MECHANISMS AND MACHINE DESIGN

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UNIT-1
MECHANISMS

MECHANICS

Science dealing with motion

DIVISIONS OF MECHANICS

Statics – Deals with systems which are not changing with time.

Dynamics – Deals with systems which are changing with time.

DIVISIONS OF DYNAMICS

KINEMATICS – Deals with Motion and Time

(Kinema – Greek Word – Motion)

KINETICS – Deals with Motion, Time and Forces.

Statics	Kinematics	Kinetics
STRUCTURE	MECHANISM	MACHINE

Some Definitions

- Machine – device to transfer or transform energy to do useful work.

- Mechanism – device to transfer or transform given input motion to specified output motion

- Structure – a single body with no motion / combination of bodies with no relative motion

Classification of Mechanisms

- Based on the nature of output speed

- Uniform motion mechanism
- Non-uniform motion mechanism

Shortcut to flat belt.ln

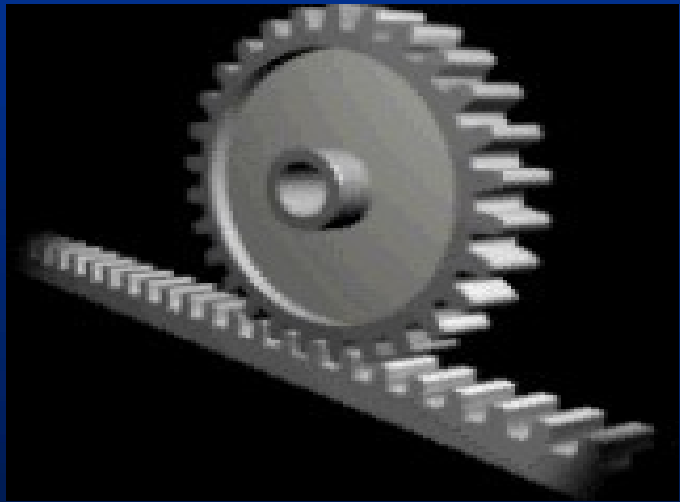
Uniform Motion Mechanisms

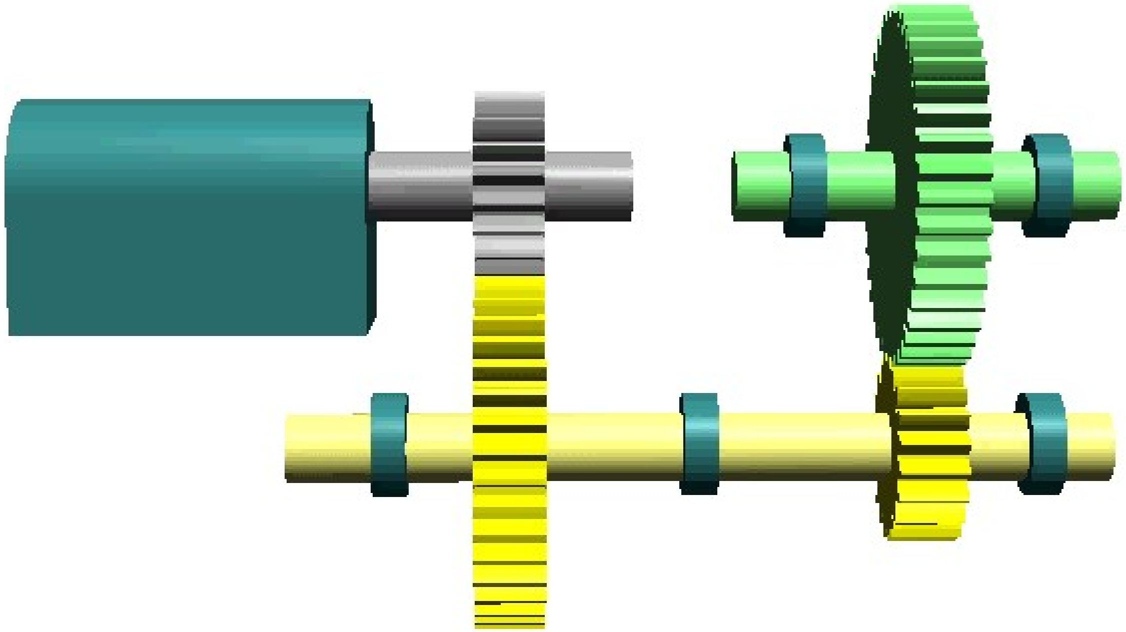
Uniform Motion – Equal Displacement For Equal Time Interval

Examples : All Gear Drives
All Chain Drives
Belt Drives without slip


C7


C9



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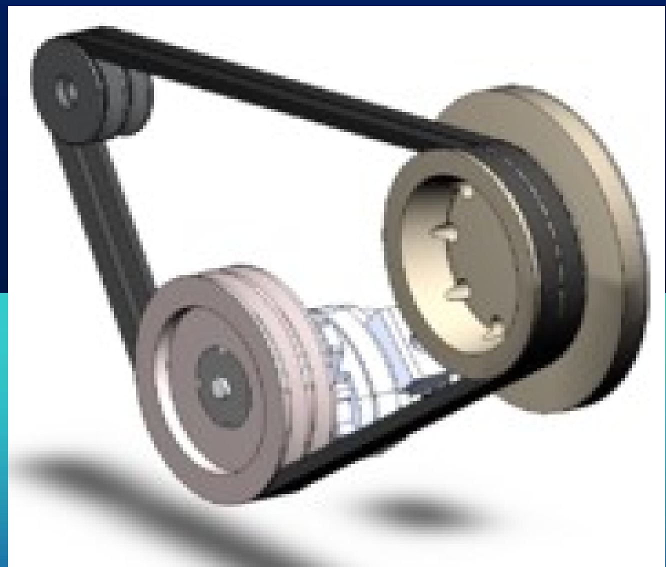
gear_train


VI



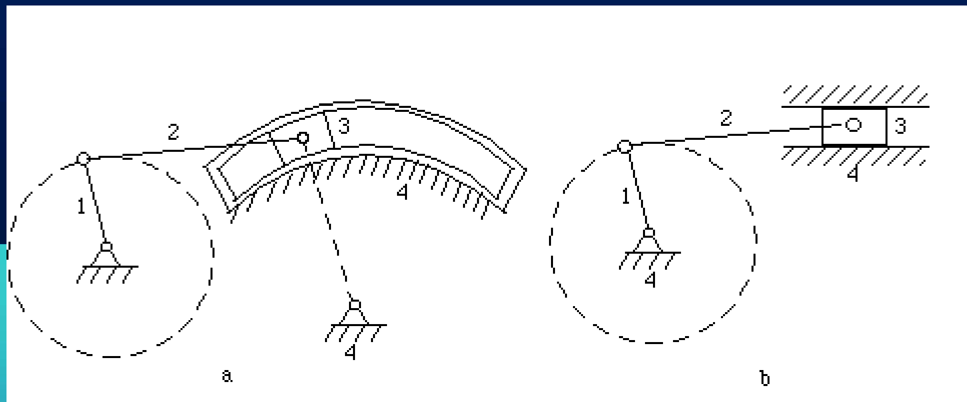
Non-Uniform Motion Mechanisms

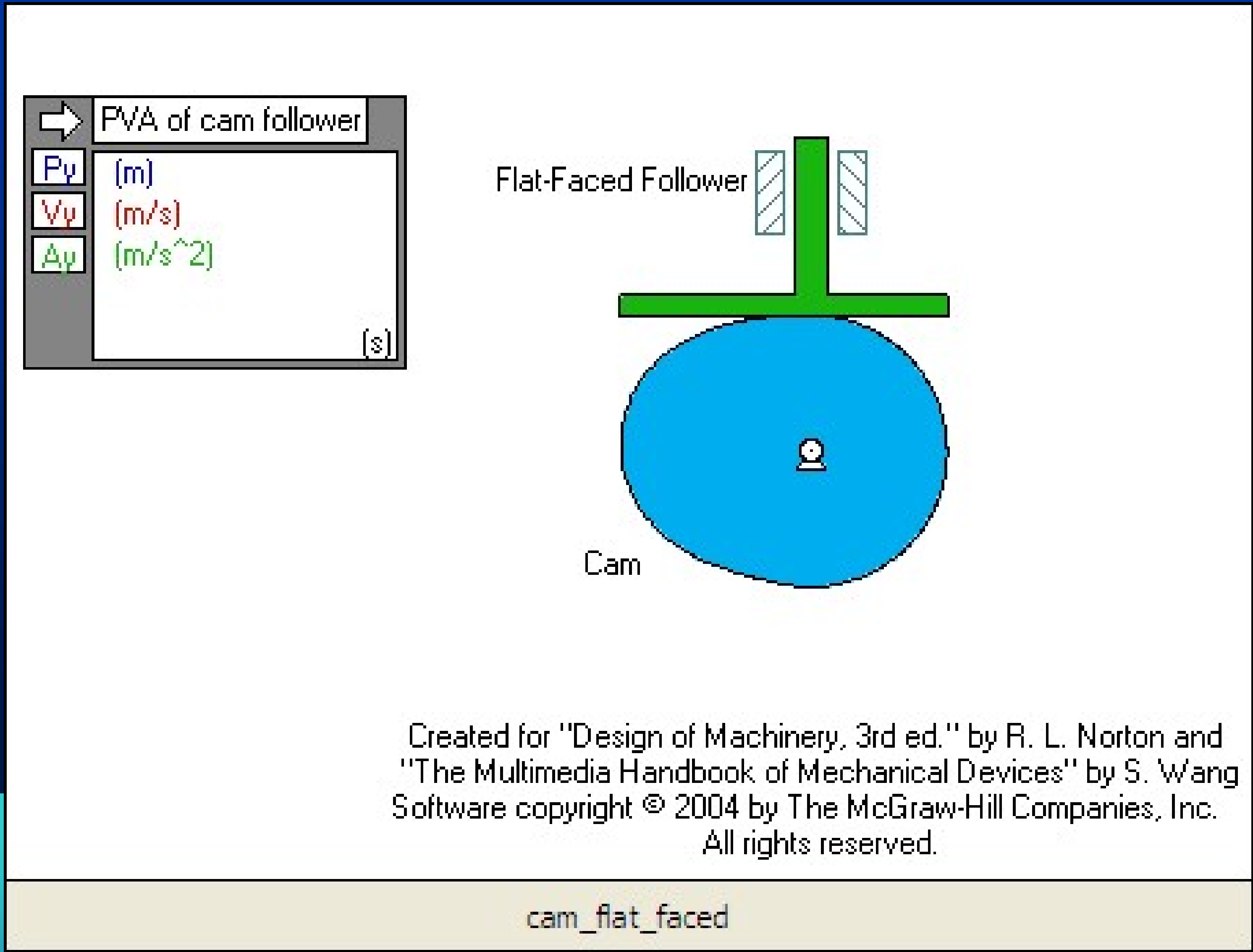
Non-Uniform Motion – Unequal Displacement
For Equal Time Interval

Examples : Linkage Mechanisms
Cam Mechanisms
Geneva Wheel


C1

C3


1
2
3
4
a
b



PVA of cam follower
Py
Vy
Ay
(m)
(m/s)
(m/s^2)
(s)
Flat-Faced Follower
Cam
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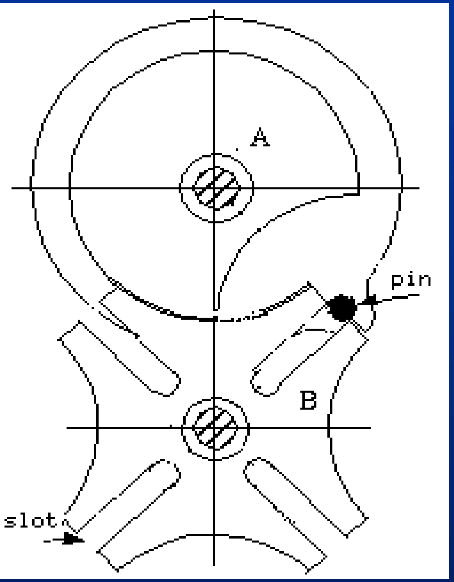
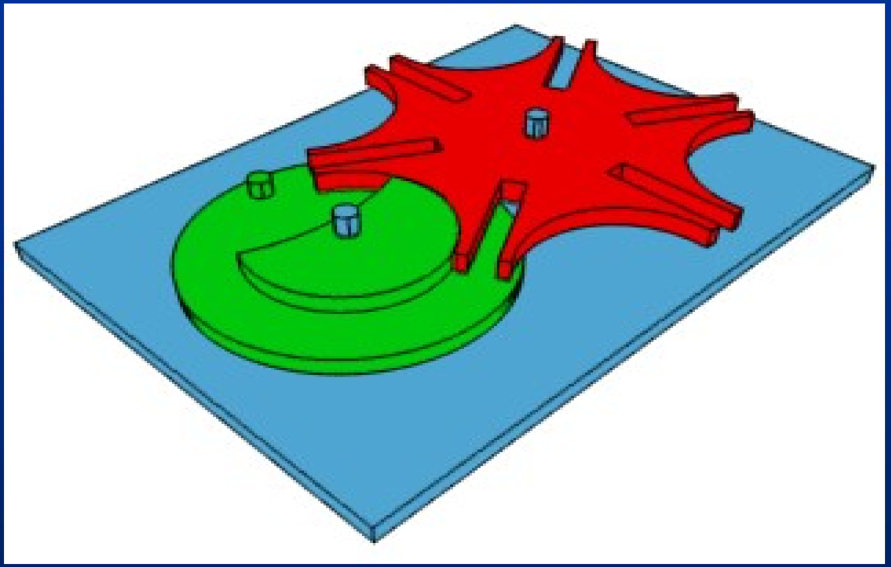
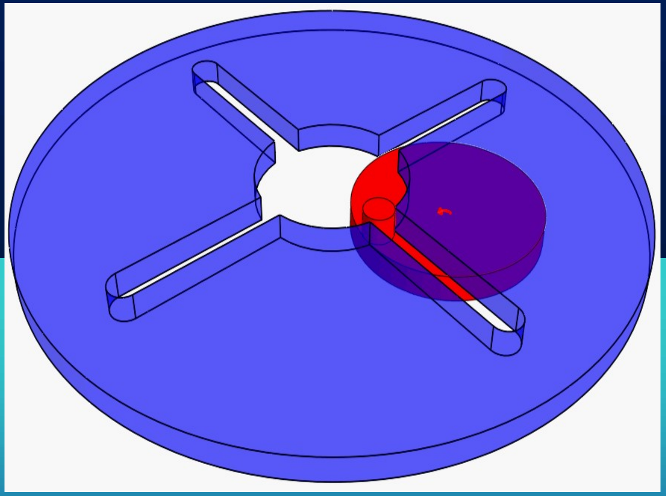
cam_flat_faced


A
pin
B
slot





Classification of mechanisms

Based on mobility (D.O.F) of the mechanism

1. Considering the D.O.F. of output only
   a) Constrained Mechanism
   b) Unconstrained Mechanism
2. Considering the sum of the D.O.F. Of input and output motions
   a) Single (one) d.o.f. mechanism
   b) Multi-d.o.f. mechanism

Constrained Mechanism

- One independent output motion. Output member is constrained to move in a particular manner only.

- Example: Four-bar mechanism
  Slider Crank Mechanism
  Five-bar mechanism with two inputs

Unconstrained mechanism

- Output motion has more than one D.O.F.
- Example: Automobile Differential during turning the vehicle on a curve

Five-bar mechanism with one input

Single D.O.F Mechanism

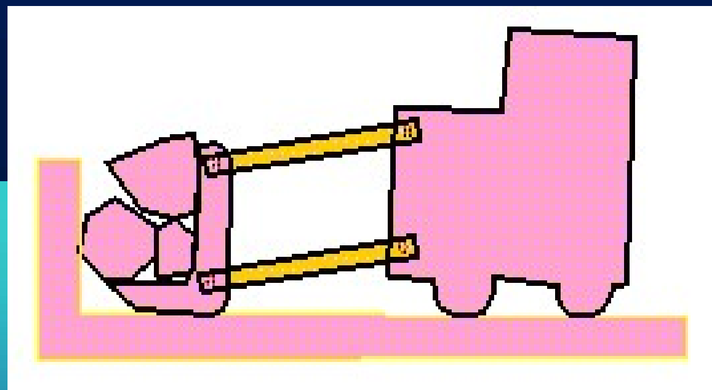
Sum of the input and output D.O.F. is two.

Single D.O.F. Motion - One Independent Input motion and one independent output motion

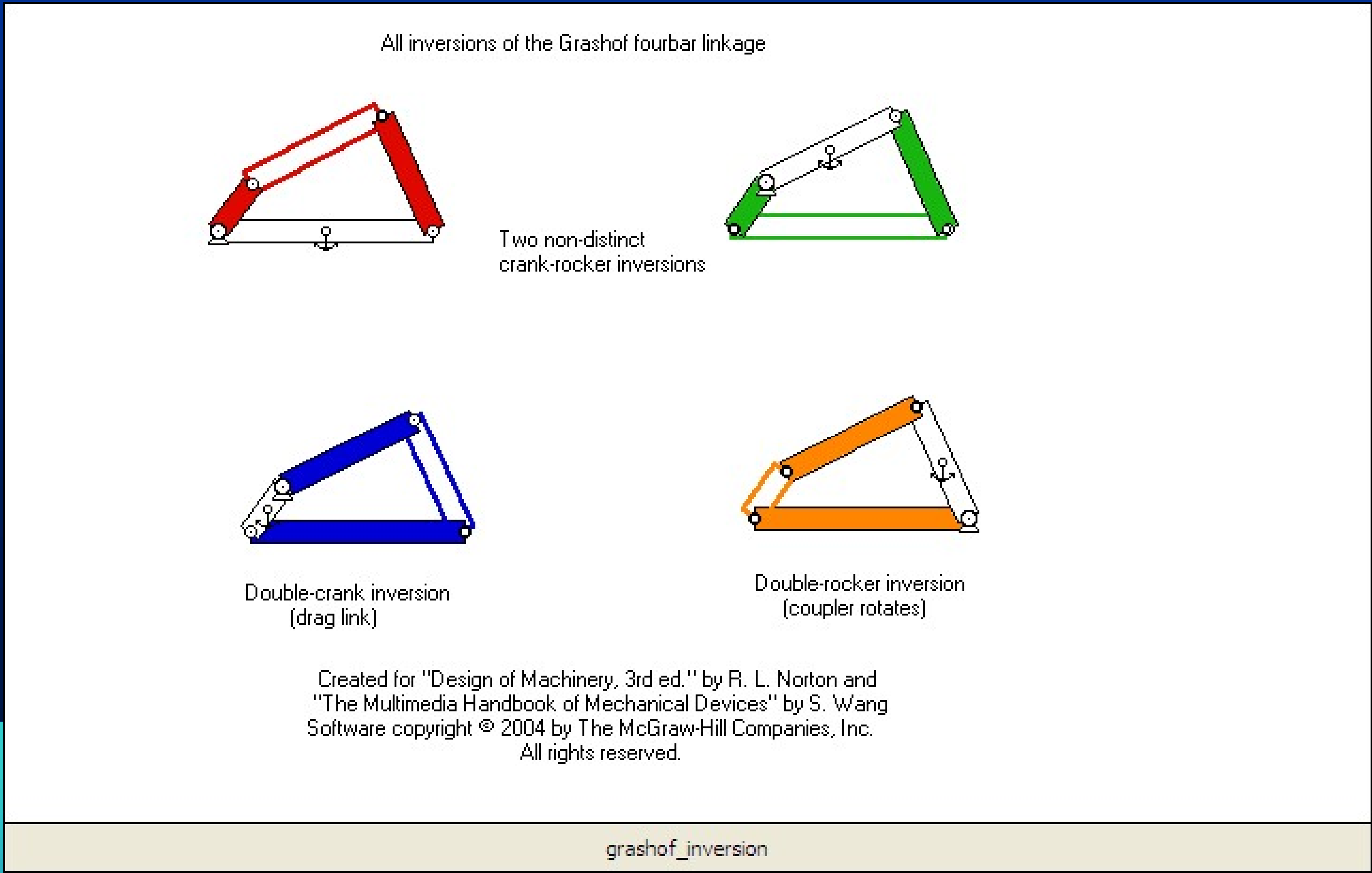
Examples : Four-Bar Mechanism

Cam-Follower Mechanism


Kurbelviereck
räumliches Kurbelviereck



UNIT-2
KINEMATIC ANALYSIS


All inversions of the Grashof fourbar linkage
Two non-distinct
crank-rocker inversions
Double-crank inversion
(drag link)
Double-rocker inversion
(coupler rotates)
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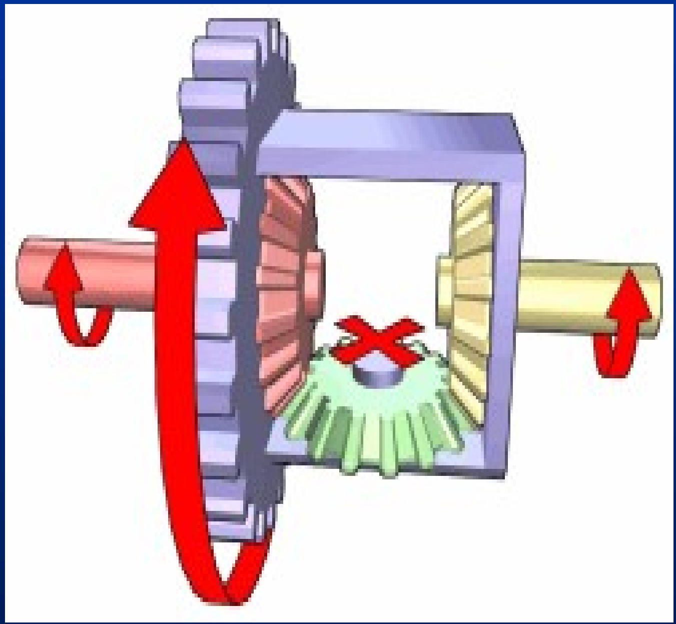
grashof_inversion

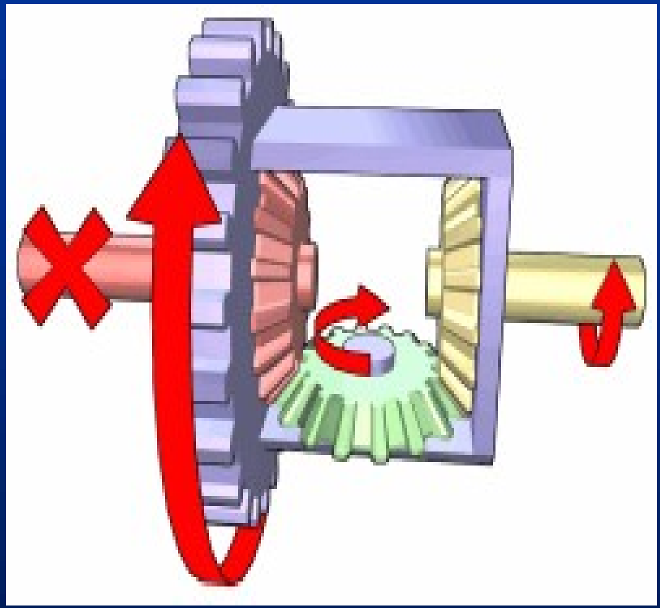
Multi D.O.F. Mechanism

Sum of the input and output motion D.O.F. is more than two.

Multi D.O.F. Motion – More than one Independent Output / Input Motions

Examples : Automobile Differential
3-D Cam Mechanism
(Camoid)
Five-Bar Mechanism





Classification of Mechanisms

- Based on position occupied in space

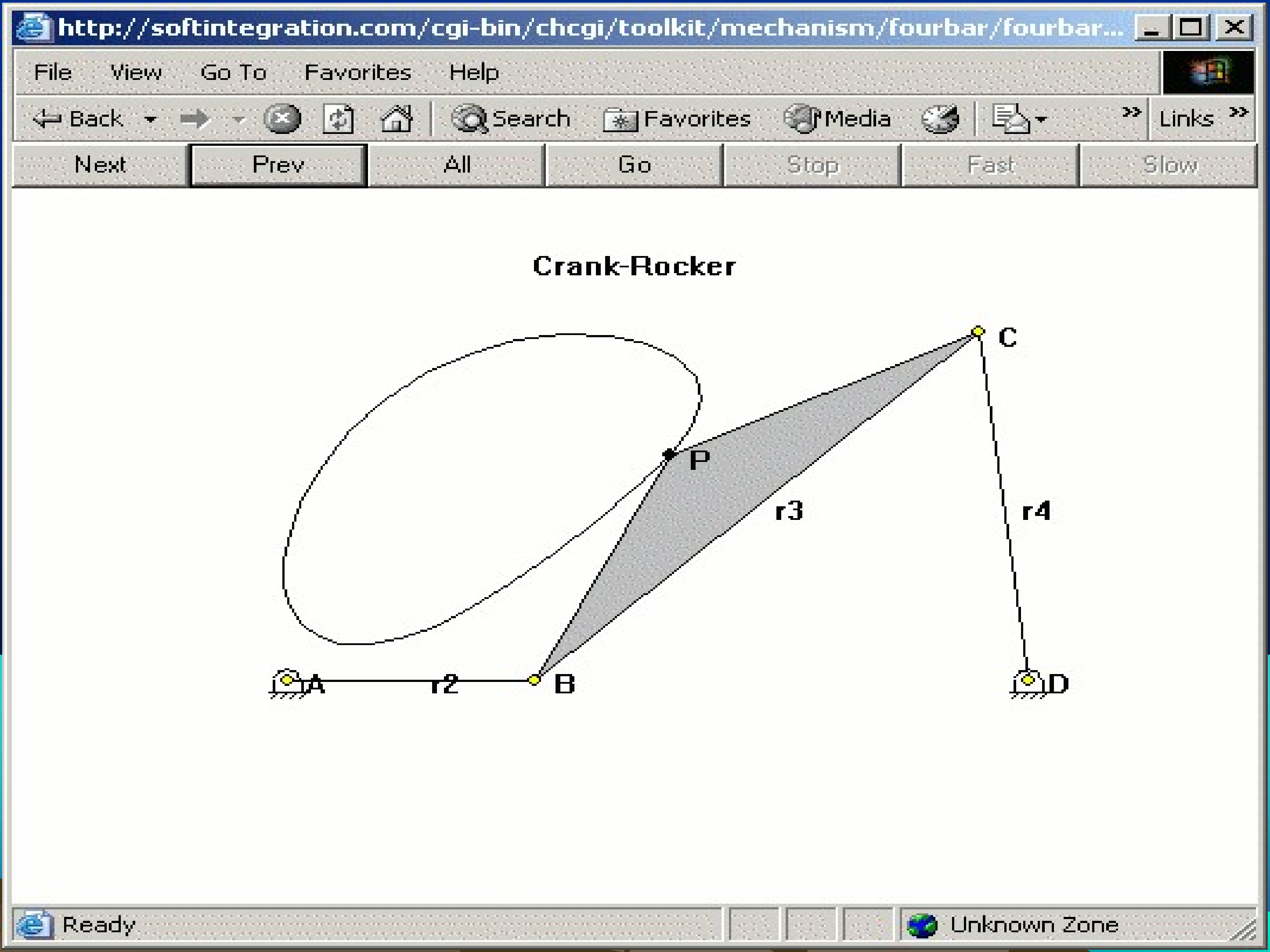
- Planar Mechanism
- Spherical Mechanism
- Spatial Mechanism

Planar Mechanism

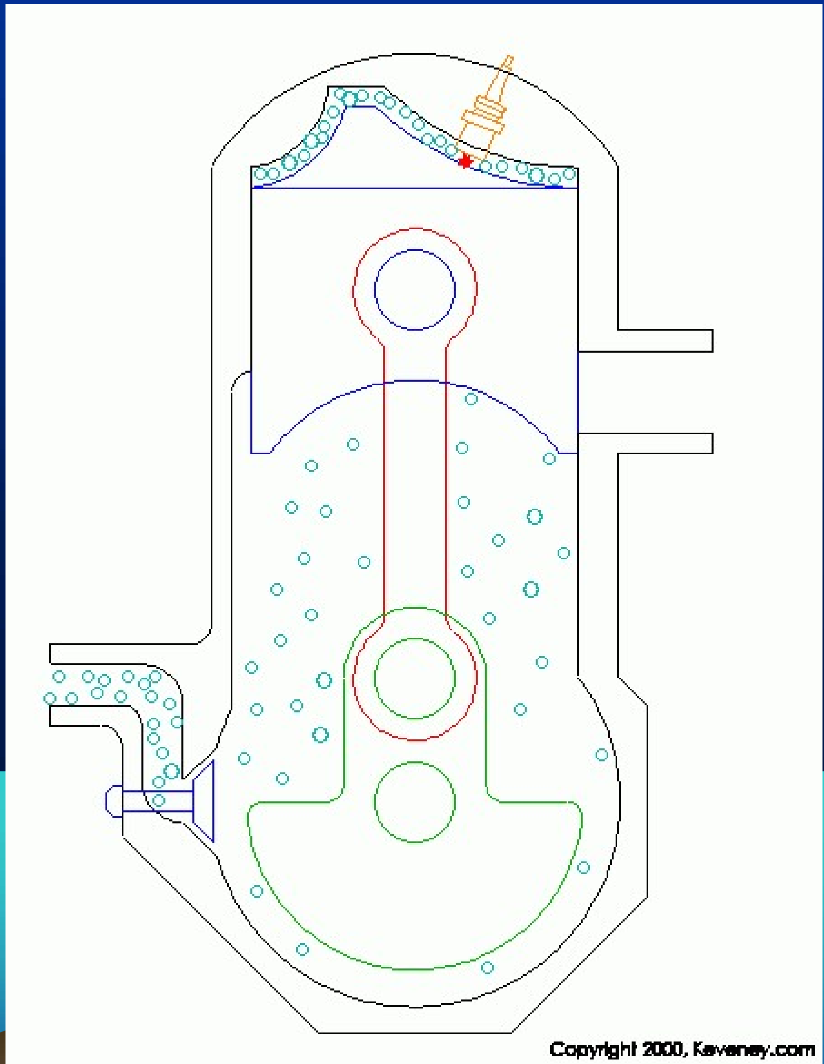
Planar Motion – Particles/Points of Members
move in parallel planes

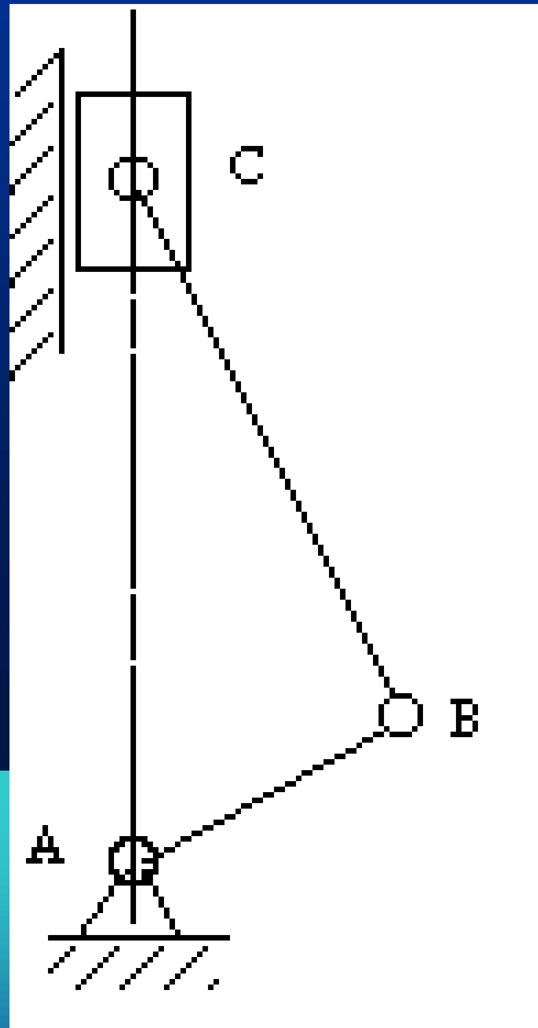
Examples : Planar Four-Bar Mechanism
Slider Crank Mechanism
Cam-Follower Mechanism
Spur/Helical Gear Drives

Four-bar Crank Rocker and Coupler Curve



Two Stroke Engine





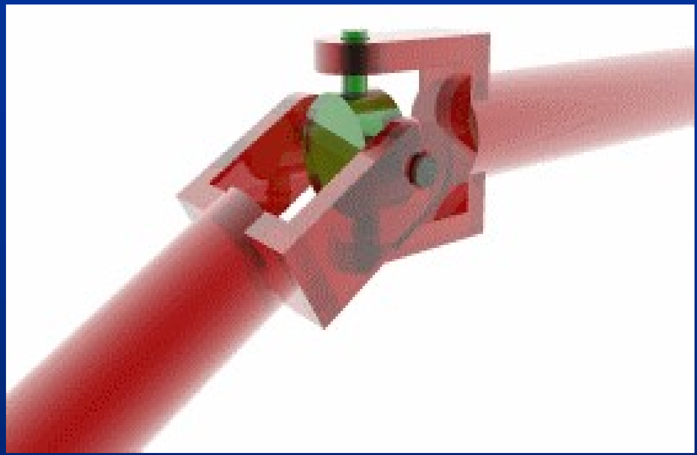
Spherical Mechanism

Spherical Motion – Points maintain Constant Distance w.r.t. a Common Centre Point in any position during motion.

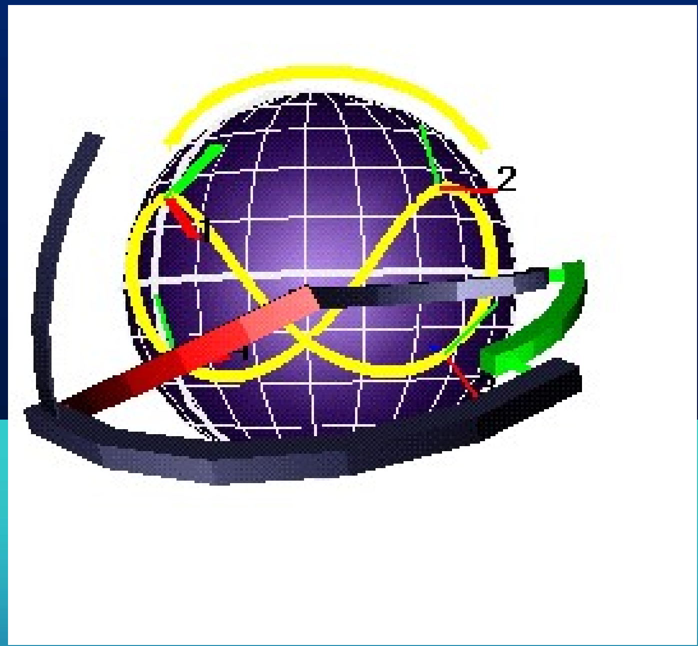
Examples : Universal Joint

Bevel Gear Drive

Spherical Four-Bar Mechanism




C3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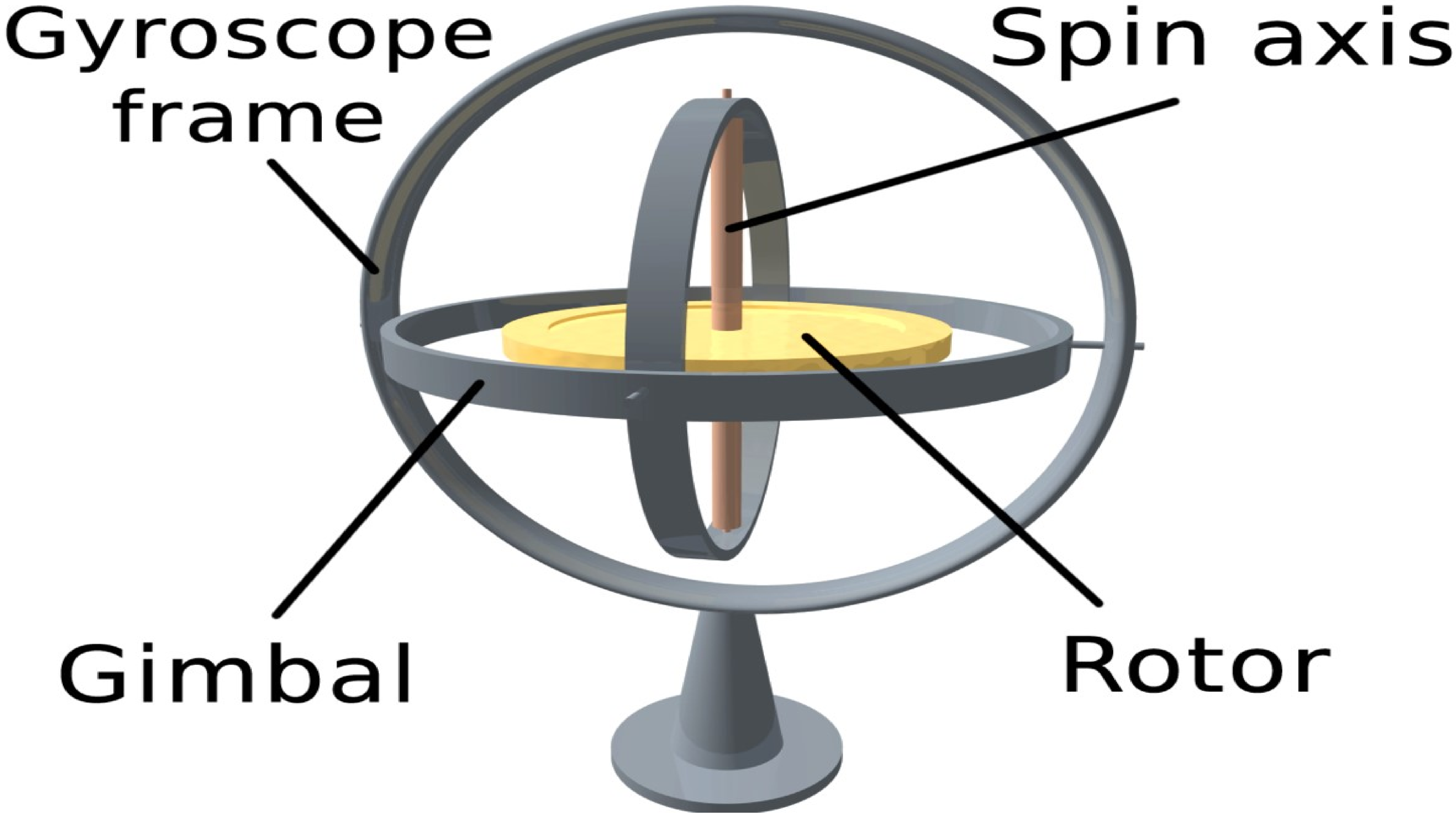
UNIT-3
GYROSCOPE AND PRECESSIONAL MOTION

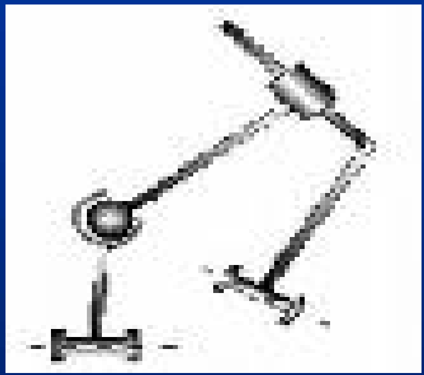
GYROSCOPE

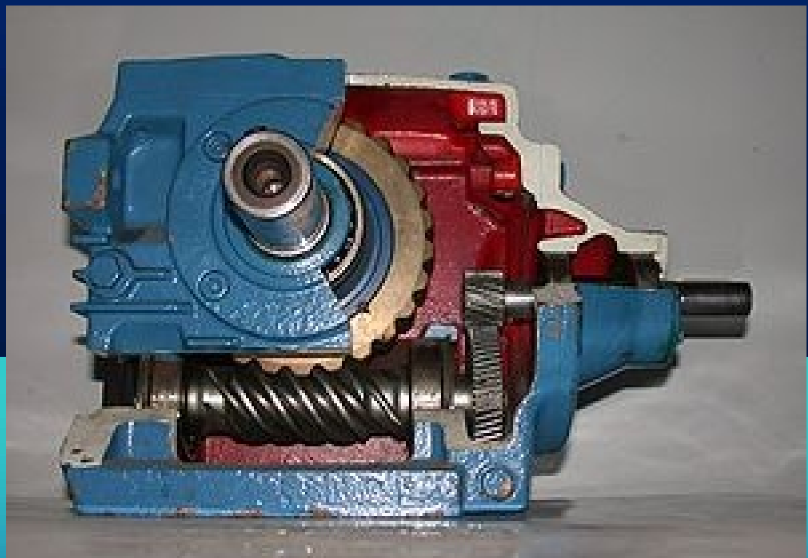


Spatial Mechanism

- Spatial Motion – Points can occupy any
- Position in space

- Examples : Spatial Four-Bar Mechanism
- Worm Gear Drive
- Serial Manipulators





Classification of mechanisms

- Based on the connection of the output member

- Open mechanism
- Closed mechanism

Open Mechanism

- Output member not connected to the fixed link / frame

- Robot arms
- Arms of earth movers




Closed Mechanism

- Output member connected to the frame.

- Four-bar mechanism
- Slider-crank mechanism
- Cam follower mechanism

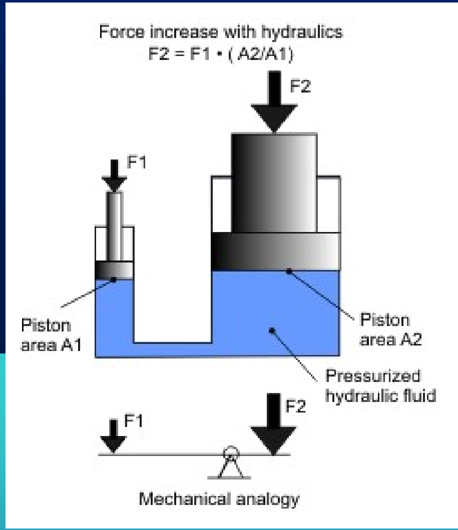
Components of Mechanisms

- Link / element
- Kinematic pairs / joints
- Kinematic chain

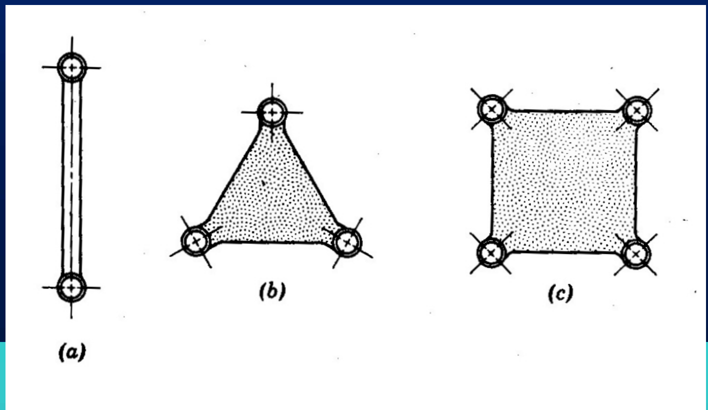
Link / Element

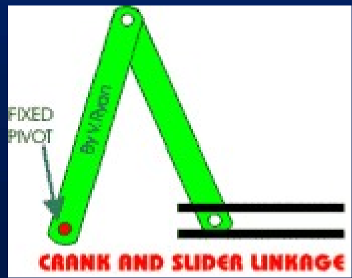
A single resistant body / combination of resistant bodies having relative motion with another resistant body / combination of resistant bodies.

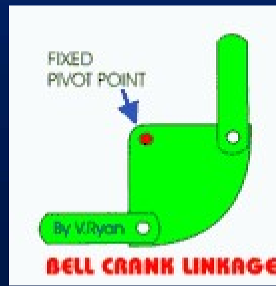
Rigid Body | Flexible Body | Liquid



- Link with one Node : Unary Link
- Link with two Nodes : Binary Link (a)
- Link with three Nodes : Ternary Link (b)
- Link with four Nodes : Quaternary Link (c)







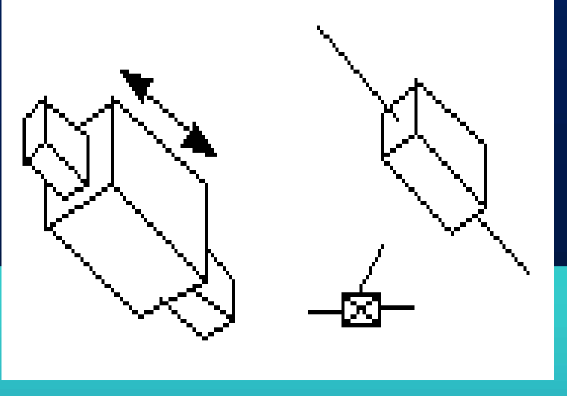
Kinematic Pairs / Joints

- Combination of two links kept in permanent contact permitting particular kind(s) of relative motion(s) between them

Classification of Pairs

- BASED ON NATURE OF CONTACT BETWEEN LINKS:

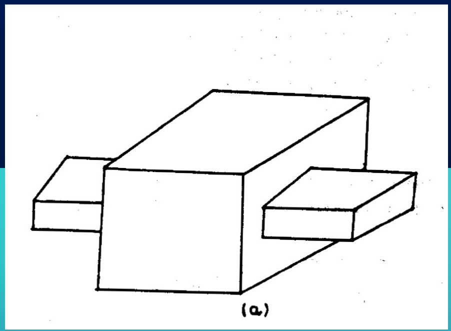
  1. Lower Pairs -- Surface Contact
  2. Higher Pairs – Point or Line Contact

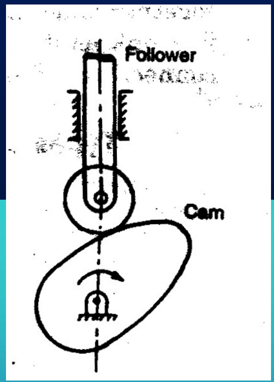


BASED ON HOW THE CONTACT IS MAINTAINED:

1. Self / Form Closed Pairs – Shape/Form of the links maintain the contact. No external force.

2. Force Closed Pairs – External forces like gravitational force, spring force etc., required to maintain the contact.



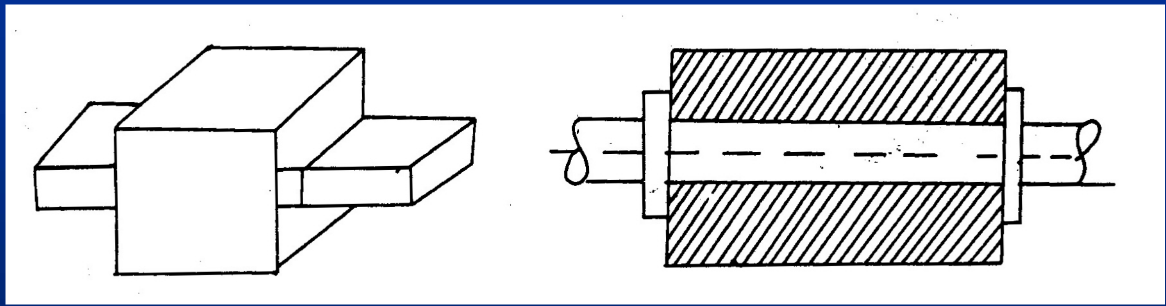


- BASED ON THE DEGREE OF FREEDOM
    1. Type I / Class I – One D.O.F
    2. Type II / Class II – Two D.O.F
    3. Type III / Class III – Three D.O.F
    4. Type IV / Class IV – Four D.O.F
    5. Type V / Class V – Five D.O.F

BASED ON THE NATURE OF CONSTRAINT

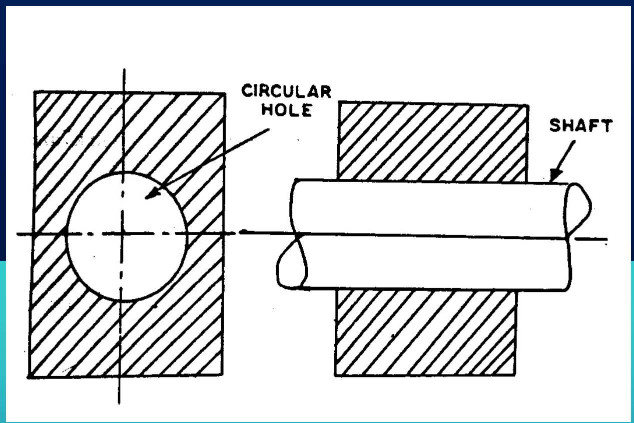
1. (Completely) Constrained Pair - 1 D.O.F
2. Unconstrained Pair – More than 1 D.O.F
3. Successfully Constrained pair – Unconstrained pair converted as Constrained pair by some means.

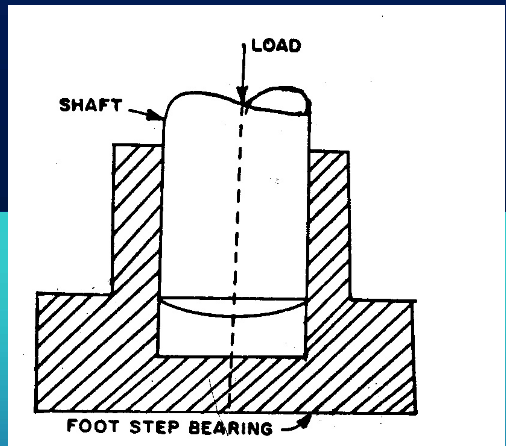
- Completely Constrained Pair



- Successfully Constrained Pair

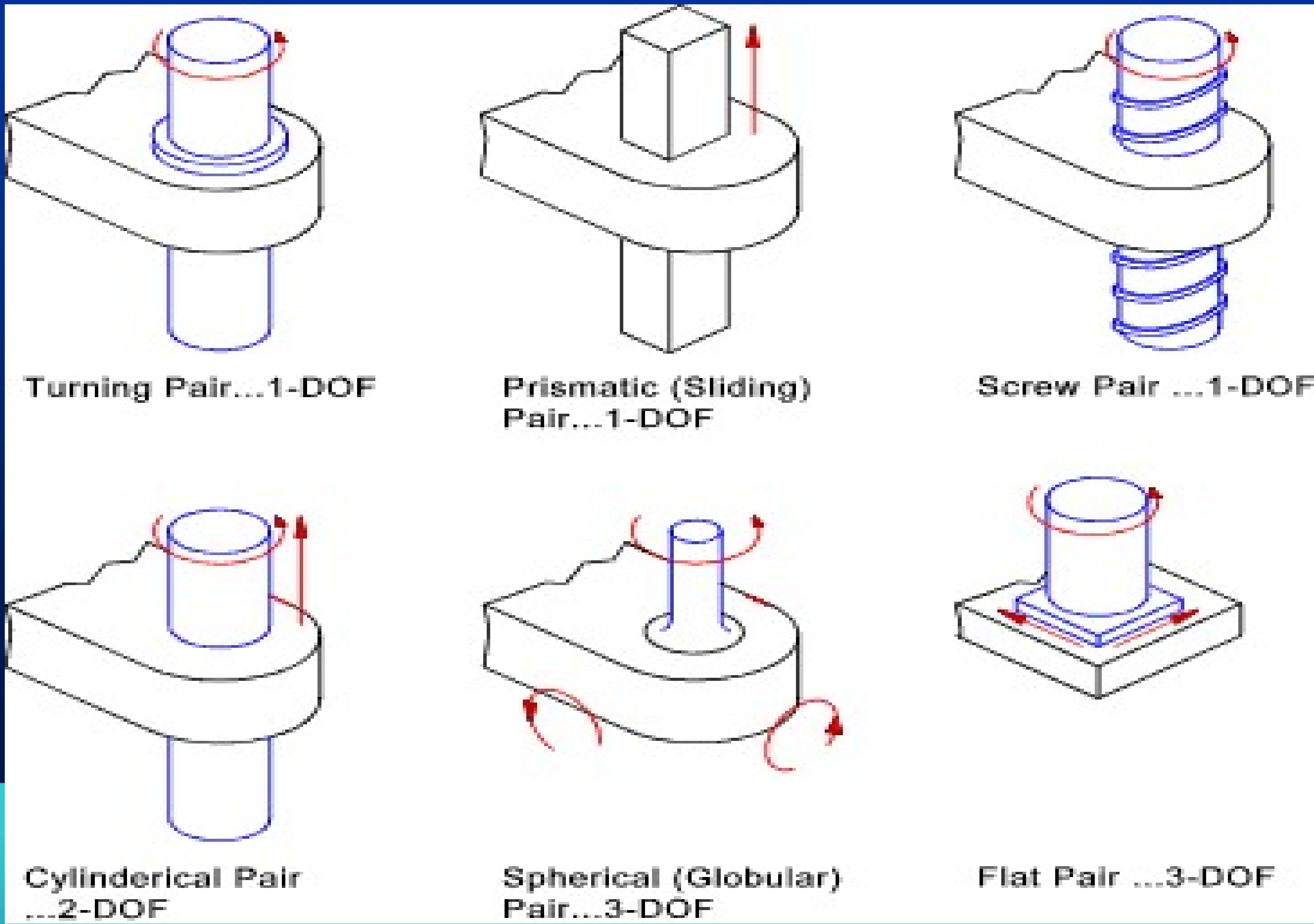
Unconstrained Pair

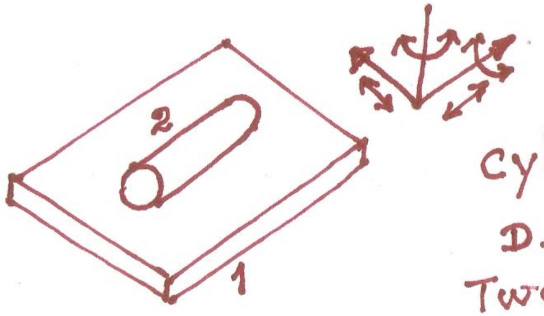




- BASED ON THE POSSIBLE MOTIONS (Few Important Types only)

Name of Pair	Letter Symbol	D.O.F
1. Revolute / Turning Pair	R	1
2. Prismatic / Sliding Pair	P	1
3. Helical / Screw Pair	H	1
4. Cylindrical Pair	C	2
5. Spherical / Globular Pair	S (or) G	3
6. Flat / Planar Pair	E	3
7. Cylindric Plane Pair	Cp	4
8. Spheric Plane Pair	Sp	5

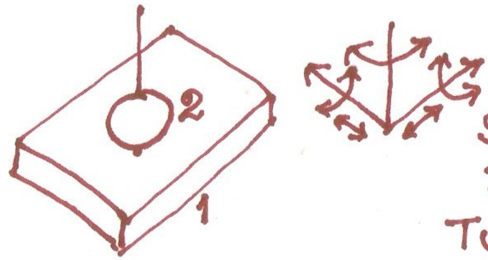

Turning Pair...1-DOF
Prismatic (Sliding) Pair...1-DOF
Screw Pair ...1-DOF
Cylinderical Pair ...2-DOF
Spherical (Globular) Pair...3-DOF
Flat Pair ...3-DOF



Cylindric Plane Pair
Cp

D.O.F - 4

Two Tramslations,
Two Rotations



Spheric Plame Pair

D.O.F - 5

Two Tramslatioms
Three Rotations

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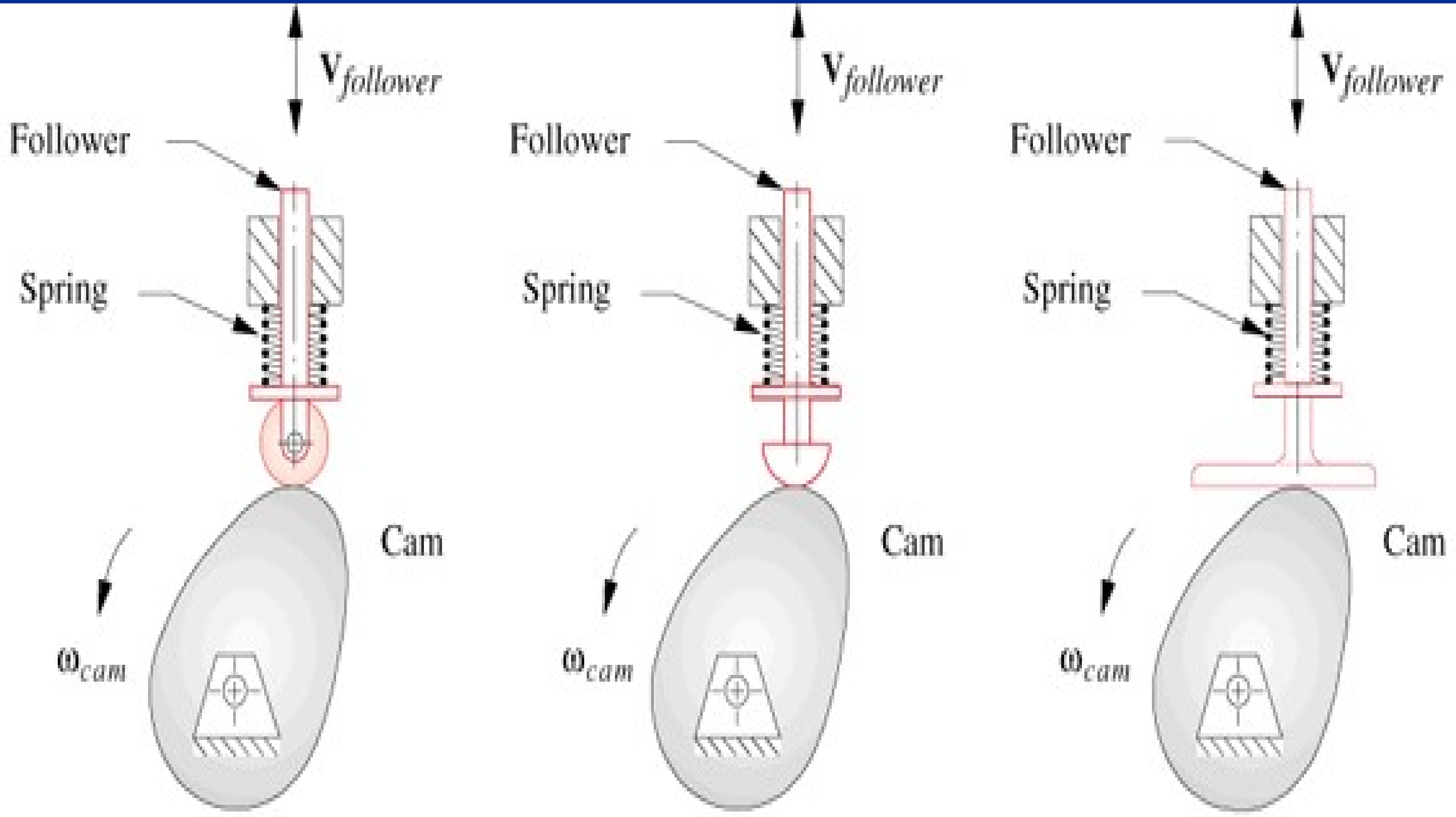
Kinematic Chain

- Assembly of links and pairs to produce required / specified output motion(s) for given input motion(s)

UNIT-4
CAMS AND FOLLOWERS

CAMS AND FOLLOWERS

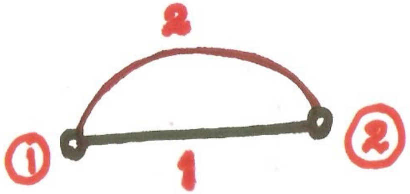


(a) Roller follower (b) Mushroom follower (c) Flat-faced follower

Mobility / D.O.F of Mechanism

- No. of inputs required to get a constrained mechanism (or) no. of position variables needed to sketch the mechanism with all link lengths known.

- KUTZBACH CRITERION FOR PLANAR MECHANISM
- $$F = 3(n-1)-2P_1-1P_2$$
- F – D.O.F n – No. of links
- P_1 – No. of kinematic pairs with 1 D.O.F.
- P_2 – No. of kinematic pairs with 2 D.O.F.



$n = 2$

$P_1 = 2$

$P_2 = 0$

$F = 3(2-1) - 2\times 2 - 1\times 0$

$= 3 - 4 - 0$

$= -1$

This is a Pre-loaded structure/ Super structure.

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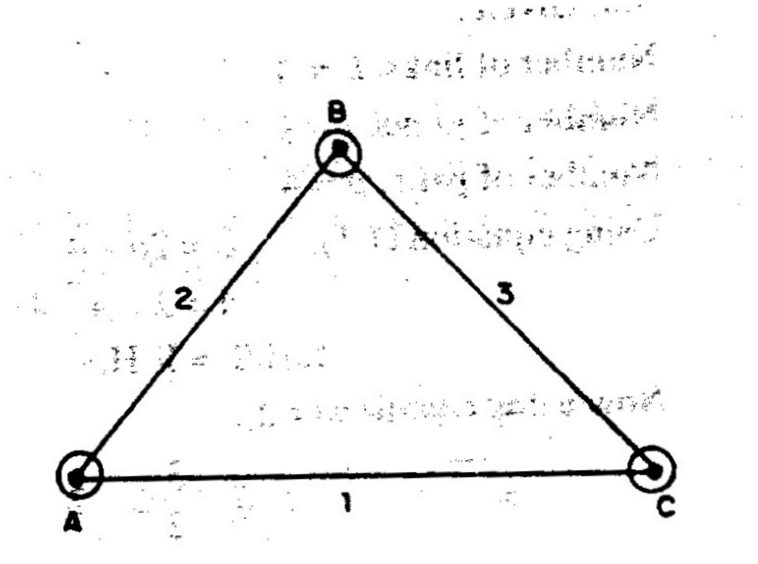
DETERMINATION OF D.O.F



$n = 3$

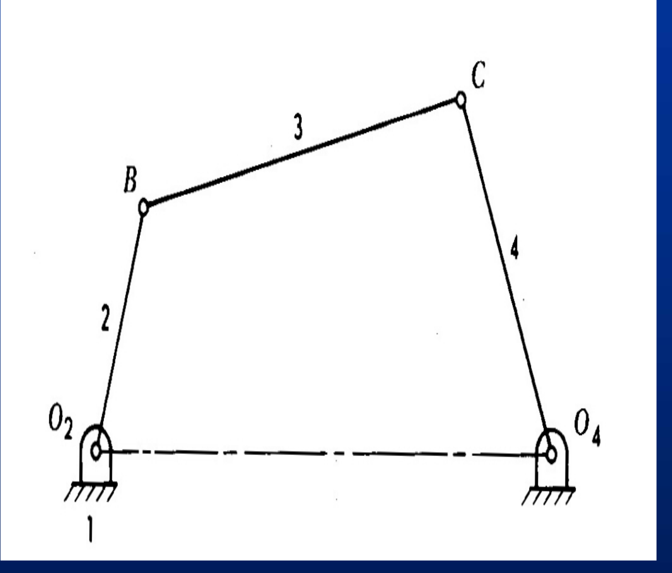
$P_1 = 3$

$P_2 = 0$

$F = 3 \times (3 - 1) - 2 \times 2 - 1 \times 0$

$= 6 - 6 - 0 = 0$

This is a STRUCTURE



$n = 4$

$P_1 = 4$

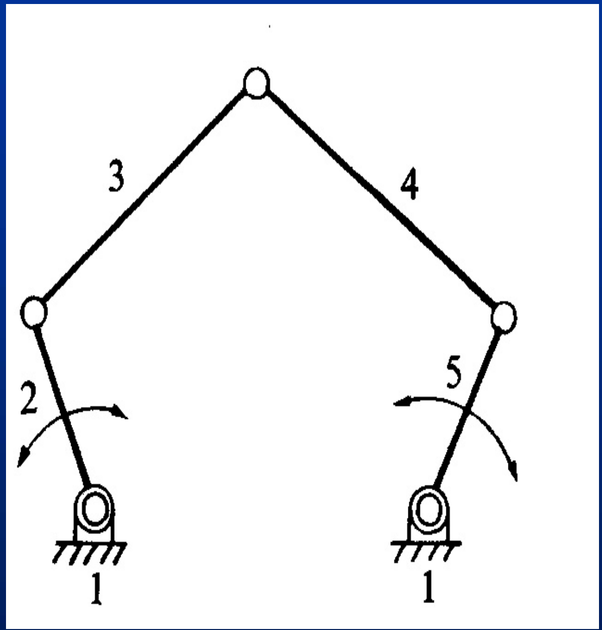
$P_2 = 0$

$F = 3x(4 – 1) – 2x4 – 1x0$

$= 9 – 8 – 0$

$= 1$

This is a Constrained Mechanism.



$n = 5$

$P_1 = 5$

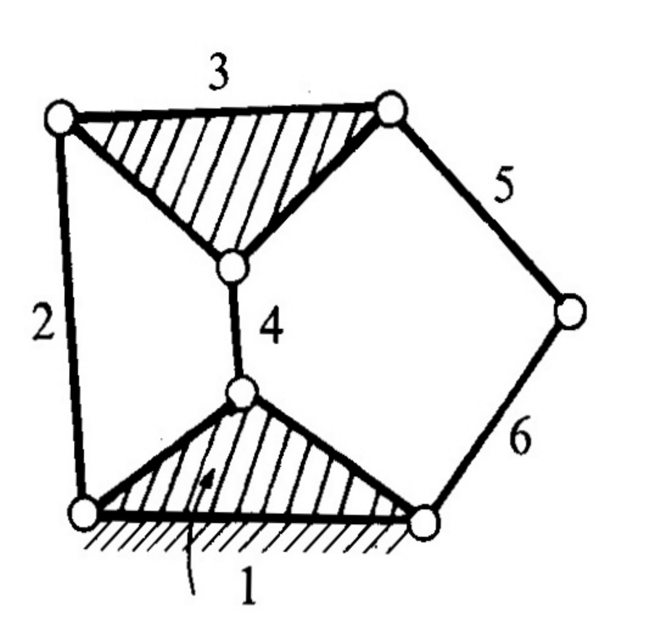
$P_2 = 0$

$F = 3 \times (5 - 1) - 2 \times 5 - 1 \times 0$

$= 12 - 10 - 0$

$= 2$

- This is an Unconstrained Mechanism.



$n = 6$

$P_1 = 7$

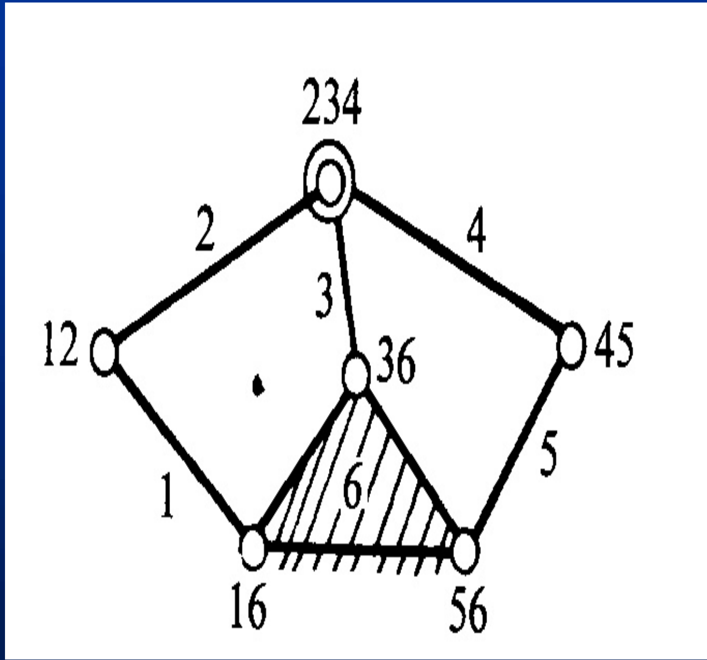
$P_2 = 0$

$F = 3 \times (6 - 1) - 2 \times 7 - 1 \times 0$

$= 15 - 14 - 0$

$= 1$

This is a Constrained Mechanism.



$n = 6$

$P_1 = 7$

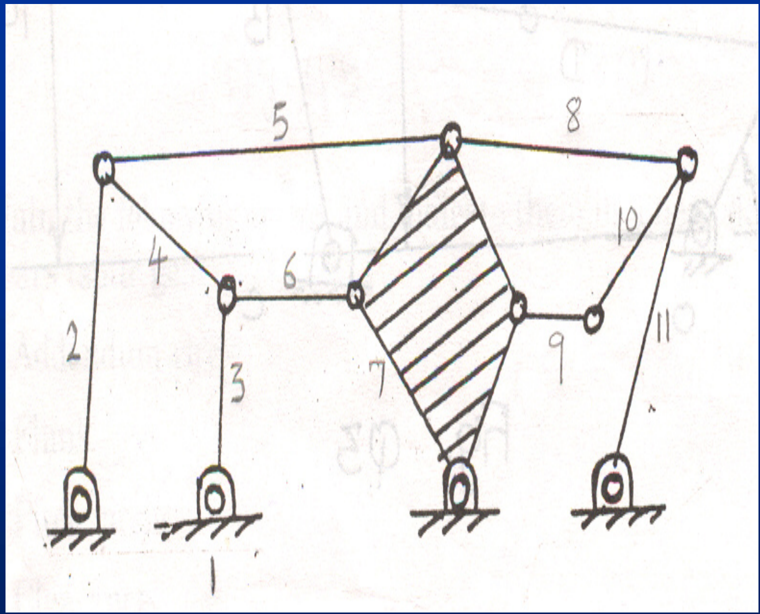
$P_2 = 0$

$F = 3 \times (6 - 1) - 2 \times 7 - 1 \times 0$

$= 15 - 14 - 0$

$= 1$

- This is a Constrained Mechanism.



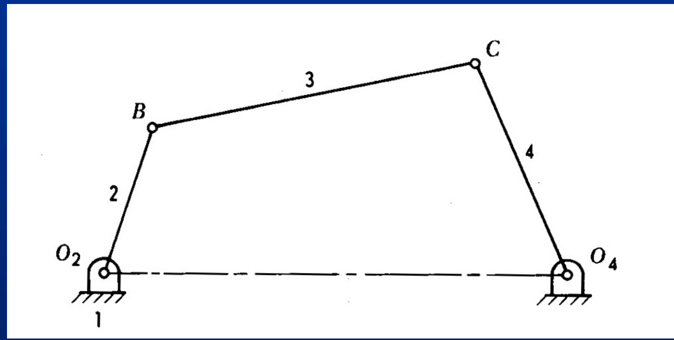
- $n = 11$
- $P_1 = 15$
- $P_2 = 0$
- $F = 3 \times (11 - 1) - 2 \times 15 - 1 \times 0$
- $= 30 - 30 - 0$
- $= 0$
- There are two pairs between Links (2,4,5); (3,4,6); (5,7,8); (8,10,11)
- This is a Structure.

Gruebler's Criterion

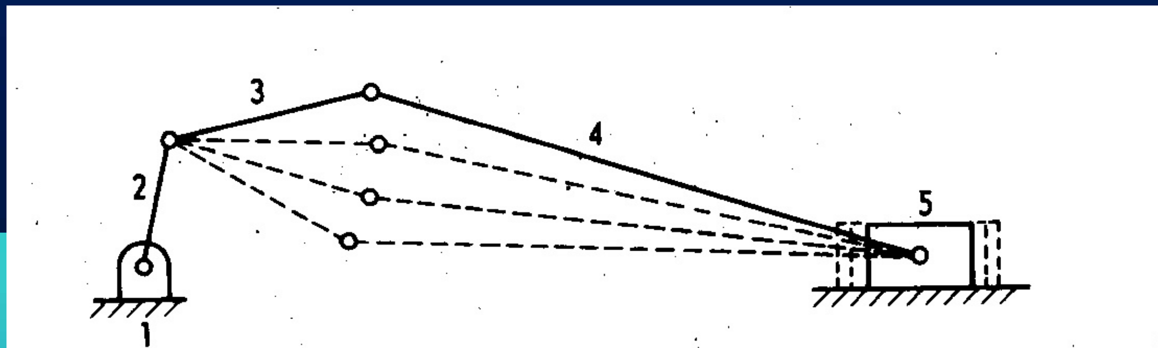
- This criterion is used to find out whether an assembly of links with 1 d.o.f. lower pairs is a constrained mechanism or not.
- $$3n - 2l - 4 = 0$$
- n – no. of links   l – no.of lower pairs with one d.o.f

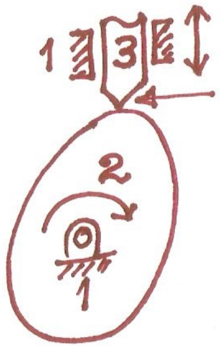
$F < 0$	Pre-loaded structure Super structure
$F = 0$	Structure
$F = 1$	Constrained Mechanism
$F > 1$	Unconstrained Mechanism

- Constrained Mechanism



- Unconstrained Mechanism





2 - 3
Slip-Rolling Pair
(Higher Pair)

1 - 2 R

3 - 1 P

$n = 3$

$P_1 = 2$

$P_2 = 1$

$$F = 3(3-1) - 2\times 2 - 1\times 1$$
$$= 6 - 4 - 1$$
$$= 1$$

This is a constrained mechanism.

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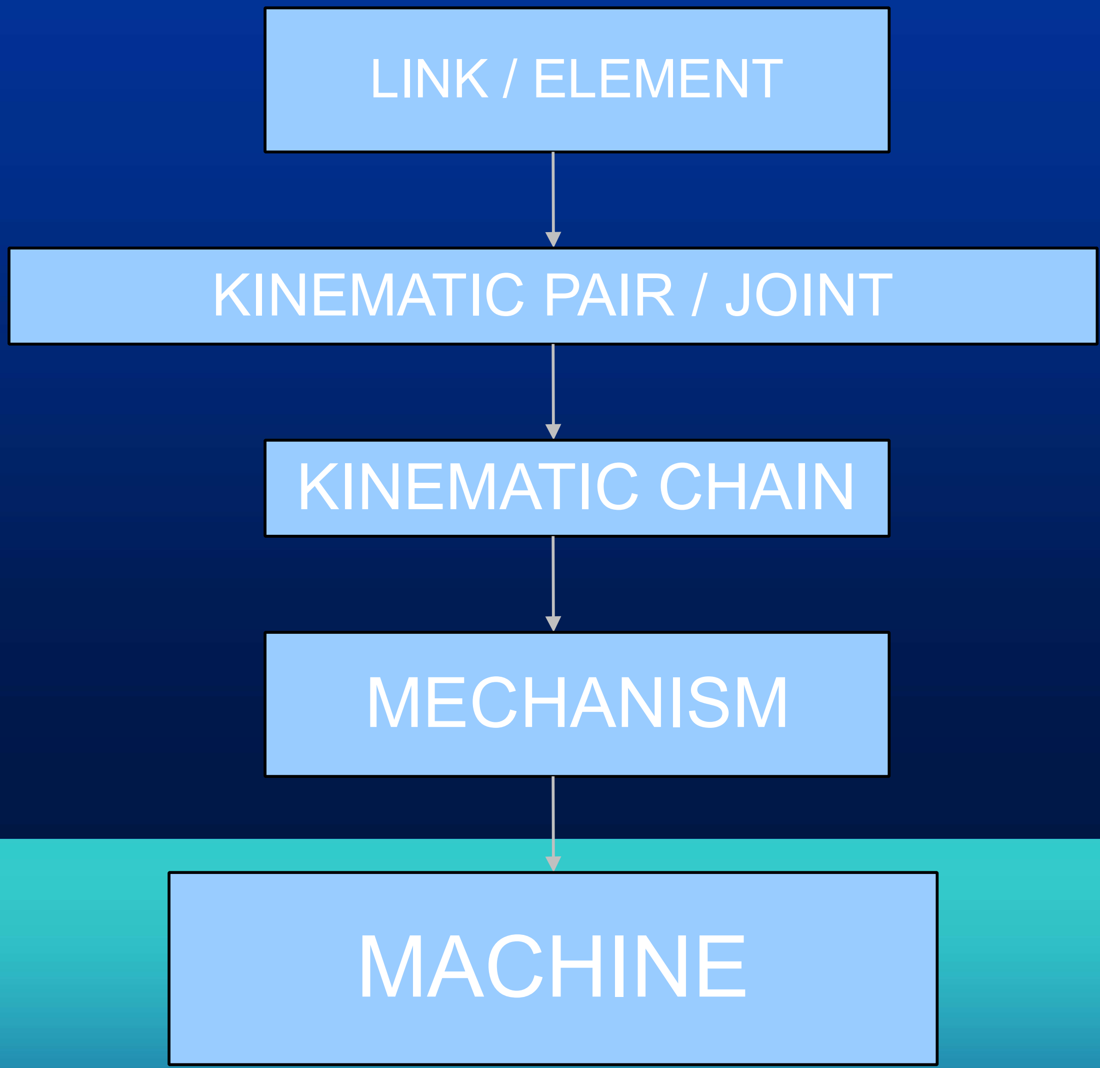
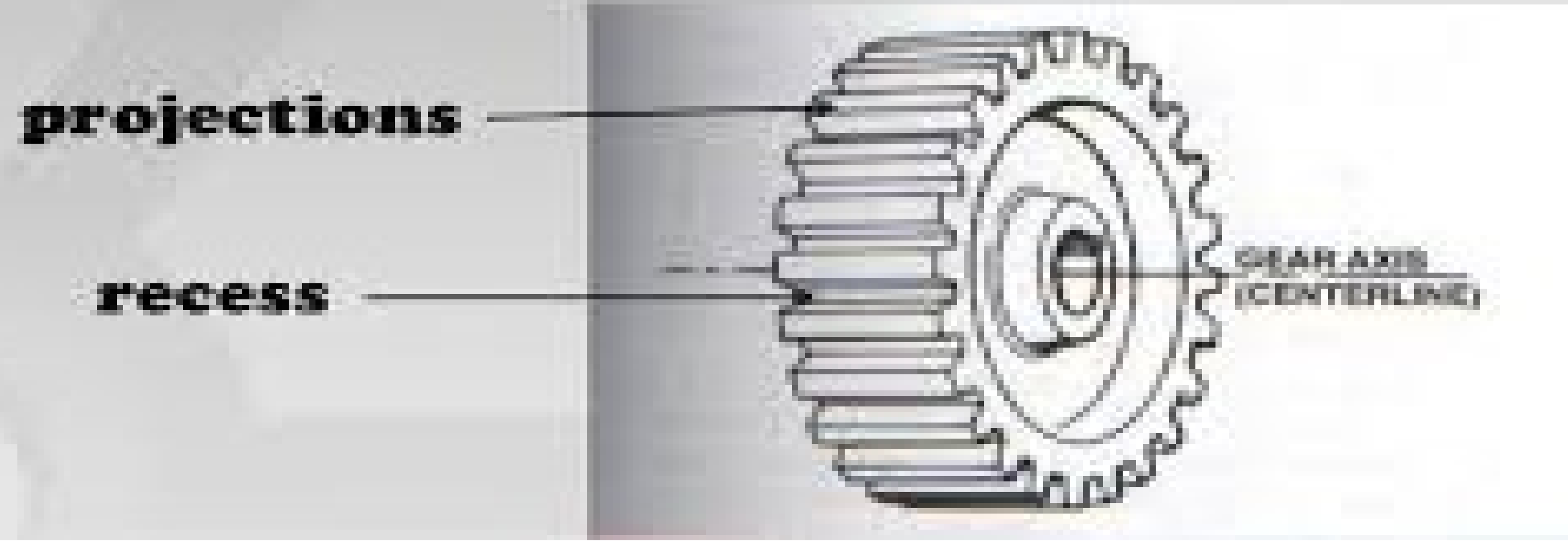

LINK / ELEMENT
KINEMATIC PAIR / JOINT
KINEMATIC CHAIN
MECHANISM
MACHINE

UNIT-5
GEARS AND GEAR TRAINS

GEARS AND GEAR TRAINS

WHAT ARE GEARS???

- A friction wheel with teeth cut on it, i.e. ; a synchronous arrangement of projections and recesses on a wheel.

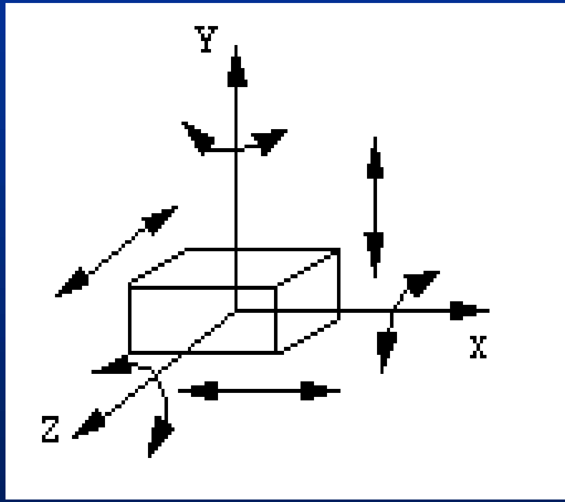


- Link / Element – A resistant body which has relative motion with another resistant body of a system.
-
- Kinematic Pair / Joint - Combination / Assembly of two links kept in permanent contact, permitting particular kind(s) of definite relative motion(s) between them.
- Kinematic Chain – Combination / Assembly of links and pairs such that each link has minimum two pairs, permitting controlled definite output motion for a specified input motion.
- Mechanism – A kinematic chain with one link fixed / stationary.
- Machine – A device, which has one or more mechanisms, transferring / transforming motion and energy to do required useful work easily.

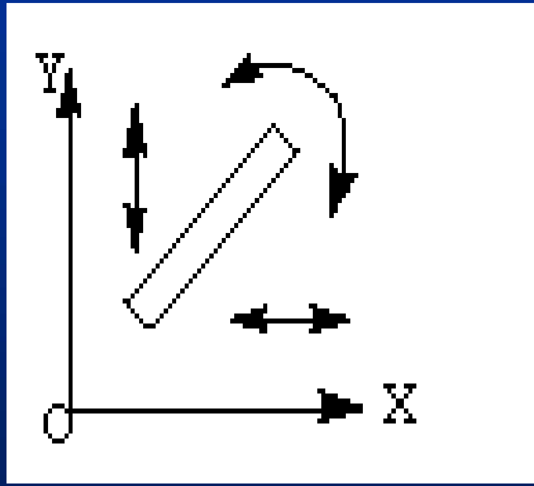
MOBILITY OR DEGREE OF FREEDOM

- For a Link – Six in spatial motion, three in planar motion.
- For a Kinematic Pair – Number of independent co-ordinates/pair variables to specify the position of one link with another link (OR) number of independent relative motions possible between the links. Maximum five and minimum one in spatial motion. Maximum two and minimum one in planar motion.
- For a Kinematic Chain/Mechanism – Number of independent position variables to sketch the configuration with known link lengths (OR) number of input motions required to get a constrained output motion

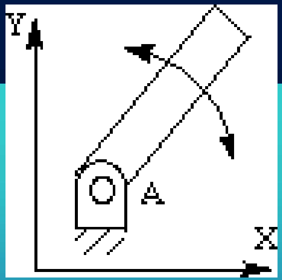
Spatial D.O.F.



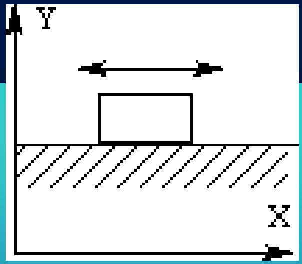
Planar D.O.F.



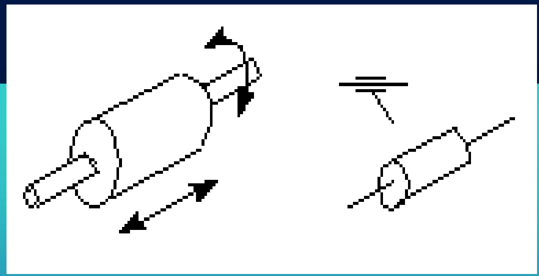
R – Pair



P – Pair



C - Pair



Kinematic Inversions

- Process of obtaining different mechanisms from the same kinematic chain, by fixing different links in turn, is known as kinematic inversion.

Four inversions are possible from four-bar kinematic chain.

Formation of four-bar mechanism

- No. of links – 4,   No. of pairs – 4.
- All the pairs are revolute pairs.
- Links are :1. Fixed link or Frame
- 2. Input Link
- 3. Coupler
- 4. Output link or Follower

Assembly Condition

- Lengths of links: Longest link - l
  Shortest link - s
  Intermediate links – p, q

$$l < s + p + q$$

Grashofian four-bar mechanism

- Atleast one link will have full rotation if

$$S + l \leq p + q$$

GRASHOF' S LAW

In a planar four bar revolute pair kinematic chain if the sum of the lengths of the shortest and the longest links is less than or equal to the sum of the lengths of the other two intermediate links at least one link will have full rotation.

Mechanisms obtained from the kinematic chain satisfying these conditions are known as Grashofian Mechanisms.

Mechanisms obtained from the kinematic chain which are not obeying these conditions are known as Non-Grashofian Mechanisms.

Inversions of four bar Mechanisms are named based on the motions of input link and output link.

Crank - Link with 360 degree rotation

Rocker/Lever – Link with less than 360 degree rotation

Four- bar Inversions

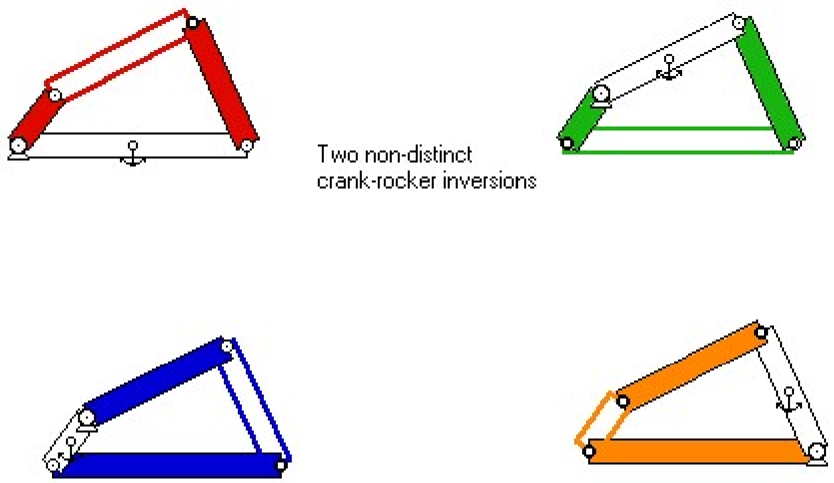
- Crank – Rocker Mechanisms (Two)
- Drag Link / Double Crank Mechanism
- Double – Rocker Mechanism
- Above are Grashofian Inversions
- All four non-Grashofian inversions are Double – Rocker mechanisms

Rockers of Grashofian Mechanisms will have less than 180 degree rotation.

Rockers of Non-Grashofian Mechanisms can have greater than 180 degree rotation.

Inversion of the kinematic chain depends upon which link is fixed.

All inversions of the Grashof fourbar linkage



Two non-distinct crank-rocker inversions

Double-crank inversion (drag link)

Double-rocker inversion (coupler rotates)

Created for "Design of Machinery, 3rd ed." by R. L. Norton and "The Multimedia Handbook of Mechanical Devices" by S. Wang

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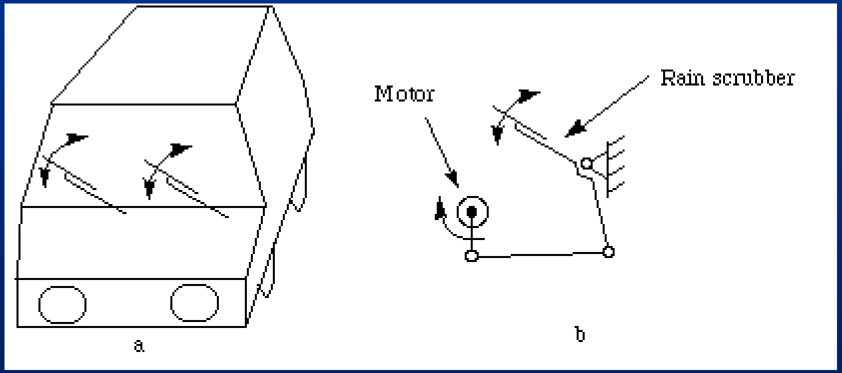
grashof_inversion

Conditions for Inversions

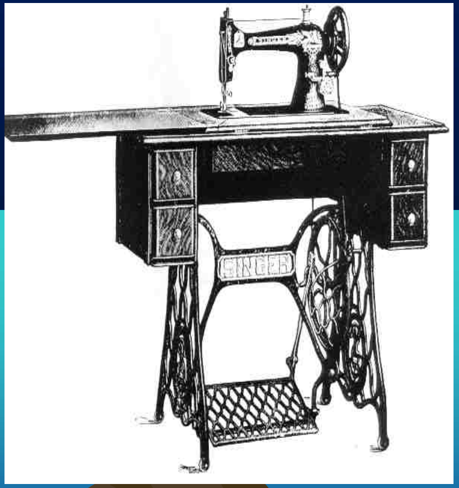
POSITION OF SHORTEST LINK	F0UR – BAR INVERSION
Adjacent to the fixed link	Crank – Rocker
Fixed link itself	Drag Link (Double Crank)
Opposite to fixed link	Double Rocker

Examples for Crank – Rocker Mechanism

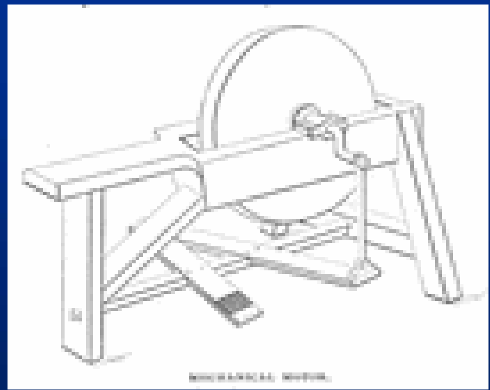
1. Wind shield wiper mechanism on Driver Side



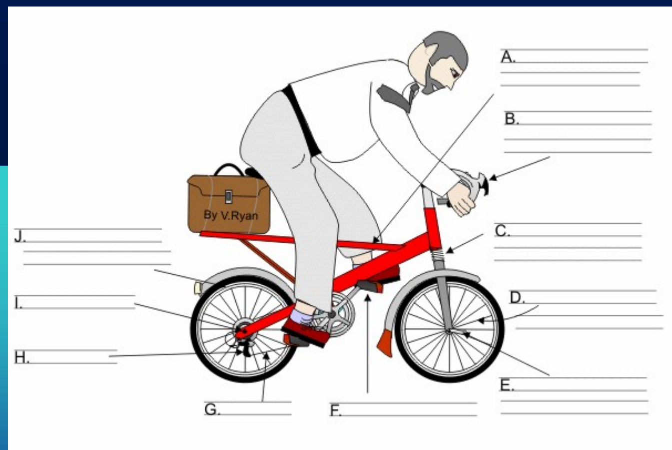
2. Sewing Machine Treadle Mechanism



3. Grinding Wheel Treadle Mechanism

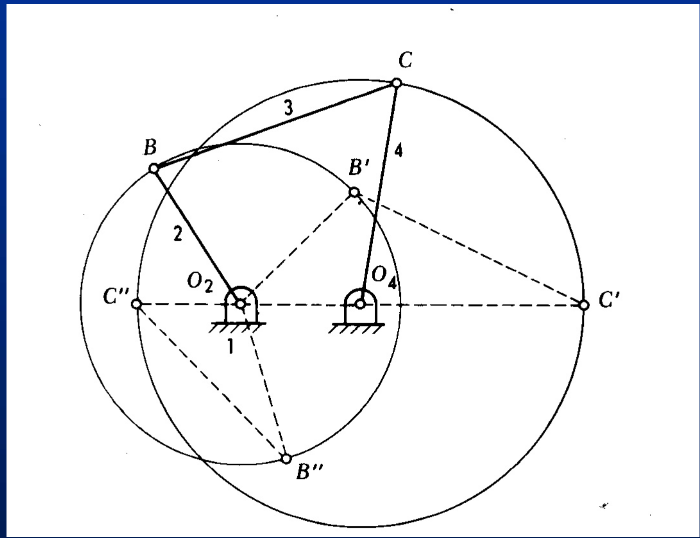


4. Pedaling action of a Bicycle

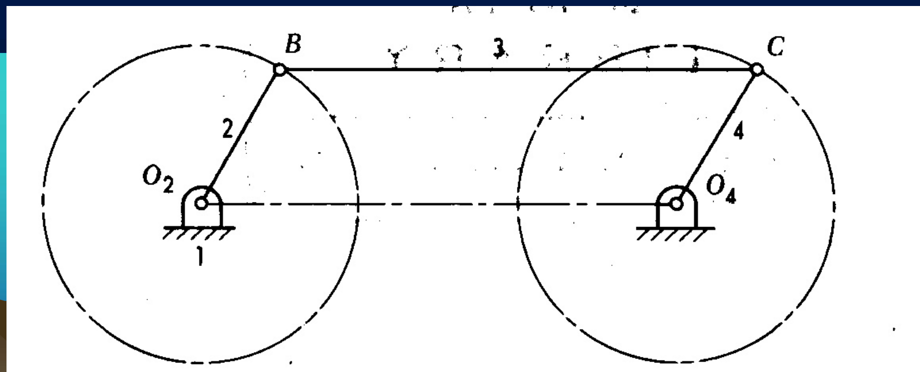


Example for Double Crank / Drag Link Mechanism

1.

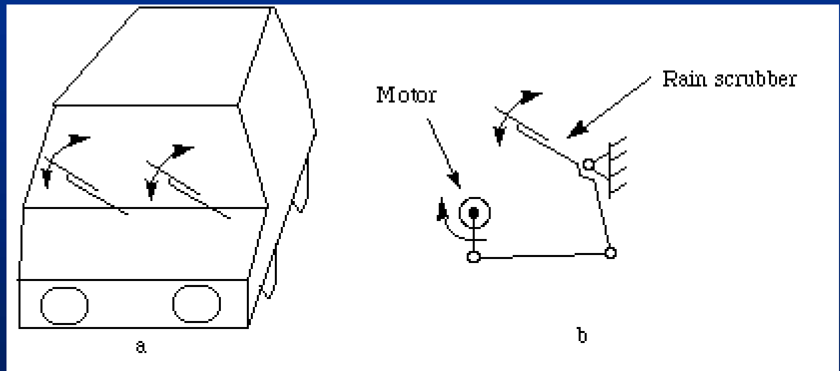


2. Locomotive Wheels Mechanism

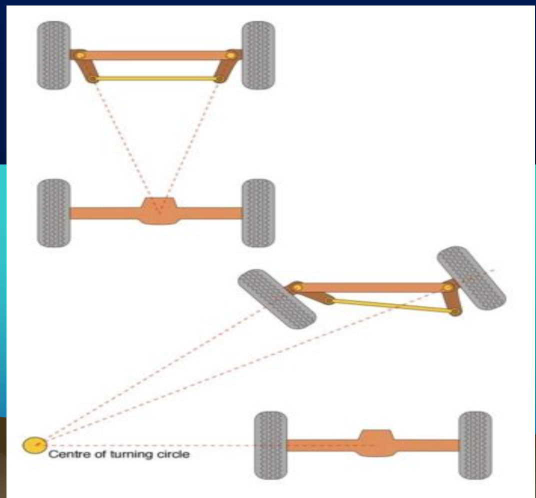


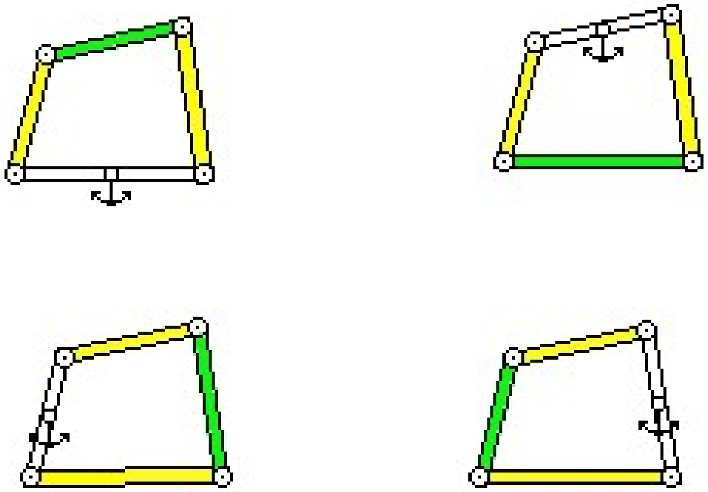
Example for Double Rocker Mechanism

1. Wind Shield wiper on Passenger Side



2. Ackerman's Steering Gear Mechanism





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inversions_non-grashof