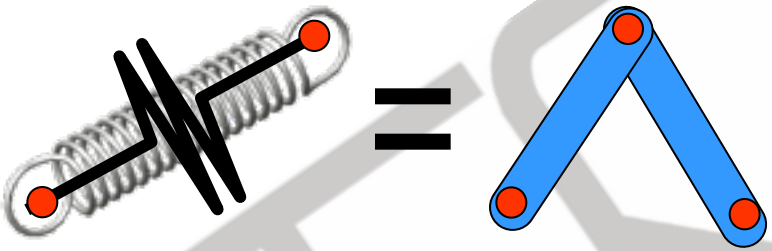


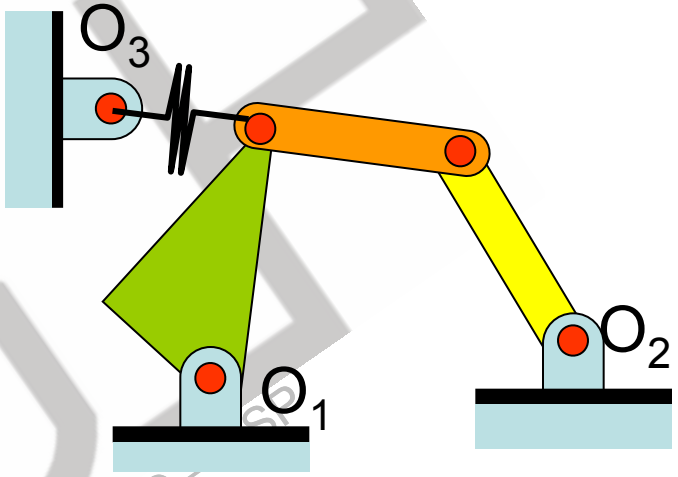


Graus de Liberdade

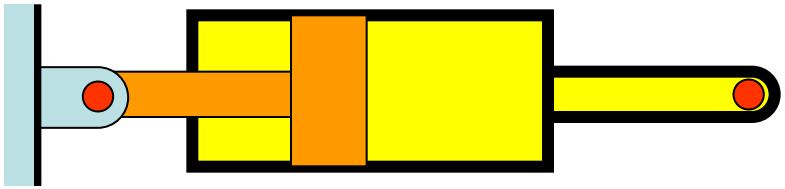
Mecanismos Planares – Observações

(3) Molas





(4) Sistemas Hidráulicos e Pneumáticos



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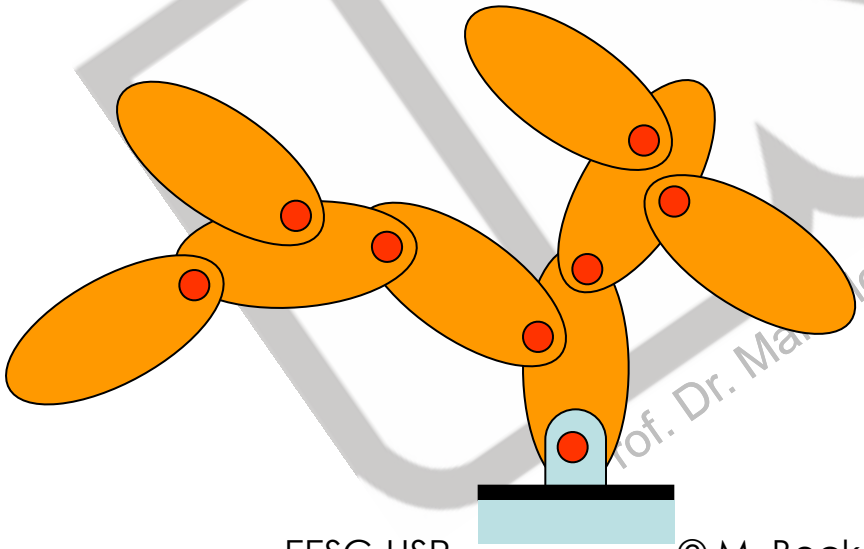
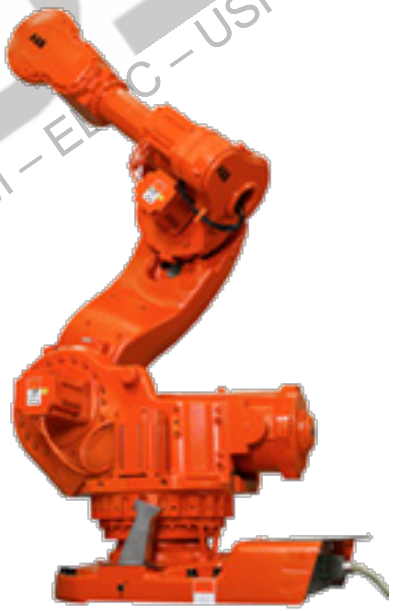
Cadeias Cinemáticas
Topologias

- Cadeias Abertas
  - A trajetória entre 2 corpos é única
  - Excluindo o solo, o número de corpos é igual ao número de juntas

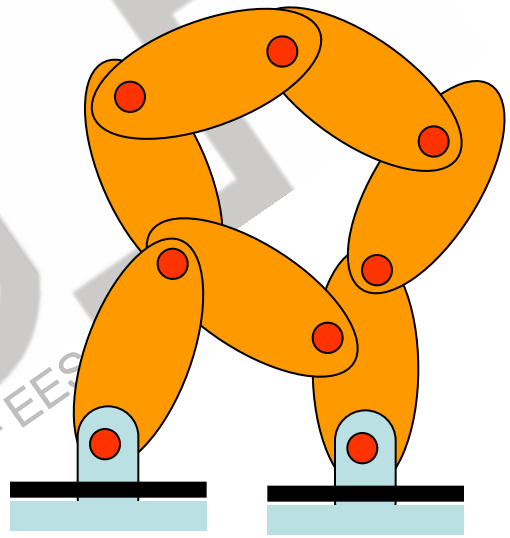




Cadeias Cinemáticas
Topologias

- Cadeias Fechadas
  - Loops

$$n_L = n_J - n_B$$



- Onde:

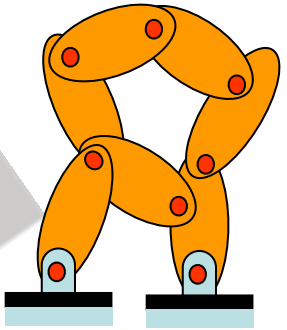
  n_L: Número de Loops

  n_J: Número de Juntas

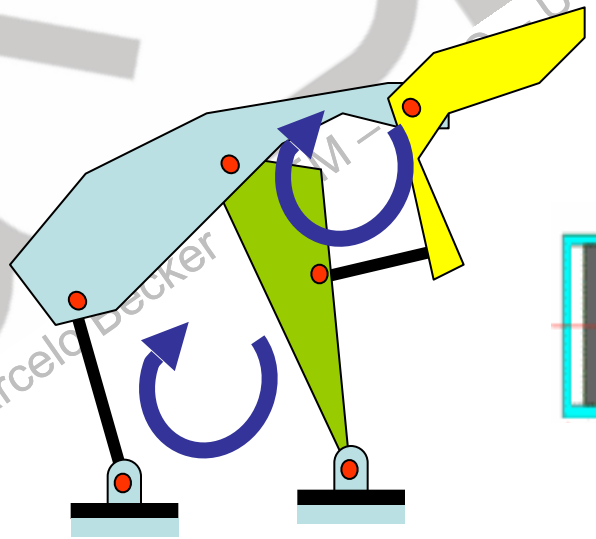
  n_B: Número de Corpos (excluindo o solo)

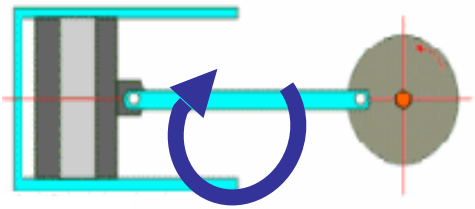
Cadeias Cinemáticas
Topologias

- Cadeias Fechadas - Exemplos



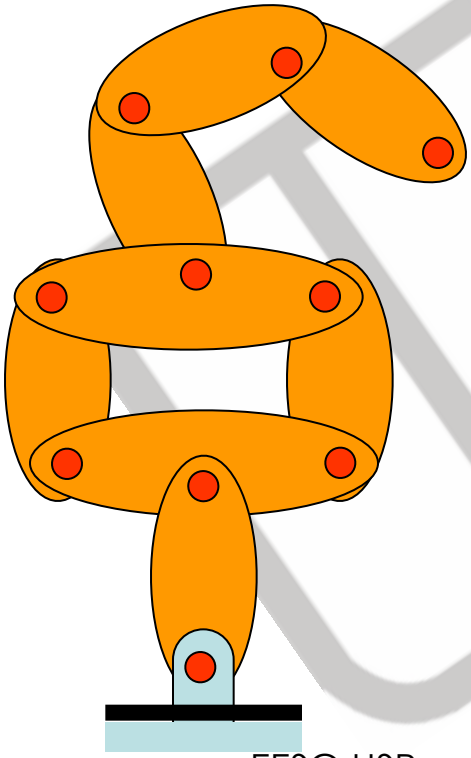
$$n_L = n_J - n_B$$

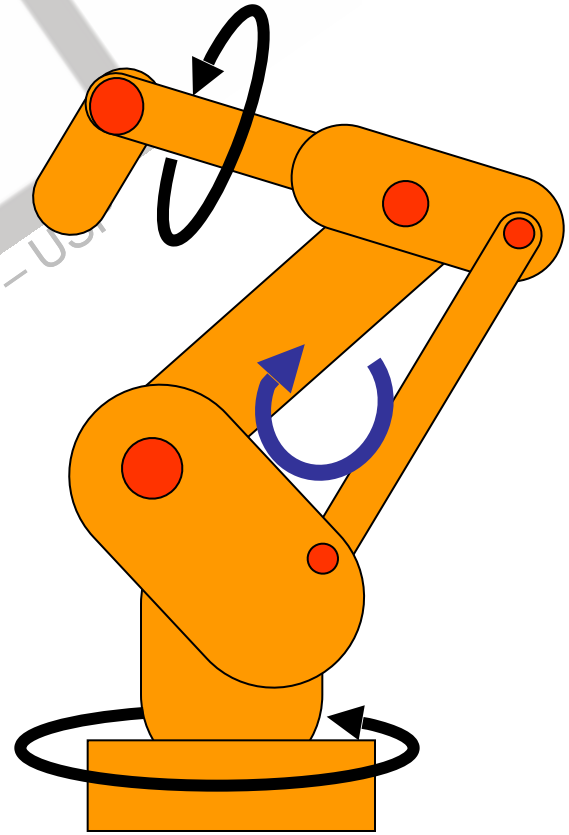




Cadeias Cinemáticas
Topologias

- Cadeias Parcialmente Fechadas





Cadeias Cinemáticas
Graus de Liberdade

- Não considerando o solo:

$$N = 3.n_B - \sum_{i=1}^{n_J} (3 - f_i)$$

- Onde:

N: Número de GDLs

n_B: Número de Corpos (excluindo o solo)

n_J: Número de Juntas

n_L: Número de Loops

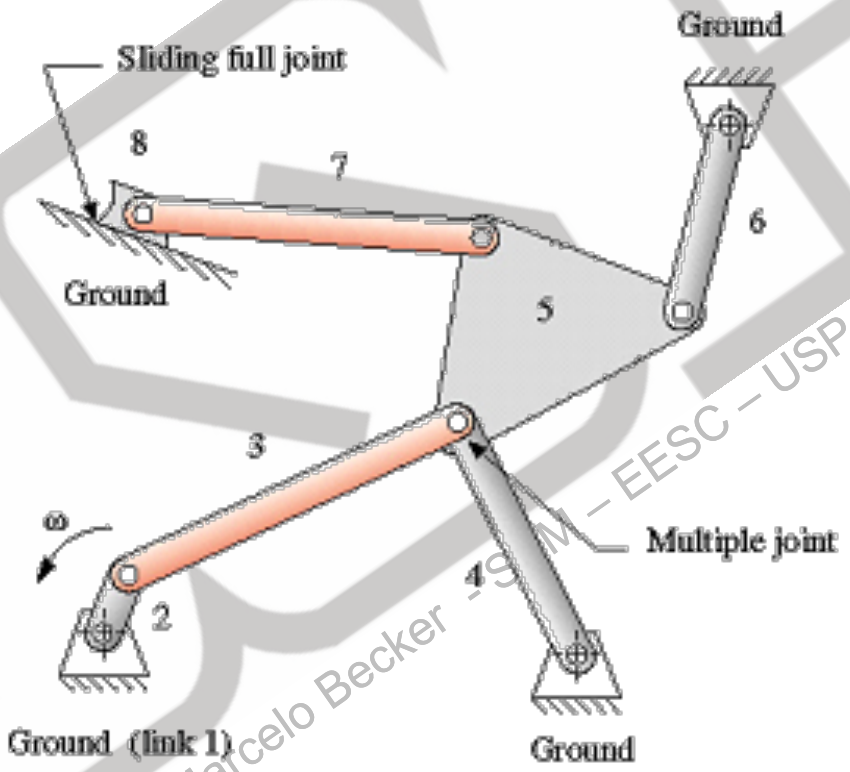
f_i: GDL da junta i

Graus de Liberdade

Mecanismos Planares – Exemplos

$$N = 3.n_B - \sum_{i=1}^{n_J} (3 - f_i)$$

?

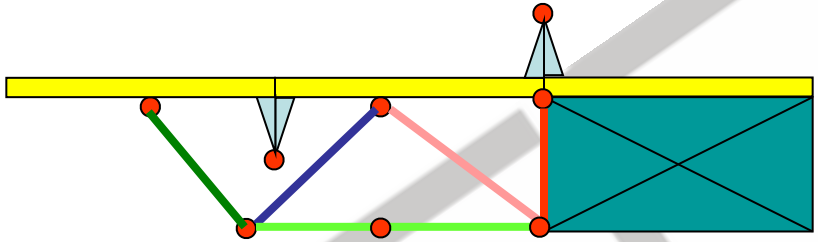


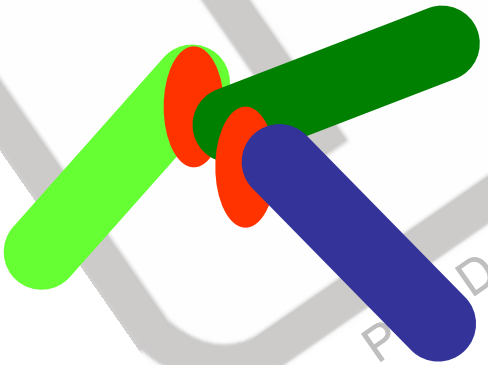
(a) Linkage with full and multiple joints

Graus de Liberdade

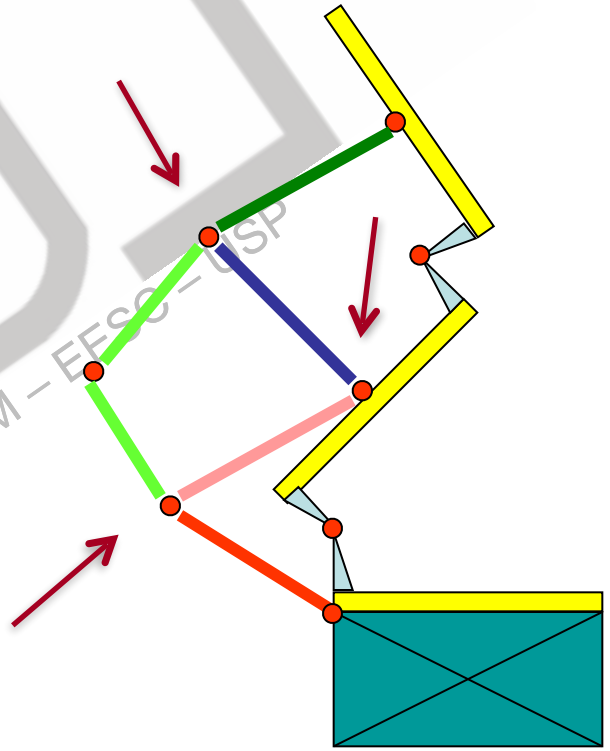
Mecanismos Planares – Exemplos

$$N = 3.n_B - \sum_{i=1}^{n_J} (3 - f_i)$$





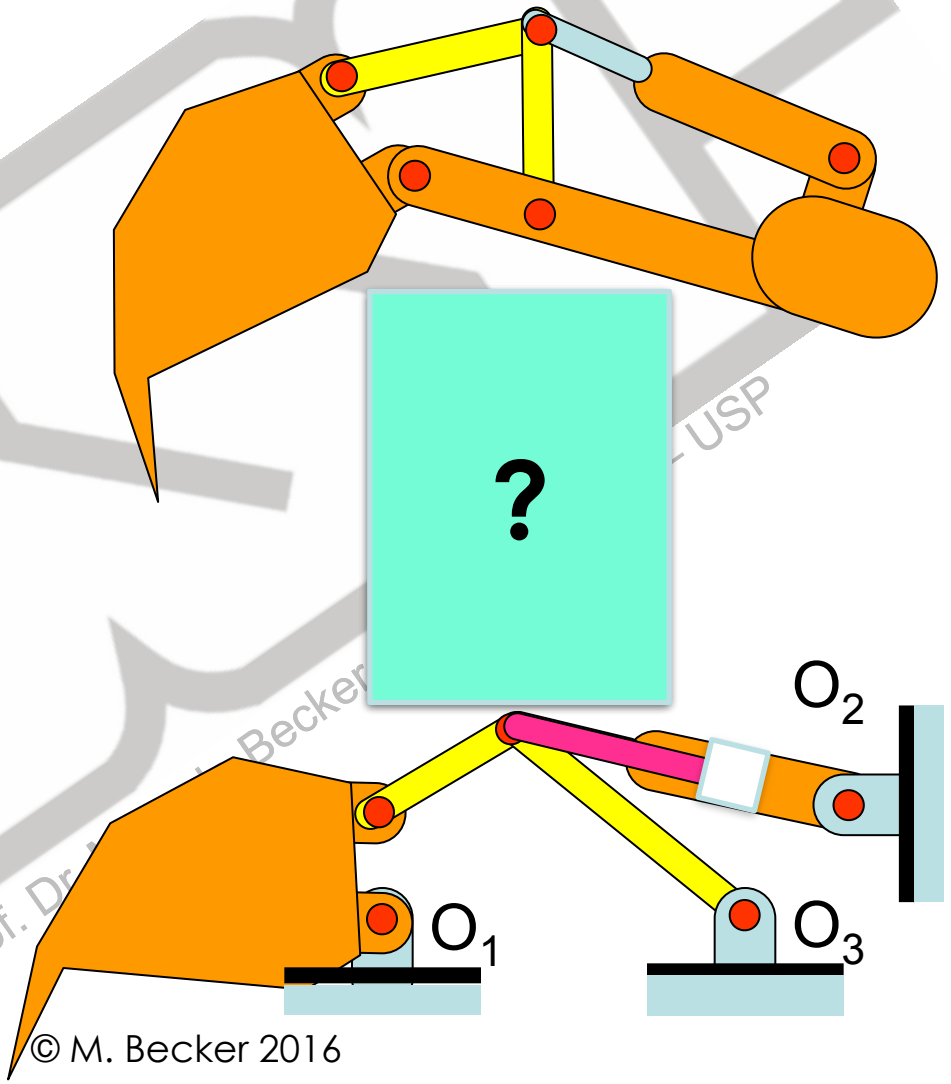
?



Graus de Liberdade

Mecanismos Planares – Exemplos

$$N = 3.n_B - \sum_{i=1}^{n_J} (3 - f_i)$$

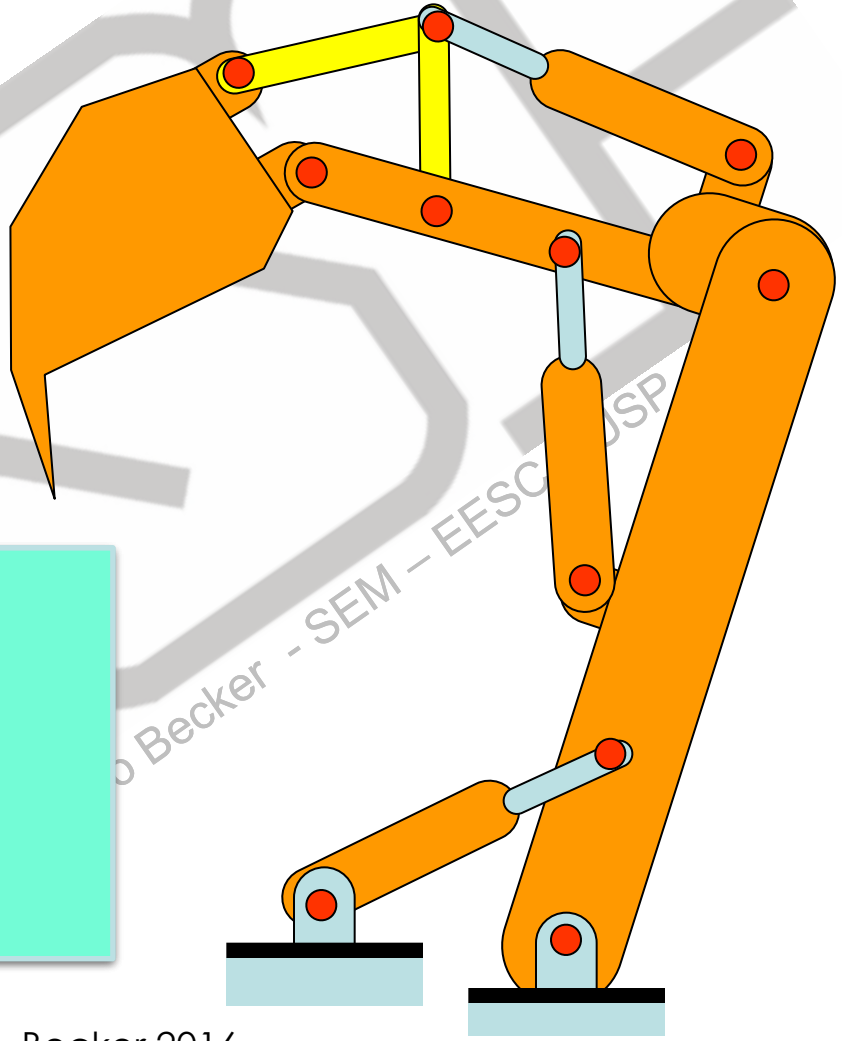


Graus de Liberdade

Mecanismos Planares – Exemplos

$$N = 3.n_B - \sum_{i=1}^{n_J} (3 - f_i)$$

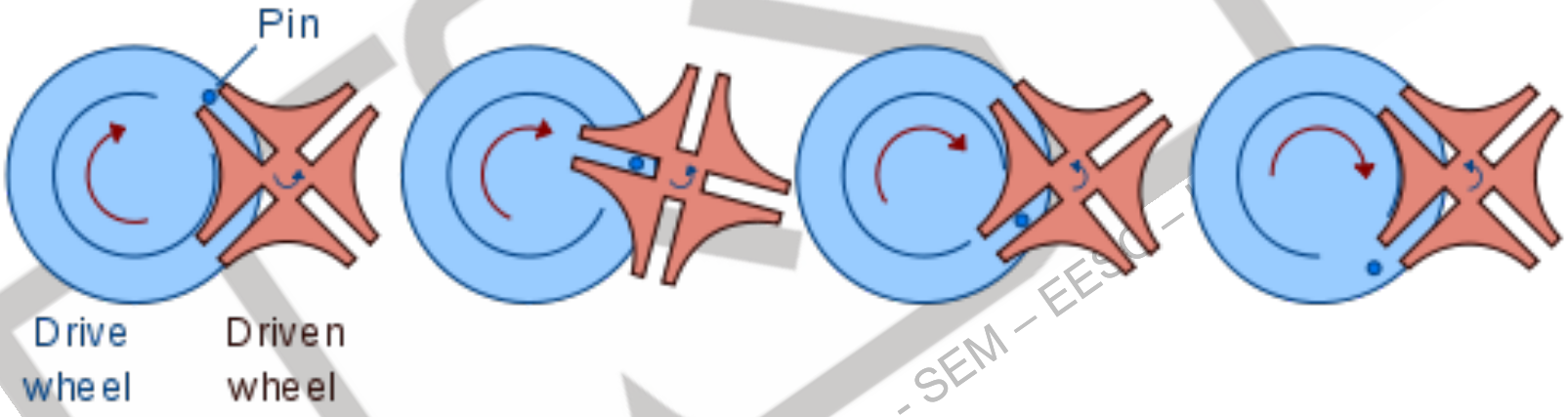
?



Graus de Liberdade

Mecanismos Planares – Exemplos

Roda de Genebra

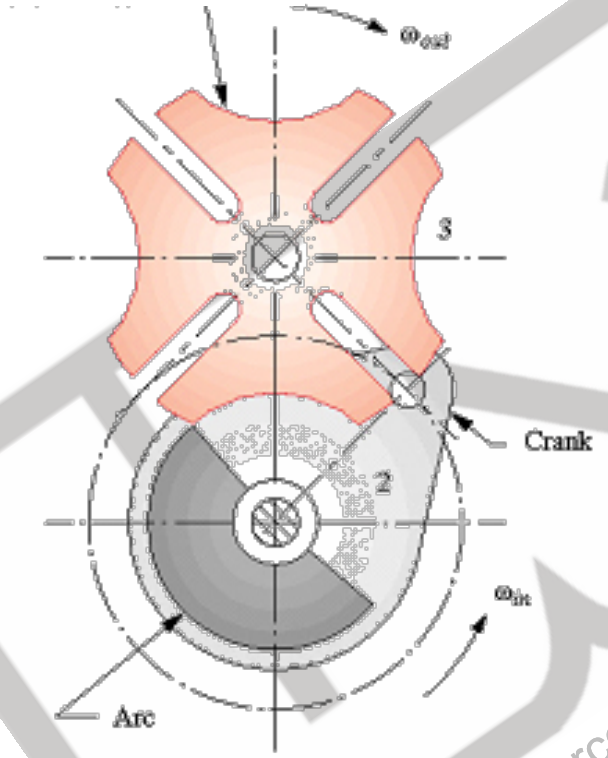


https://en.wikipedia.org/wiki/Geneva_drive

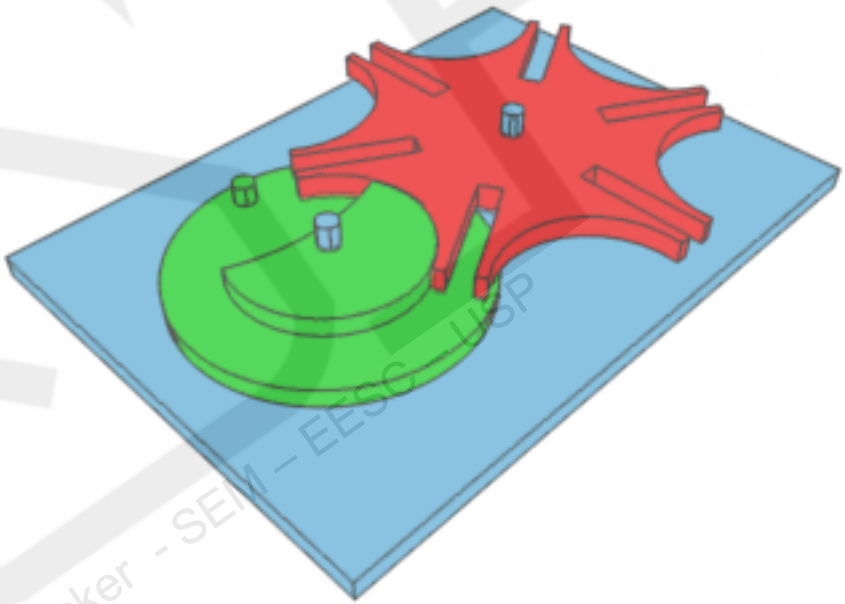
Graus de Liberdade

Mecanismos Planares – Exemplos

Roda de Genebra



(a) Four-stop Geneva mechanism



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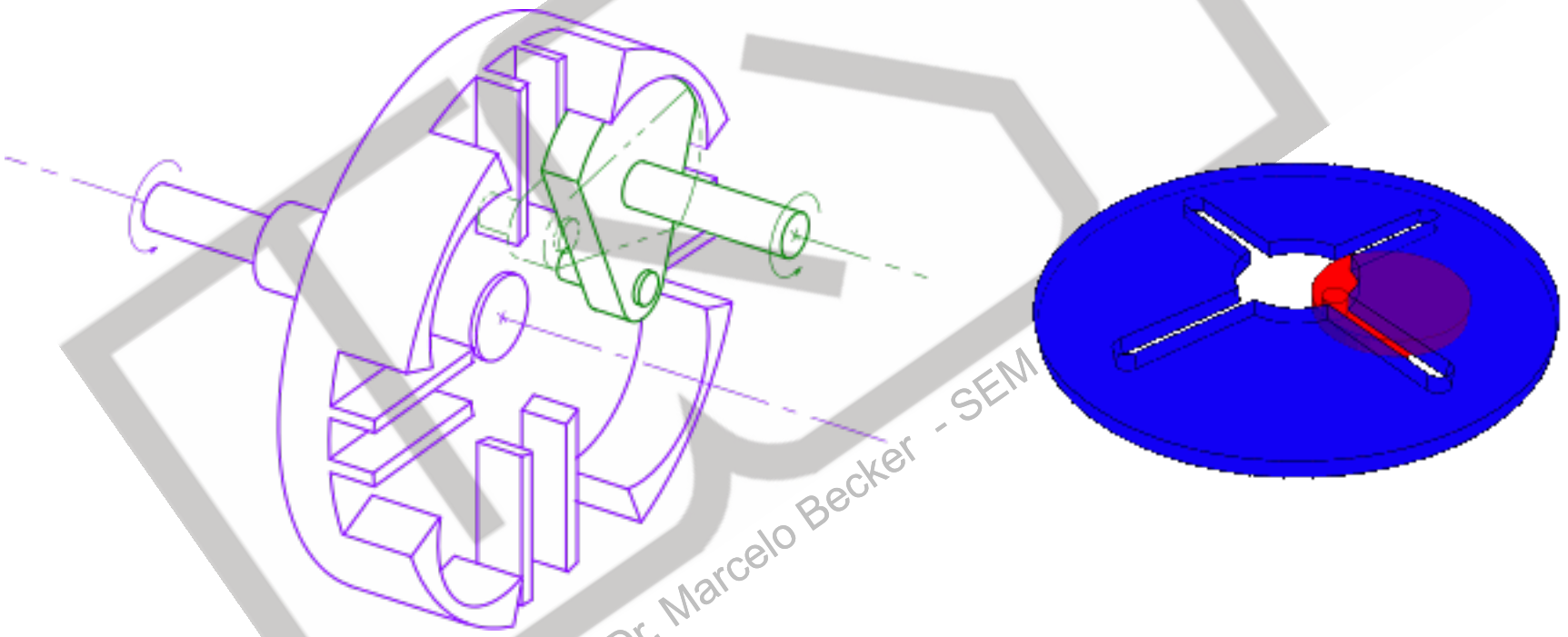
Graus de Liberdade

Mecanismos Planares – Exemplos

Roda de Genebra



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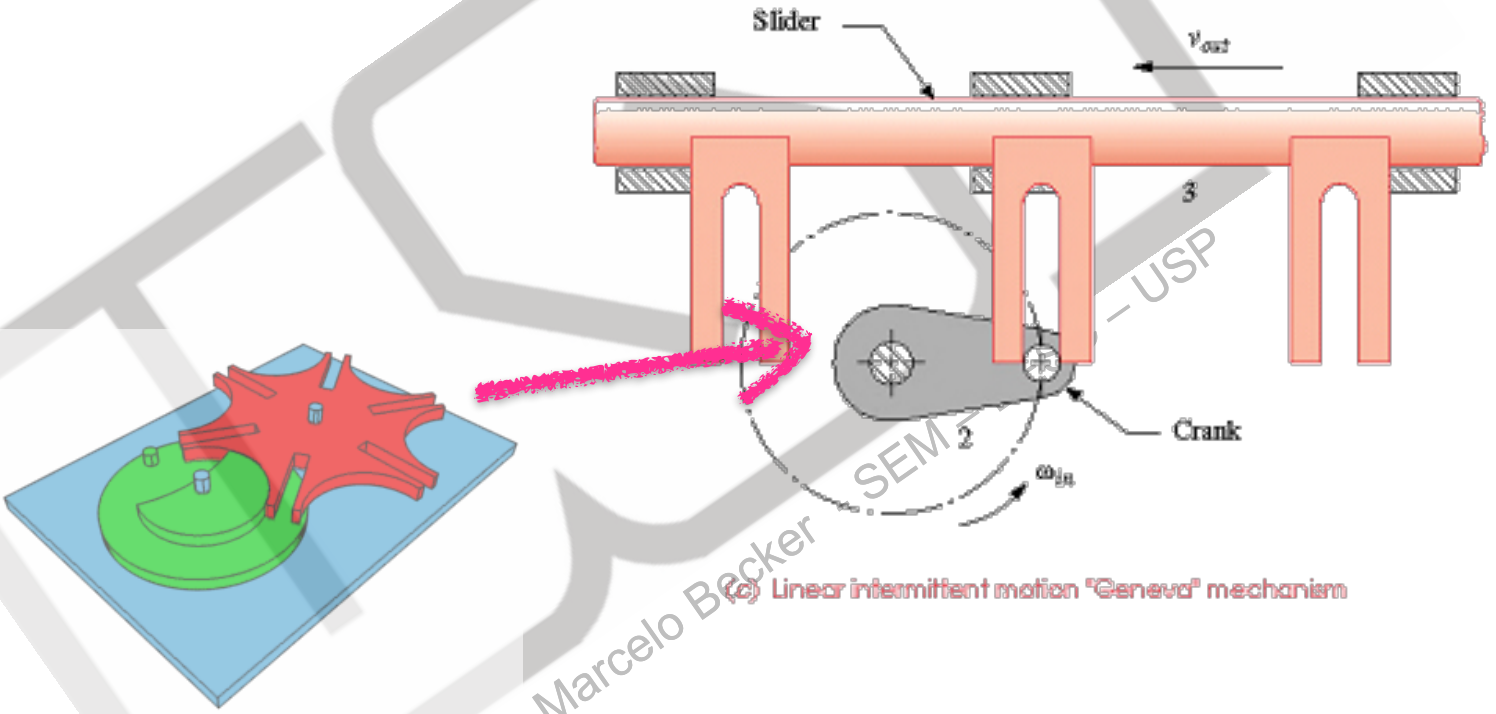
Graus de Liberdade

Mecanismos Planares – Exemplos



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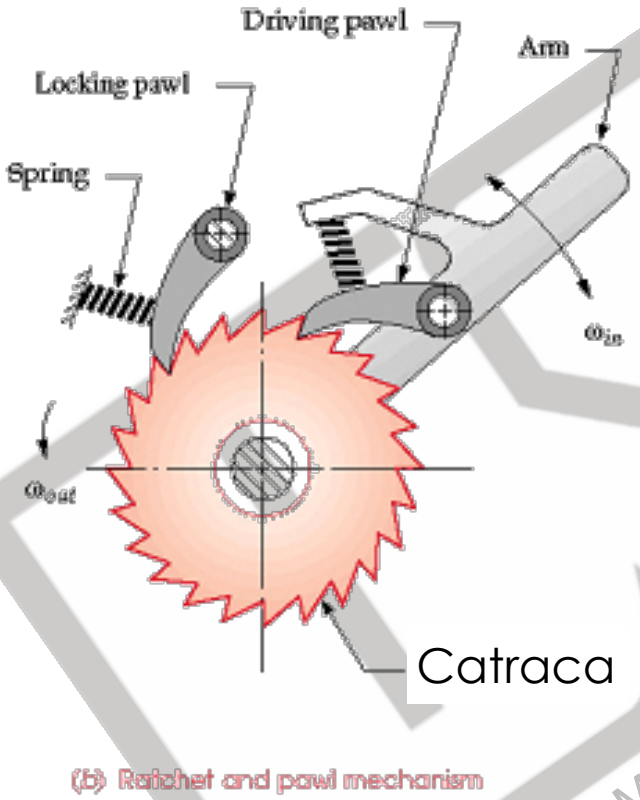
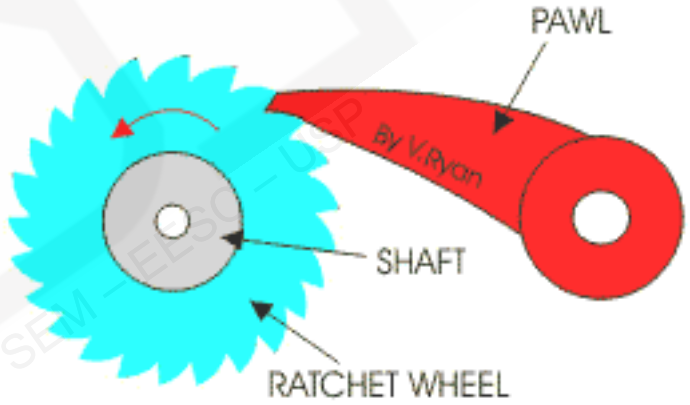
Graus de Liberdade

Mecanismos Planares – Exemplos





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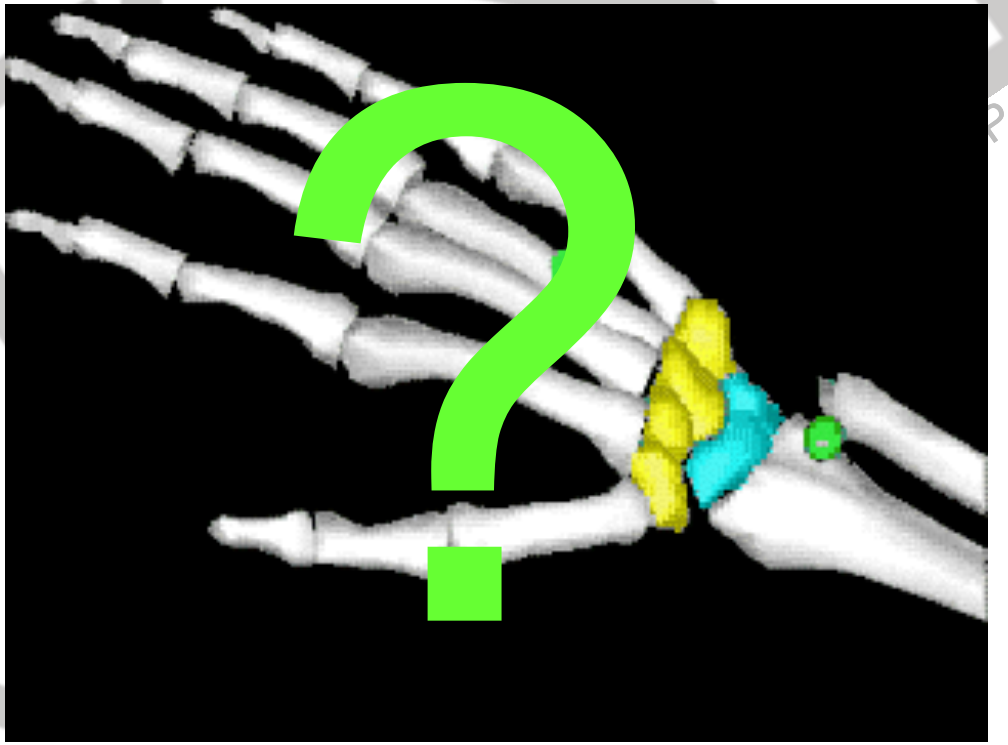
Graus de Liberdade

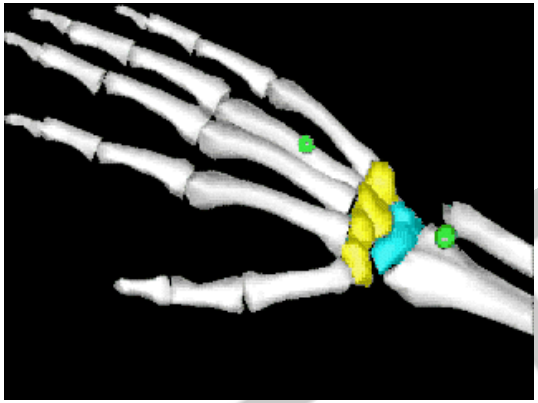
Pergunta da Aula Passada

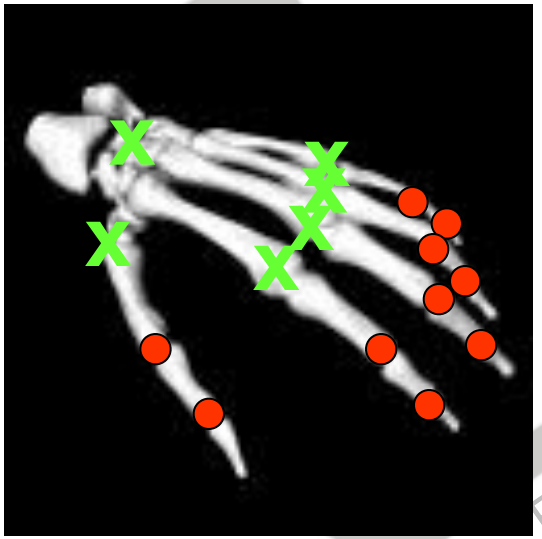
Quantos GDLs possui uma mão?



Graus de Liberdade

Pergunta da Aula Passada

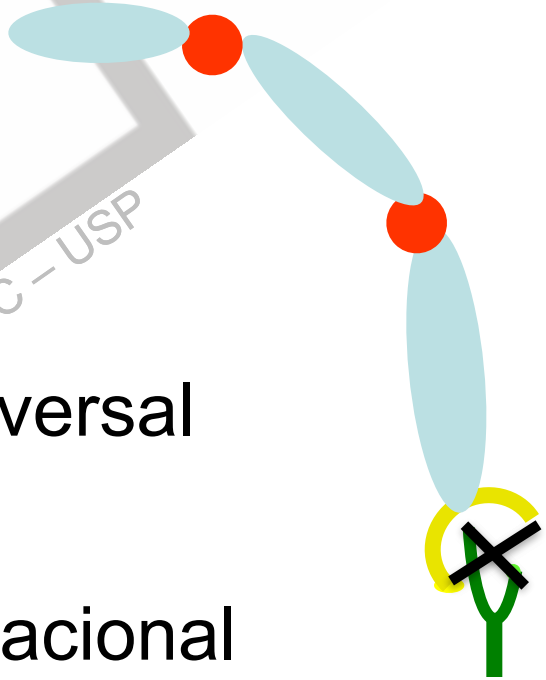




22 DOFs

x Junta Universal

Junta Rotacional

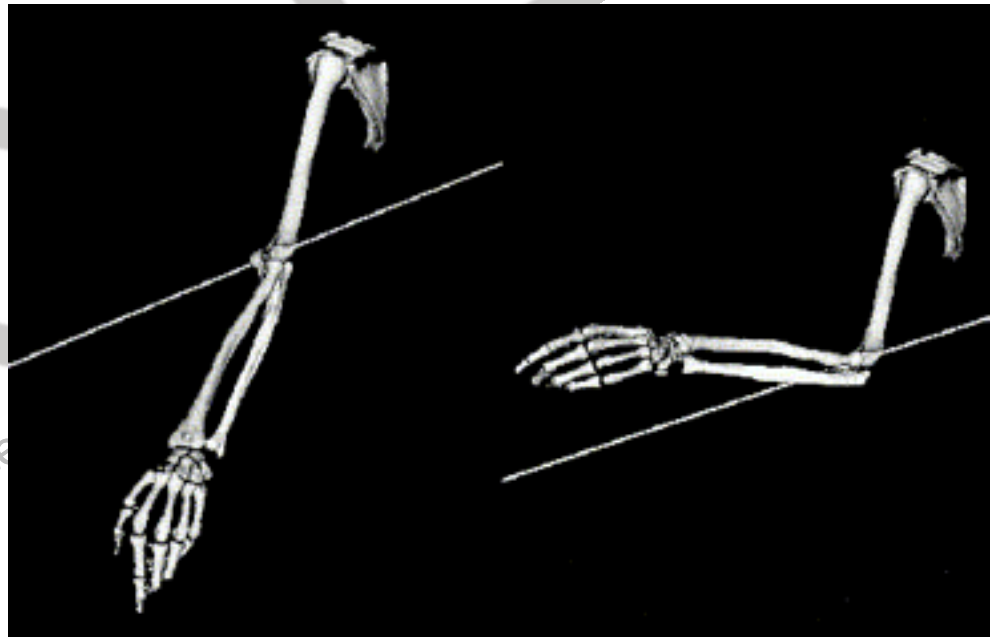


Próxima Aula

- Mecanismos Simples
- Mecanismos Complexos

- Pergunta:

E o conjunto braço, ante-braço e mão, quantos GDLs possui?



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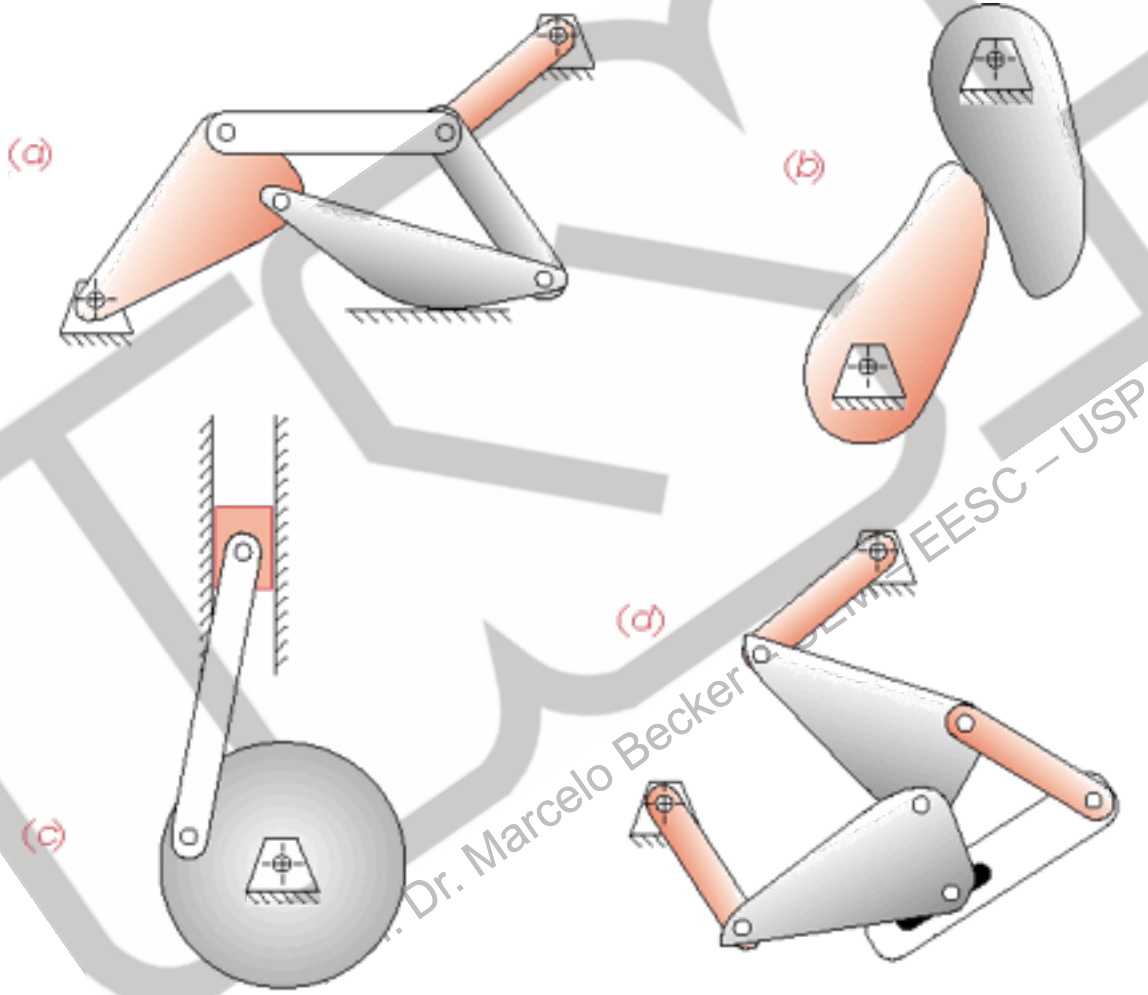
- Introdução
- Graus de Liberdade
- Cadeias Cinemáticas
- **Exercícios Recomendados**
- Bibliografia Recomendada

Graus de Liberdade

Mecanismos Planares – Exercícios



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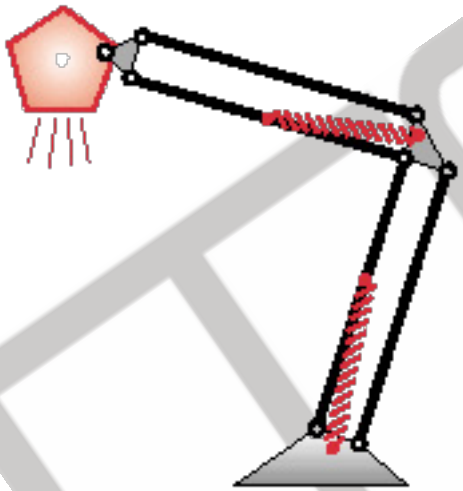

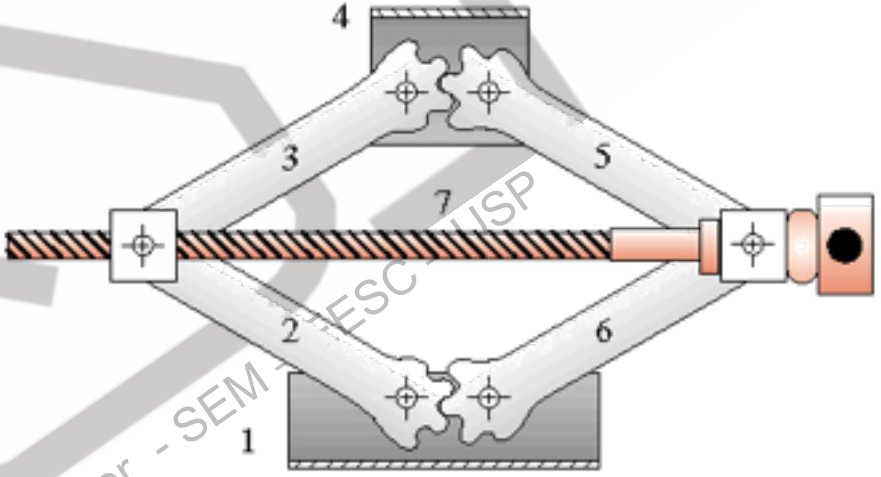

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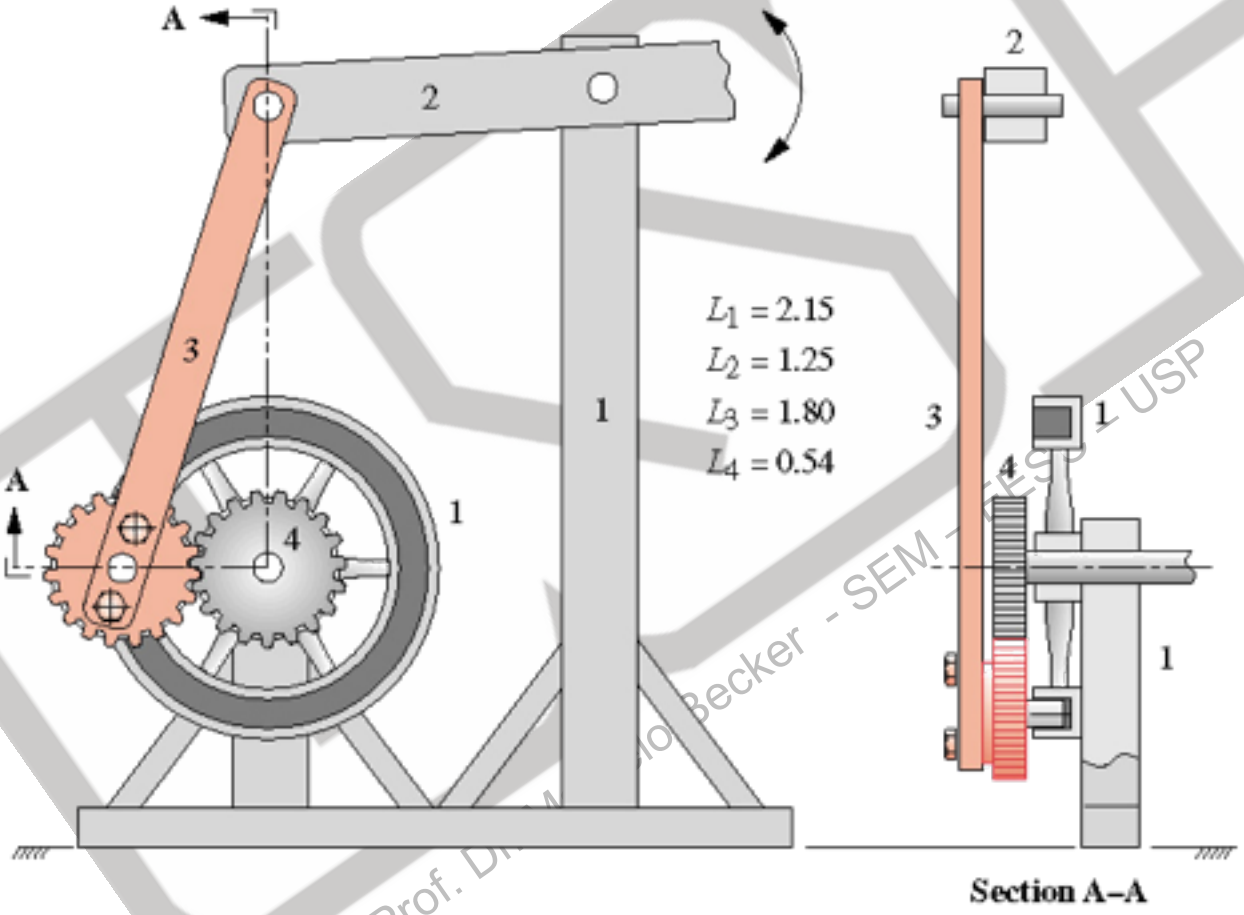

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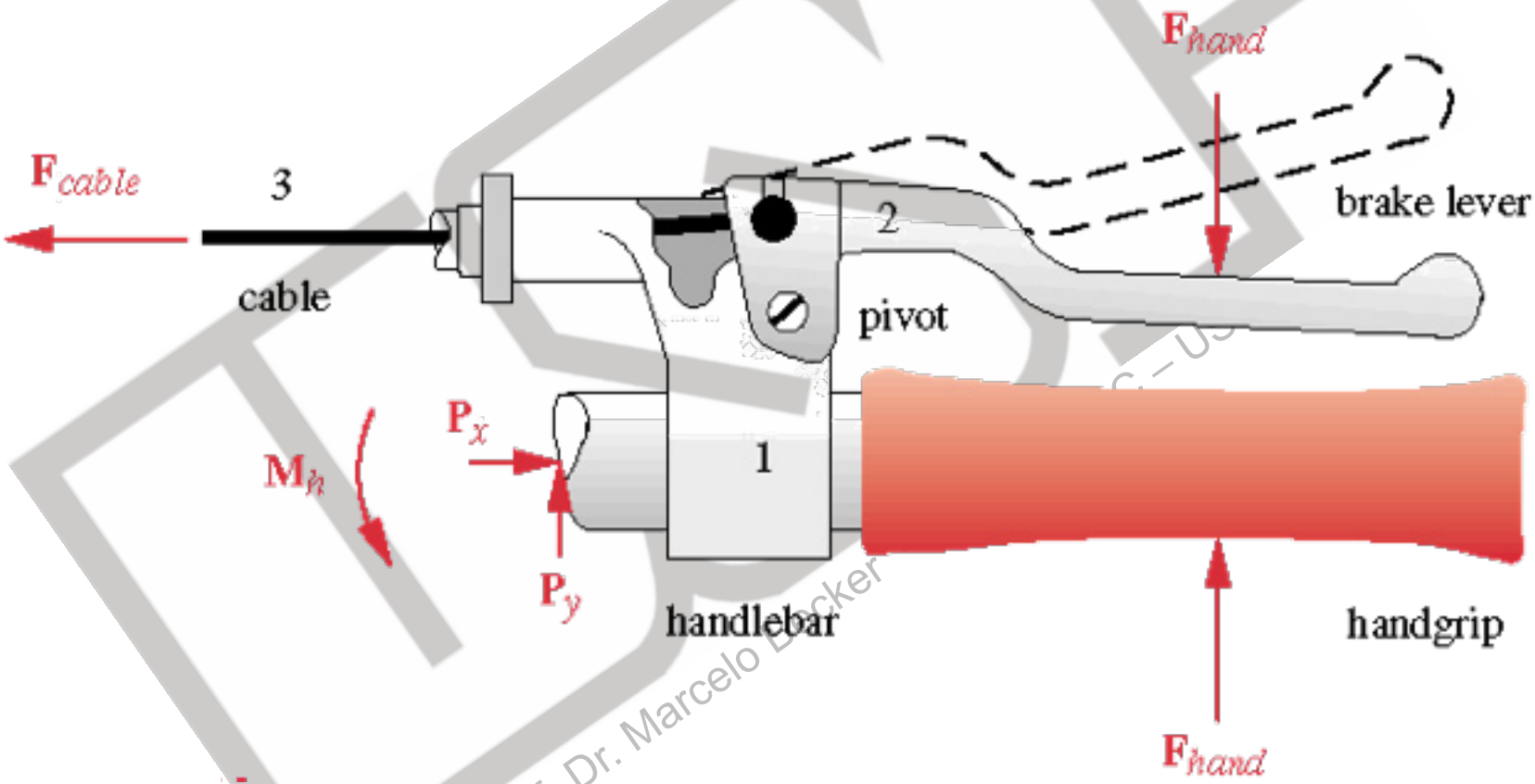

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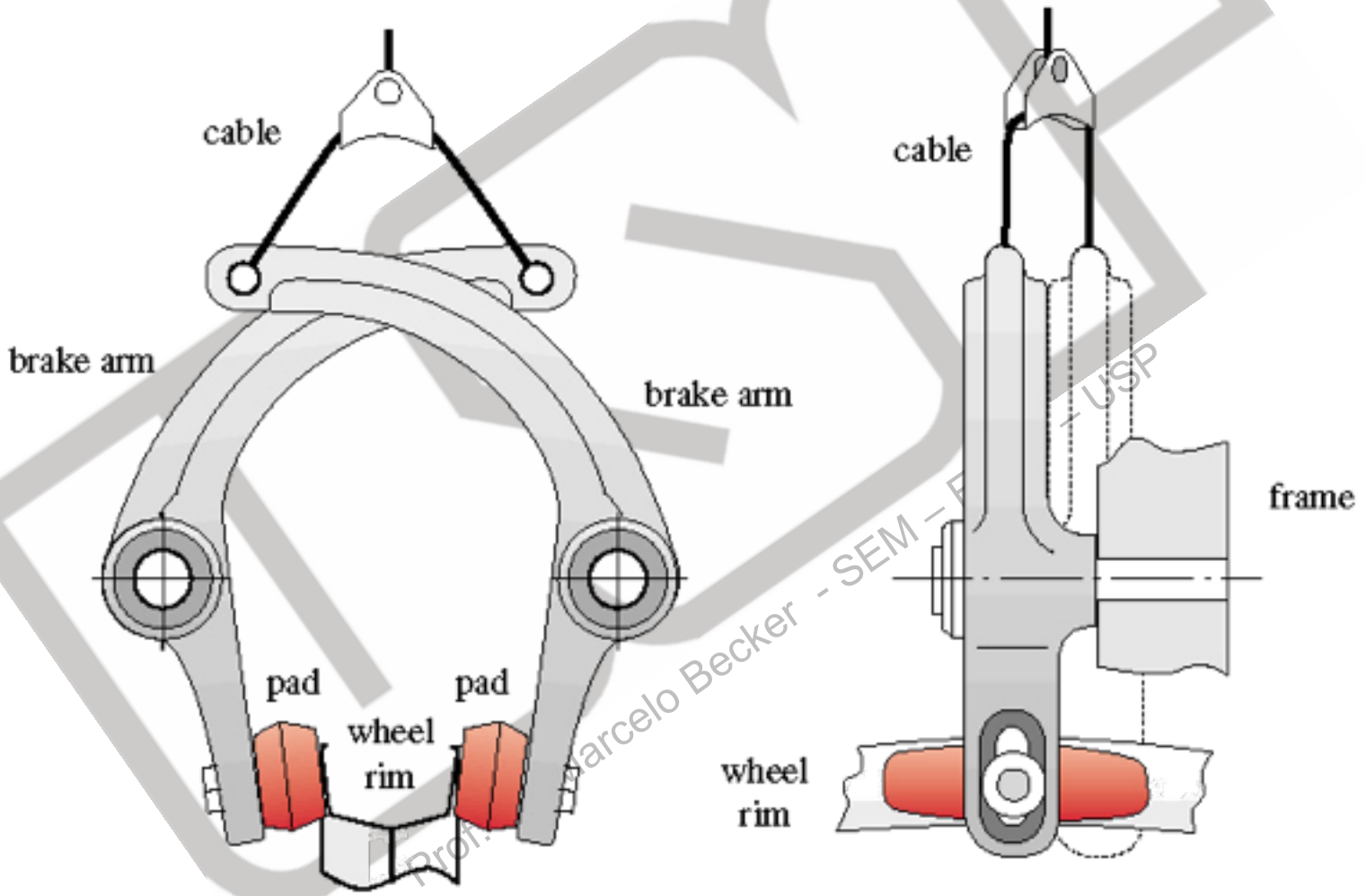

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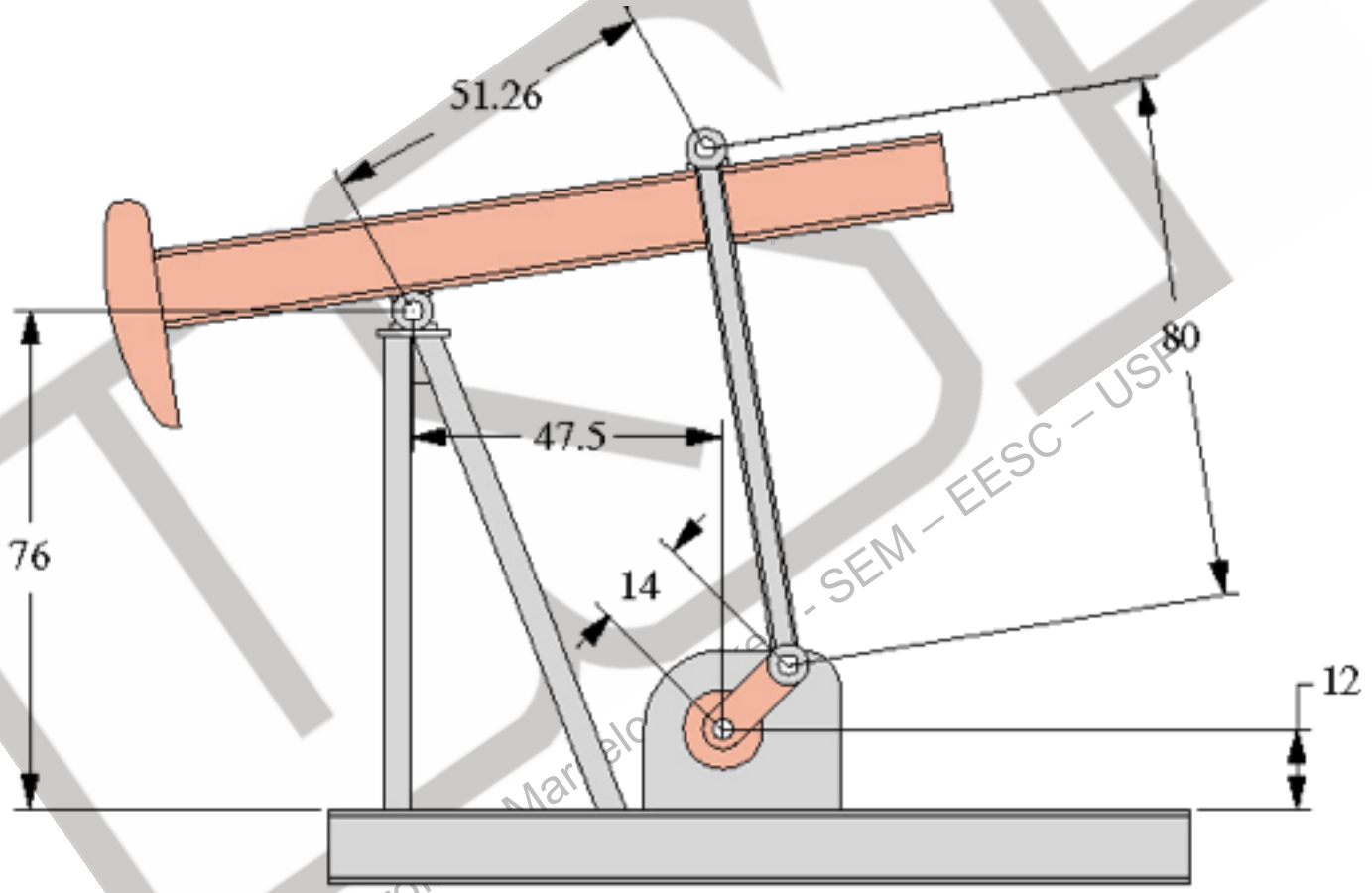

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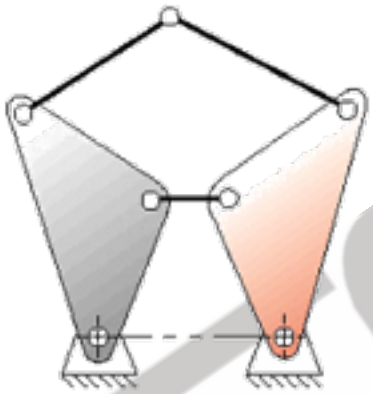
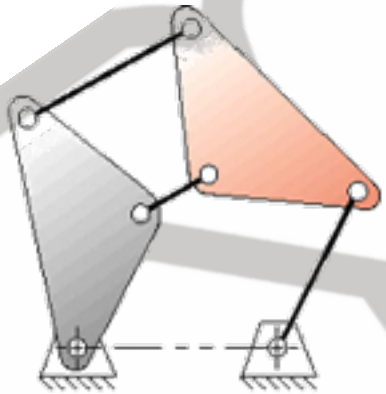
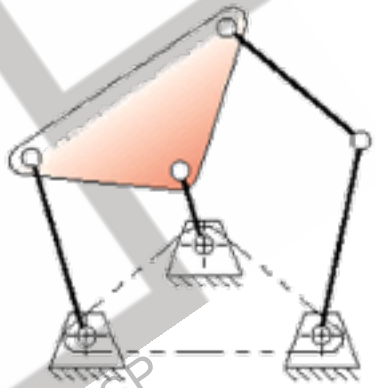
Mecanismos Planares – Exercícios



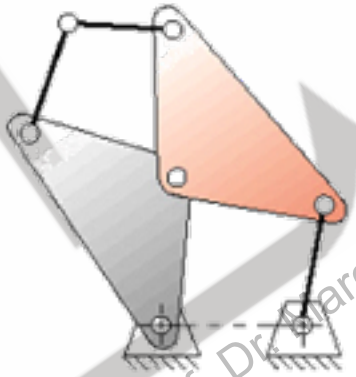
(a) Stephenson´s sixbar inversion I



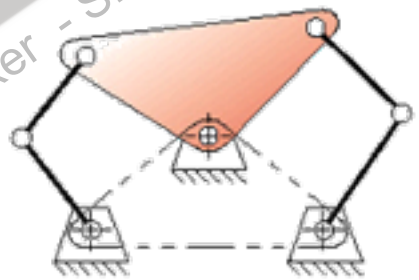
(b) Stephenson´s sixbar inversion II



(c) Stephenson´s sixbar inversion III



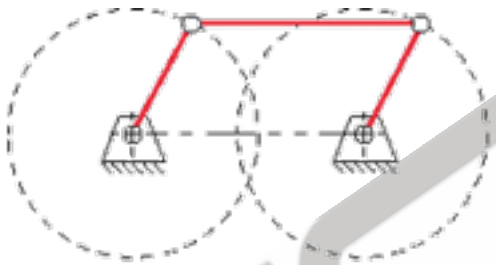
(d) Watt´s sixbar inversion I



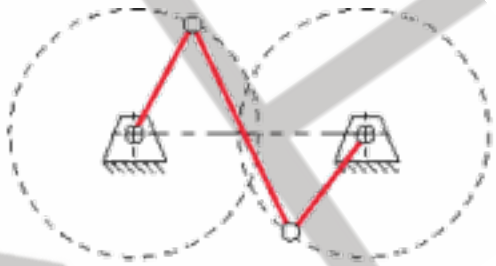
(e) Watt´s sixbar inversion II

Graus de Liberdade

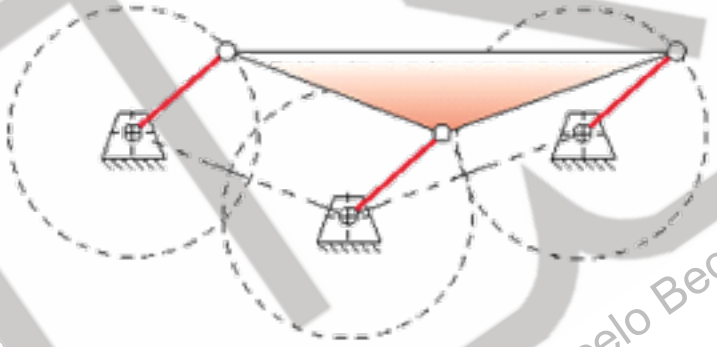
Mecanismos Planares – Exercícios



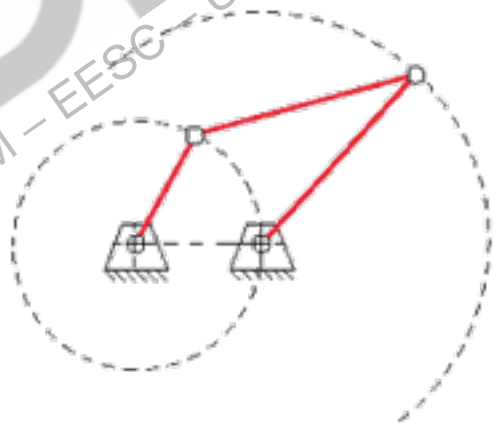
(a) Parallelogram form



(b) Antiparallelogram form



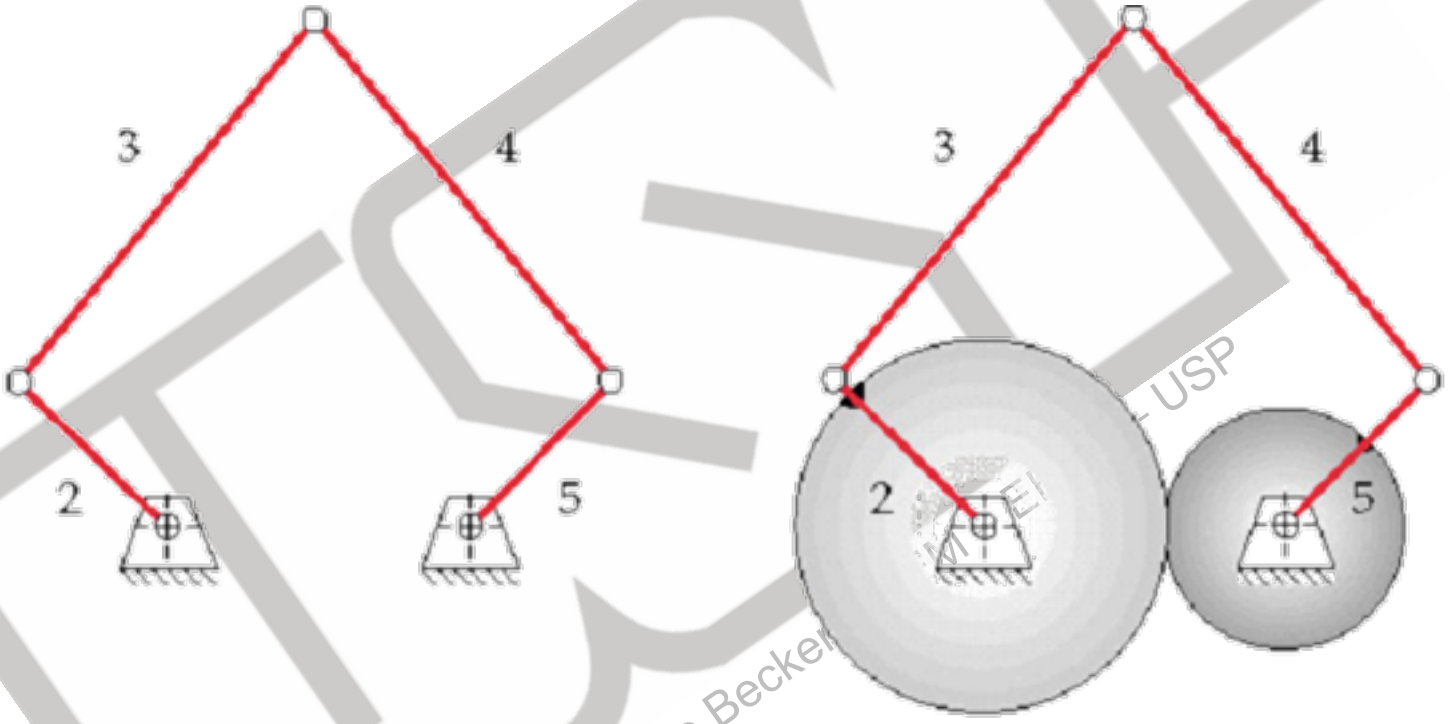
(c) Double-parallelogram linkage gives parallel motion (pure curvilinear translation) to coupler and also carries through the change points



(d) Deltoid or kite form

Graus de Liberdade

Mecanismos Planares – Exercícios



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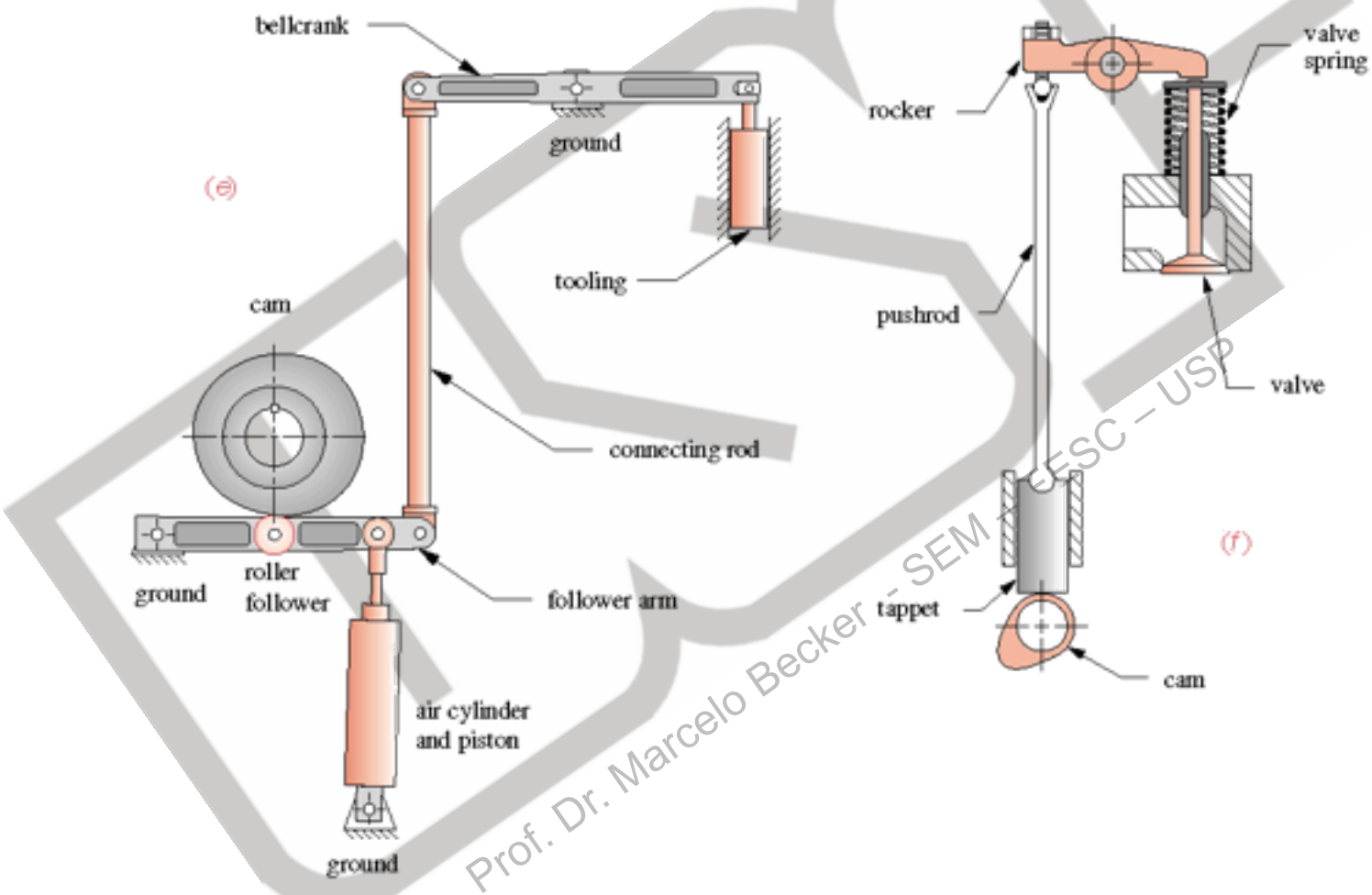

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- MABIE, H.H., OCVIRK, F.W. "Mecanismos e dinâmica das máquinas".
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- Notas de Aula