Toppersnotes
Unleash the topper in you

ENGINEERS ACADEMY

RPSC - A.En.

Assistant Engineering

MECHANICAL

Rajasthan Public Service Commission (RPSC)

Volume - 3

Theory of Machines (TOM)

SIERRA INNOVATIONS

MECHANISMS, MACHINES AND PLANER MECHANISM

THEORY

1.1 Mechanisms

If a number of bodies are assembled in such a way that the motion of one causes constrained and predictable motion to the other, it is known as a *mechanism.*

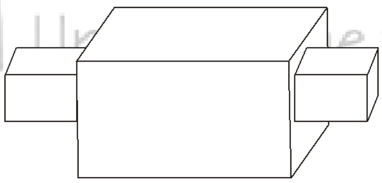
A mechanism transmits and modifies a motion.

A *machine* is a mechanism or a combination of mechanisms which, apart from imparting definite motions to the parts, also transmits and modifies the available mechanical energy in to some kind of desired work.

1.2 Types of Motion

1.2.1 Completely constrained Motion

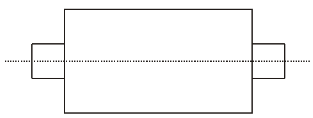
When the motion between two elements of a pair is in a definite direction irrespective of the direction of the force applied, it is known as completely constrained motion. The constrained motion may be linear or rotary.



1.2.2 Incompletely Constrained Motion

When the motion between two elements of a pair is possible in more than one direction and depends upon the direction of the force applied.

Ex.: Circular shaft inside circular hole.

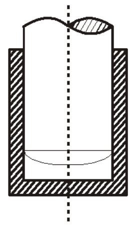


1.2.3 Successfully Constrained Motion

When the motion between two elements of a pair is possible in more than one direction but is made to have motion only in one direction by using some external means, it is a successfully constrained motion, For example

(i) A shaft in a footstep bearing.

(ii) Piston reciprocating inside a cylinder in an IC engine.



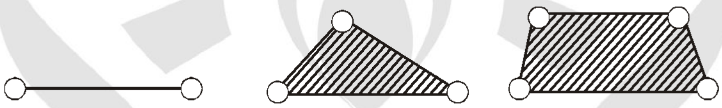
Footstep bearing

1.3 Rigid And Resistant Bodies

- A body is said to be rigid if under the action of forces, it does not suffer any distortion or the distance between any two points on it remains constant.
- Resistant bodies are those which are rigid for the purposes they have to serve. A belt is rigid when subjected to tensile forces. Therefore, the belt-drive acts as a resistant body.

1.4 Link

Every part of machine which is having the relation motion with respect to some other part is known as kinematic link/element.



Binary link Ternary link Quaternary link

Links can be classified into binary, ternary and quaternary depending upon their ends on which revolute or turning pairs can be placed.

1.5 Kinematic Pair

A kinematic pair or simply a pair is a joint of two links having relative motion between them.

Types of Kinematic Pairs : Kinematic pairs can be classified according to

- Types of contact.
- Types of mechanical constraint.
- Types of relative motion.

1.5.1 Kinematic Pairs According to Types of Contact

(i) **Lower Pair :** A pair of links having surface or area contact is know as a lower pair. The contact surfaces of the two links are similar.

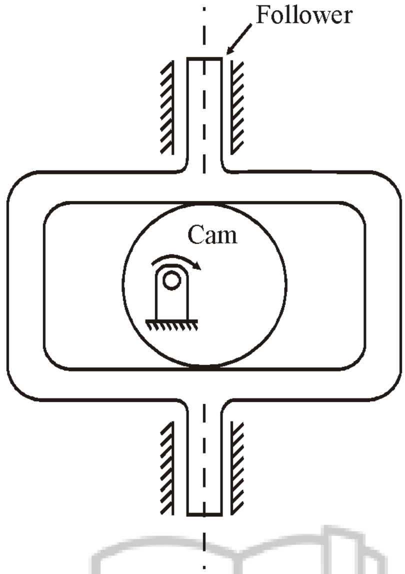
Ex.: Nut turning on a screw, shaft rotating in a bearing, all pairs of a slider-crank mechanism, universal joint etc.

(ii) **Higher Pair :** When a pair has a point or line contact, it is known as a higher pair. The contact surfaces of the two links are dissimilar.

Ex.: Wheel rolling on a surface, cam and follower pair, tooth gears, ball and roller bearings, etc.

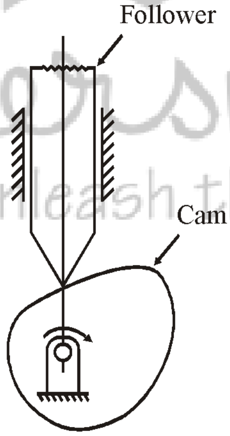
1.5.2 Kinematic Pairs According to Types of Mechanical Constraint

(i) Closed Pair : When the elements of a pair are held together mechanically, it is known as a closed pair.



All the lower pairs and some of the higher pairs are closed pairs.

(ii) Open Pair (Forced Close Pair) : When two links of a pair are in contact either due to force of gravity or some spring action, they constitute an open pair.



1.5.3 Kinematic Pairs according to Nature of Relative Motion

(i) **Sliding Pair :** If two links have a sliding motion relative to each other, they form a sliding pair.

(ii) **Turning Pair :** When one link has a turning or revolving motion relative to the other, they constitute a turning or revolving pair.

(iii) **Rolling Pair :** When the links of a pair have a rolling motion relative to each other, they form a rolling pair.

(iv) **Screw Pair (Helical Pair) :** If two mating links have a turning as well as sliding motion between them, they form a screw pair.

(v) Spherical Pair : When one link in the form of a sphere turns inside a fixed link, it is a spherical pair.

1.6 Types of Joint

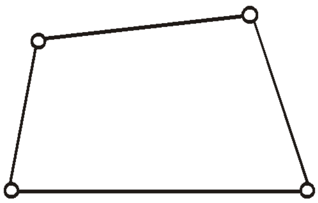
(i) Binary Joint : If two links are joined at the same connection.

(ii) Ternary Joint : If three links are joined at a connection.

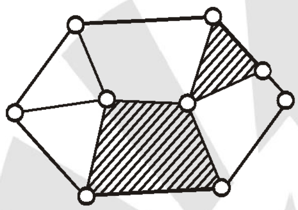
(iii) Quaternary Joint : If four links are joined at a connection.

1.7 Kinematic Chain

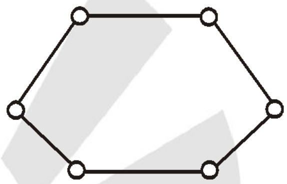
A kinematic chain is an assembly of links in which constrained relative motions of the links is possible and first link attached with last link.



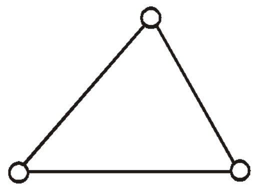
Kinematic chain



Kinematic chain



Non-Kinematic chain



Redundant chain

In case the motion of a link results in indefinite motions of other links, it is non-kinematic chain.

1.8 Linkage, Mechanism and Structure

- A linkage is obtained if one of the links of a kinematic chain is fixed to the ground. If motion of any of the moveable links results in definite motion of the others, the linkage is known as a mechanism.
- If one of the links of redundant chain is fixed, it is known as a structure or a locked system.
- The degree of freedom of a structure or a locked system is zero. A structure with negative degree of freedom is known as a superstructure.

1.9 Mobility of Mechanism

Expressing the number of degrees of freedom of a linkage in terms of the number of links and the number of pair connections of different types is known as number synthesis.

N = total number of links in a mechanism

F = degrees of freedom

P_1 = number of pairs having one degree of freedom

P_2 = number of pairs having two degrees of freedom and so on.

In a mechanism, one link is fixed.

Number of movable links = N − 1

Number of degrees of freedom of (n − 1) movable links = 6(N − 1)

$$F = 6(N-1) - 5P_1 - 4P_2 - 3P_3 - 2P_4 - P_5$$

For plane mechanisms, the following relation may be used to find the degrees of freedom.

$$F = 3(N - 1) - 2P_1 - 1P_2$$

This is known as Gruebler's criterion for degrees of freedom of plane mechanisms in which each movable link possesses three degrees of freedom.

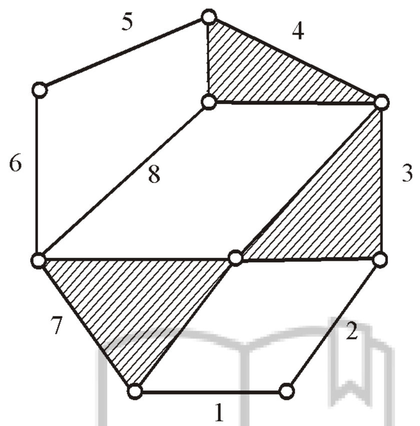
Some authors mention the above relation as Kutzback's criterion and a simplified relation

$$F = 3(N - 1) - 2P_1$$

Which is applicable to linkages having pairs with a single degree of freedom only as Grubler's criterion.

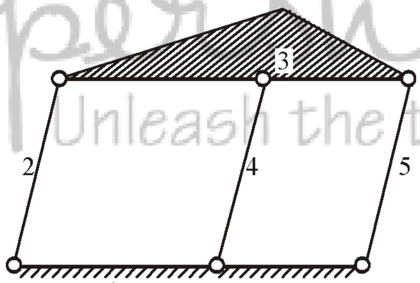
The following emperical relation formulated by the author provide the degree of freedom and the number of joints is a linkage when the number of links and the number of loops in a kinematic chain are known.

These relations are valid for linkages with turning pairs,



$$F = 3(N - 1) - 2P_1$$
$$= 3(8 - 1) - 2 \times 10 = 1$$

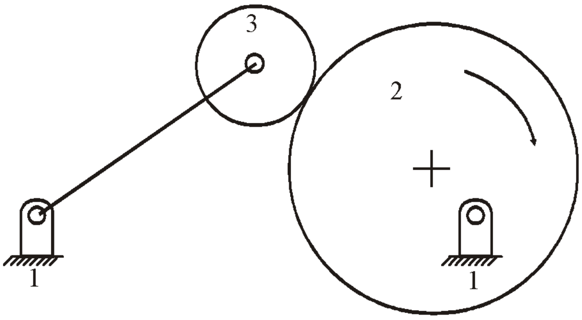
Exceptions are bound to come with equal lengths or parallel links.



$$N = 5$$
$$J = 6$$
$$F = 3(N - 1) - 2P_1$$
$$= 3(5 - 1) - 2 \times 6 = 0$$

Note : But here Degree of freedom F = 1.

Sometimes, a system may have one or more links which do not introduce any extra constraint. Such links are known as redundant links and should not be counted to find the degree of freedom.



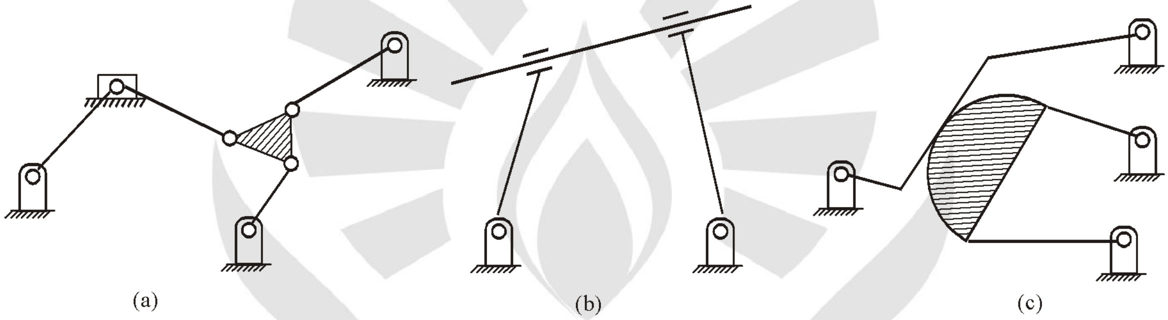
Sometimes, one or more links of a mechanism can be moved without causing any motion to the rest of the links of the mechanism. Such a link is said to have a redundant degree of freedom.

In case of a mechanism possessing some redundant degree of freedom, the effective degree of freedom is given by

$$F = 3(N - 1) - 2P_1 - 1P_2 - F_r$$

Where, F_r = number of redundant degrees of freedom.

Example 1 : Determine the degree of freedom of the mechanisms shown



Solution :

(a) The mechanism has a sliding pair, its degree of freedom must be found from Gruebler's criterion. Total number of links = 8.

Number of pairs with 1 degree of freedom = 10

(At the slider, one sliding pair and two turning pairs)

$$F = 3(N - 1) - 2P_1 - P_2$$
$$= 3(8 - 1) - 2 \times 10 - 0 = 1$$

Thus, it is a mechanism with a single degree of freedom.

(b) The system has a redundant degree of freedom as the rod of the mechanism can slide without causing any movement in the rest of the mechanism.

$\therefore$ Effective degree of freedom $= 3(N - 1) - 2P_1 - P_2 - F_r$

$$= 3(4 - 1) - 2 \times 4 - 0 - 1 = 0$$

(c) The mechanism has a cam pair. Therefore, its degree of freedom must be found from Gruebler's criterion.

Total number of links = 7

Number of pairs with 1 degree of freedom = 8

Number of pairs with 2 degree of freedom = 1

$$F = 3(N - 1) - 2P_1 - P_2$$
$$= 3(7 - 1) - 2 \times 8 - 1 = 1$$

Thus, it is a mechanism with one degree of freedom.

1.10 Four Bar Chain

A four-bar chain consist of four rigid links which are connected in the form of a quadrilateral by four pin-joints.

When one of the links is fixed, it is known as a linkage or mechanism.

A link that makes complete revolution is called the crank, the link opposite to the fixed link is called the coupler and the fourth link is called a lever or rocker if it oscillates or another crank, if it rotates.

Link Classification

- Ground : Link(s) that are fixed with respect to the reference frame.
- Crank : Pivoted to ground. Makes complete revolution.
- Rocker : Pivoted to ground, has oscillatory motion.
- Coupler : Not attached to ground, has complex motion.

1.11 Grashof's Law

If the lengths of link for a four bar chain mechanism be shortest (s), Longest (l) other two links (p and q) then

$$l + S \le p + q$$

then the shortest link can rotate fully w.r.t. neighbouring link.

(i) Double crank (drag-link)

Shortest link is grounded.

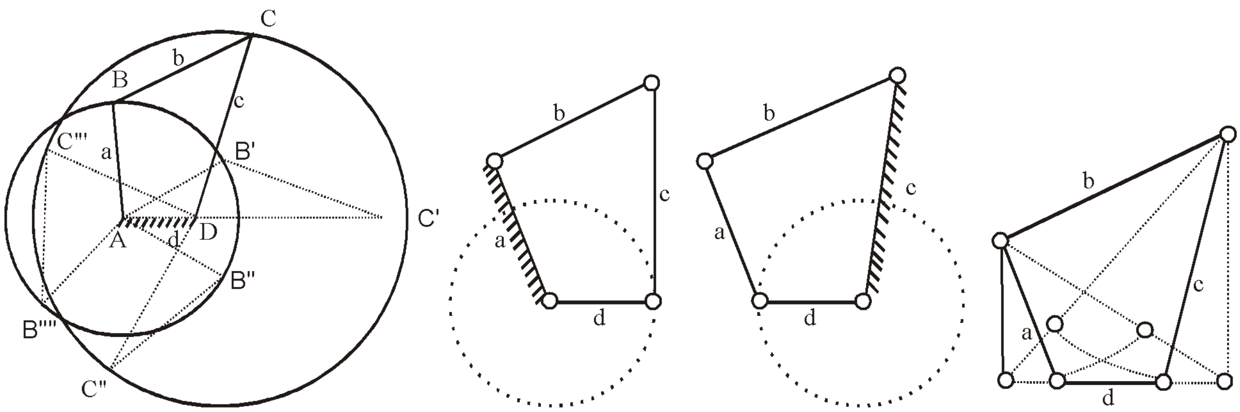
(ii) Two different crank-rocker mechanisms

- Shortest link is crank
- One of adjacent link is grounded

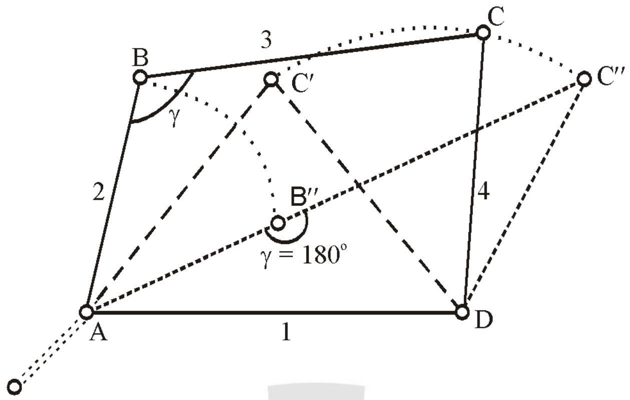
(iii) Double rocker

- Shortest link is coupler

Note : If $l + S > p + q$ then only double rocker mechanisms are possible.



1.12 Mechanical Advantage



The mechanical advantage (MA) of a mechanism is the ratio of the output force or torque to the input force or torque at any instant. Friction and inertia forces ignored and the input torque T_2 is applied to the link 2 to drive the output link 4 with a resisting torque T_4.

$$\text{Power input} = \text{Power output}$$

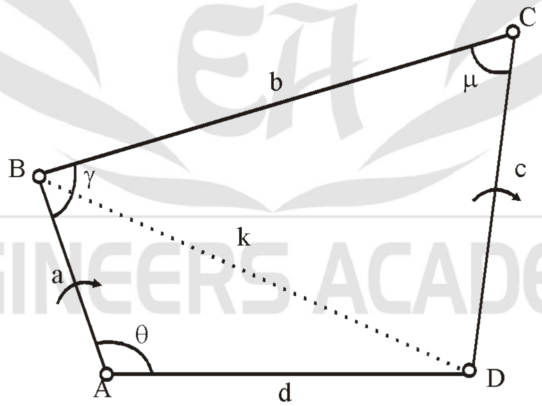
$$T_2\omega_2 = T_4\omega_4$$

or
$$MA = \frac{T_4}{T_2} = \frac{\omega_2}{\omega_4}$$

Thus, it is the reciprocal of the velocity ratio.

The extreme positions of the linkage are known as toggle positions ($\gamma = 0°$ and $\gamma = 180°$).

1.13 Transmission Angle



The angle μ between the output link and the coupler is know as transmission angle.

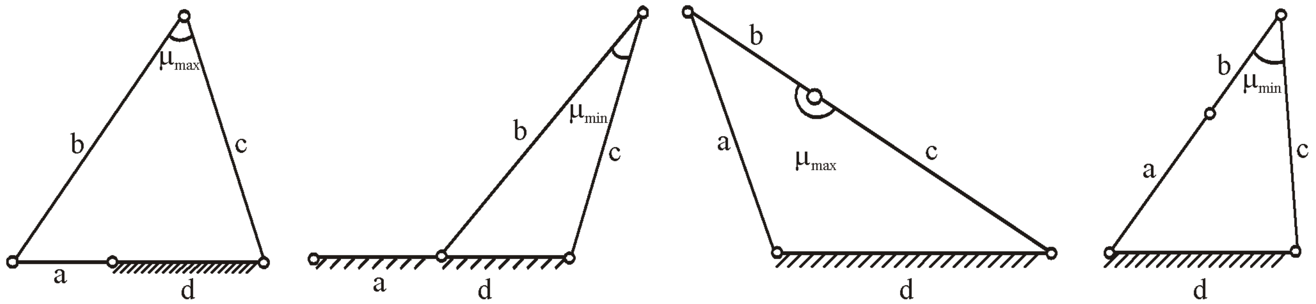
For a particular value of force in the coupler rod, the torque transmitted to the output link is maximum when the transmission angle μ is 90°. If μ deviates significantly from 90°, the torque on the output link decreases.

$$a^2 + d^2 - 2ad\cos\theta = k^2$$

and
$$b^2 + c^2 - 2bc\cos\mu = k^2$$

$$\frac{d\mu}{d\theta} = \frac{ad\ \sin\theta}{bc\ \sin\mu}$$

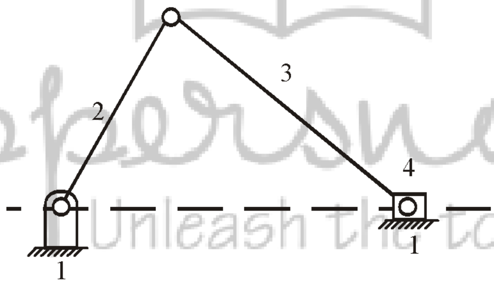
Thus, if $\frac{d\mu}{d\theta}$ is to be zero, the term ad sin θ has to be zero which means θ is either 0° or 180°. It can be seen that μ is maximum when θ is 180° and minimum when θ is 0°. However, this would be applicable to the mechanisms in which the link a is able to assume these angles, i.e., in double-crank or crank-rocker mechanisms.



1.14 Slider-Crank Chain

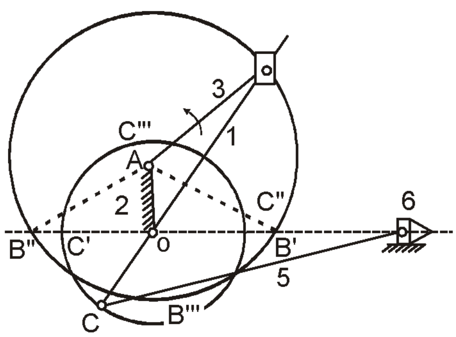
In a slider-crank chain mechanisms three turning pair and one slider pair are present. There are four inversion described below

(i) First Inversion



- Reciprocating engine
- Reciprocating compressor

(ii) Second Inversion (Crank Fixed)



- Whitworth quick-return mechanism
- Rotary engine

Whitworth Quick-Return Mechanism : It is a mechanism used in workshops to cut metals. The forward stroke takes a little longer and cuts the metal where as the return stroke is idle and takes a shorter period.

The time taken for the forward stroke of the slider is proportional to the obtuse angle B″ AB′ at A.

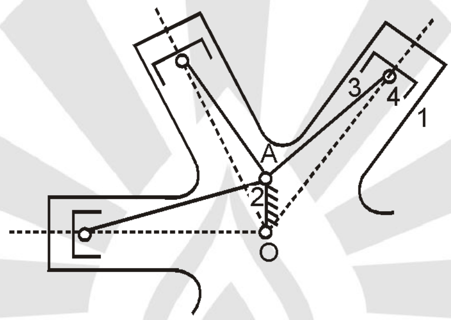
There is backward stroke of the tool. The time taken in this is proportional to the acute angle B″ AB′ at A.

θ = Obtuse angle B′ AB″ at A

β = Acute angle B′ AB″ at A

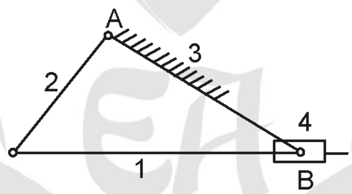
Then $$\frac{\text{Time of cutting}}{\text{Time of return}} = \frac{\theta}{\beta} = \frac{\text{Forward stroke}}{\text{Backward stroke}}$$

Rotary Engine :



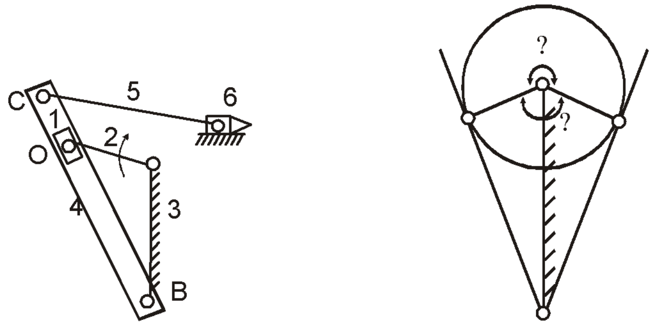
(iii) Third Inversion (connecting rod fixed)

- Oscillating cylinder engine.



- Crank and slotted-lever mechanism.

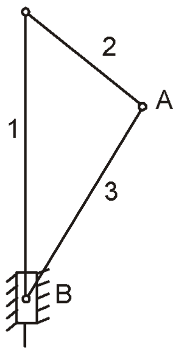
On comparing a crank and slotted-lever quick-return mechanism with a Whitworth quick-return mechanism, crank 3 of the Whitworth mechanism is longer than its fixed link 2 whereas the crank 2 of the slotted-lever mechanism is shorter than its fixed link 3.



(a) (b)

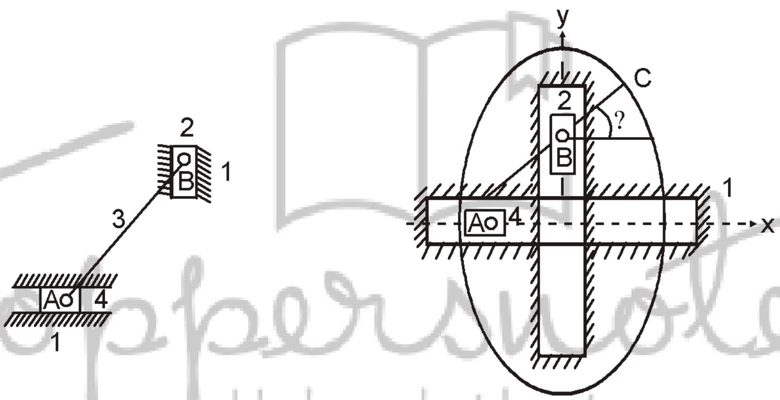
(iv) Fourth Inversion (Slider fixed)

Application : Hand-pump



1.15 Double Slider-Crank Chain

(i) First Inversion (Slotted plate fixed)



(a) (b)

Application : Elliptical trammel

Elliptical Trammel

$$x = BC\cos\theta \text{ and } y = AC\sin\theta$$

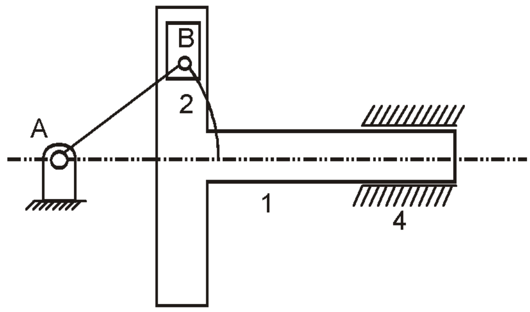
$\therefore$
$$\frac{x}{BC} = \cos\theta \text{ and } \frac{y}{AC} = \sin\theta$$

Squaring and adding,

$$\frac{x^2}{(BC)^2} + \frac{y^2}{(AC)^2} = \cos^2\theta + \sin^2\theta = 1$$

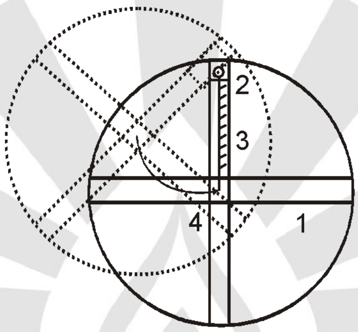
(ii) Second Inversion (Any of the slider fixed)

Application : Scotch yoke



Scotch Yoke : A scotch-yoke mechanism is used to convert the rotary motion into a sliding motion.

(iii) Third Inversion (connecting rod fixed)



Application : Oldham's coupling

Used to connect two parallel shafts when the distance between their axis is small.

Maximum sliding velocity = Peripheral velocity along the circular path

= Angular velocity of shaft × distance between shafts

Example 2 : The distance between two parallel shafts is 18 mm and they are connected by an Oldham's coupling. The driving shaft revolves at 160 r.p.m. What will be the maximum speed of sliding of the tongue of the intermediate piece along its groove?

Solution :

$$\omega = \frac{2\pi \times 160}{60} = 16.75 \text{ rad/s}$$

$$\text{Maximum velocity of sliding} = \omega \times d = 16.75 \times 0.018 = 0.302 \text{ m/s}$$

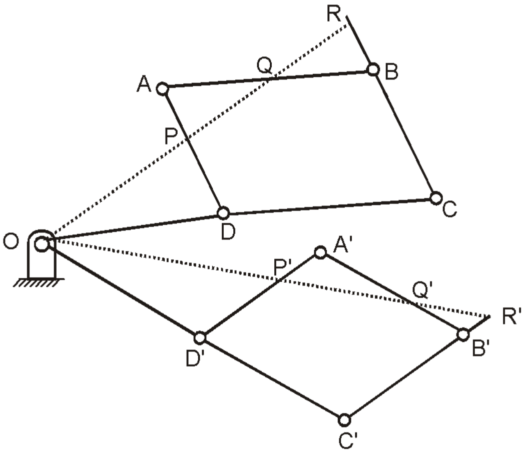
1.16 Miscellaneous Mechanisms

Lower pairs usually comprise turning (pivoted) and sliding pairs. An exact straight-line mechanism guides a reciprocating part in an exact straight line.

1.16.1 Pantograph

A pantograph is a four-bar linkage used to produce paths exactly similar to the ones traced out by a point on the linkage. The paths so produced are, usually, on an enlarged or reduced scale and may be straight or curved ones. It is a copier mechanism.

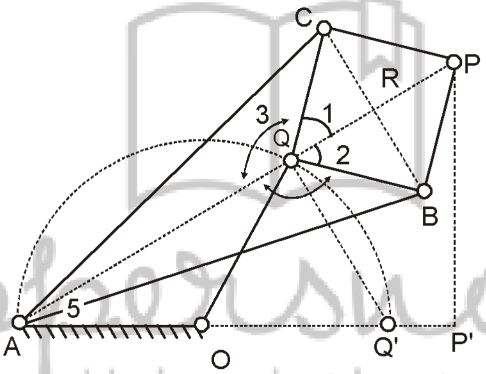
As the linkage is moved, the ratio of the distances of P and R from the fixed point remains the same. Thus P, Q and R trace similar paths when the linkage is given motion.



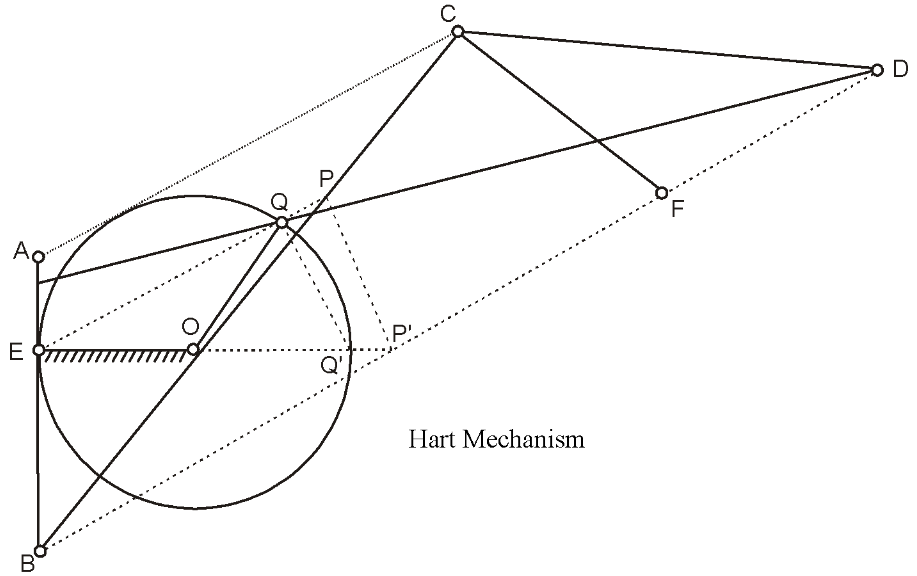
1.16.2 Straight line Mechanisms

(1) Exact Straight-line Mechanisms :

(i) Peculiar Mechanism : A Peculiar mechanism consists of eight links. P moves in a straight line perpendicular to OA. All the joints are pin-jointed. The projection of P and AQ produced in constant for all the configurations. Thus, PP' is always a normal to AO produced or P moves in a straight line perpendicular to AO.



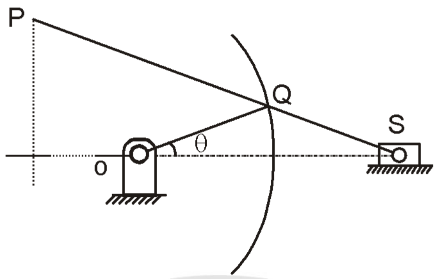
(ii) Hart Mechanism : A Hart mechanism consists of six links



Hart Mechanism

Thus, EP' is always constant. Therefore, the projection of P on EO produced is always the same point or P moves in a straight line perpendicular to EO.

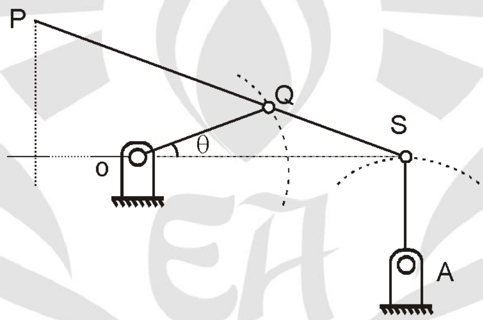
(iii) Scott-Russel Mechanism : A Scott-Russel mechanism consists of three movable links.



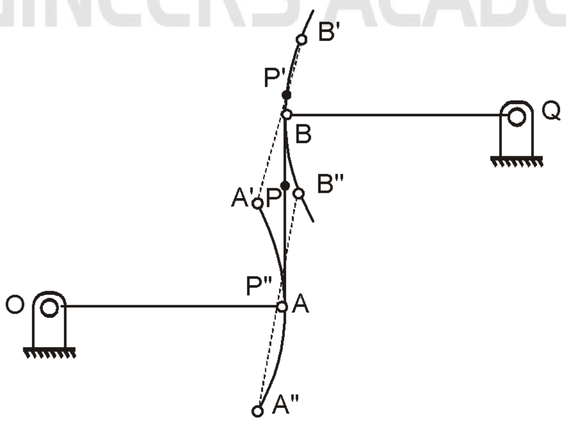
(2) Approximate Straight-line Mechanisms :

(i) Grasshopper Mechanism : S moves in an approximated straight line perpendicular to AS (or in line with OS) for small angular movements. P again will move in an approximate straight line if QS is the mean proportional between OQ and QP, i.e.

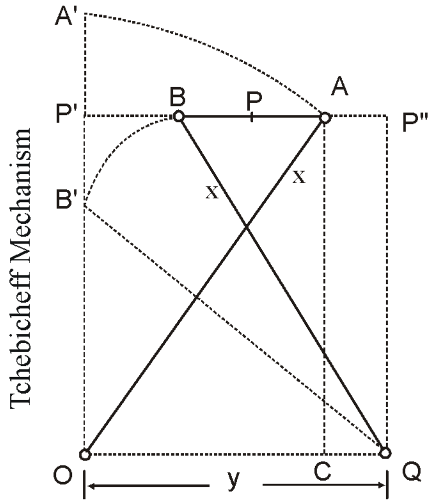
$$\frac{OQ}{QS} = \frac{QS}{QP}$$



(ii) Watt Mechanism : It has four links. P will trace an approximately straight line.



(iii) Tchebicheff Mechanism : It consists of four links

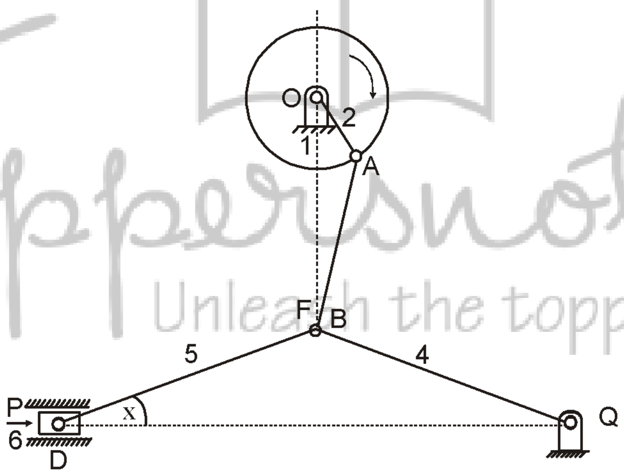


$$AB : OQ : OA = 1 : 2 : 2.5$$

This ratio of the links ensures that P moves approximately in a horizontal straight line parallel to OQ.

1.16.3 Toggle Mechanism

A toggle mechanism is a six-link mechanism and is used to overcome a large resistance with a small application of force.



$$F = 2P \tan \alpha$$

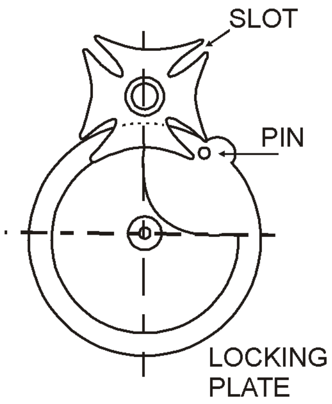
or
$$P = \frac{F}{2 \tan \alpha}$$

As α approaches zero, for a gives small value of F, P approaches infinity or with a small force F a large force is applied to crush the stone.

1.16.4 Intermittent Motion Mechanisms

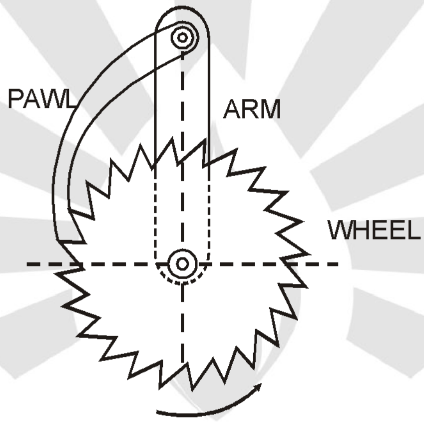
An intermittent motion is a motion which is repeated after a specific interval of time.

(i) Geneva Mechanism : Consists of a locking plate which rotates continuously and has driving pin attached to it



(ii) Ratchet Mechanism : Allows continuous rotary or linear motion in only one direction while preventing motion in the opposite direction.

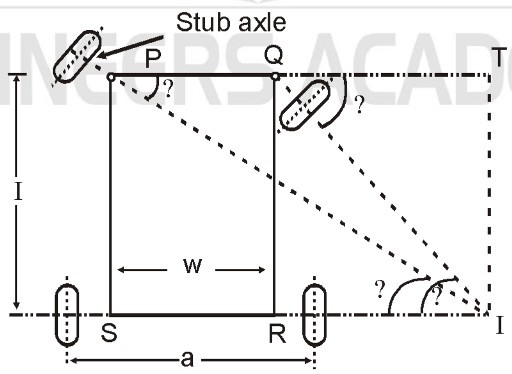
A ratchet has a toothed wheel or rack engaged with a pawl that allows it to move in one direction only.



Ratchet Mechanism

1.16.5 Automobile Steering Gears

When an automobile takes turns on a road, all the wheels should make concentric circles to ensure that they roll on the road smoothly. This is achieved by mounting the two front wheels on two short axels, known as *stub axels*. In figure



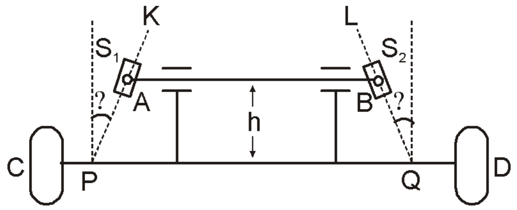
Where, θ and ϕ = angles turned by the stub axles

l = wheel base

w = distance between the pivots of front axles

$$\cot \phi - \cot \theta = \frac{PT - QT}{T\ell} = \frac{PQ}{T\ell} = \frac{w}{\ell}$$

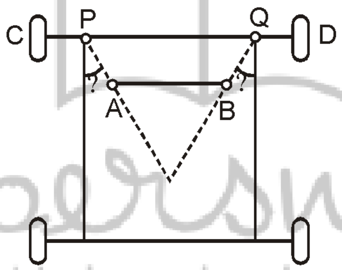
(i) Davis steering gear : A *Davis steering gear* has sliding pairs which means more friction and easy wearing. The gear fulfils the fundamental equation of gearing in all the positions. However, due to easy wearing it becomes inaccurate after some time.



A Davis steering gear consists of two arms *PK* and *QL* fixed to the stub axles *PC* and *QD* to form two similar bell-crank levers *CPK* and *DQL* pivoted at *P* and *Q* respectively. A cross link or track arm *AB,* constrained to slide parallel to *PQ,* is pin-jointed at its ends to two sliders. The sliders S_1 and S_2 are free to slide on the links *PK* and *QL* respectively.

During the straight motion of the vehicle, the gear is in the mid-position with equal inclination of the arms *PK* and *QL* with *PQ.*

(ii) Ackermann Steeing Gear : An *Ackermann steering gear* has only turning pairs and thus is preferred. Its drawback is that it fulfils the fundamental equation of correct gearing at the middle and the two extreme positions and not in all position.



Ackermann steeing gear consists of a four-link mechanism *PABQ* having four turning pairs. Two equal arms *PA* and *QB* are fixed to the stub axles *PC* and *QD* to form two similar bell-crank levers *CPA* and *DQB* pivoted at *P* and *Q* respectively. A cross link *AB* is pin-jointed at the ends to the two bell-crank levers.

An Ackermann gear does not fulfil the fundamental equation of correct gearing in all the positions but only in three positions.

This is known as the *fundamental equation of correct gearing.* Mechanisms that fulfil this fundamental equation are known as *steering gears.* There are two main types steering gears.

Three positions of correct gearing are

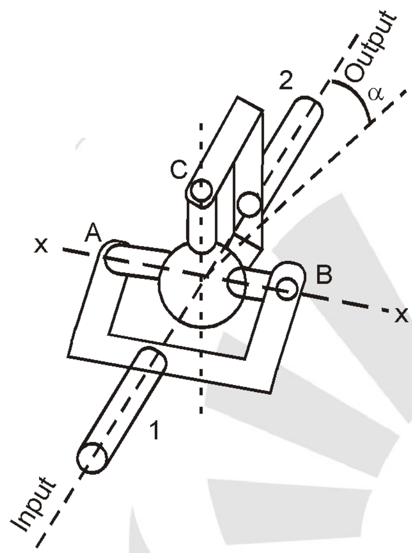
1. When the vehicle moves straight.
2. When the vehicle moves at a correct angle to the right.
3. When the vehicle moves at a correct angle to the left.

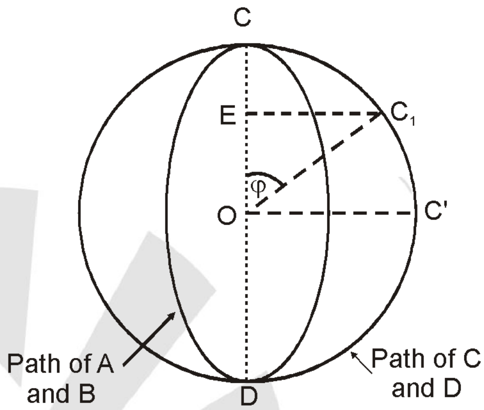
1.17 Hooke's Joint

A Hooke's joint commonly known as a *universal joint* or *coupling* is used to connect two non-parallel and intersecting shafts. It is also used for shafts with angular misalignment. A common application of this joint is in an automobile where it is used to transmit power from the gear box (of the engine) to the rear axle. The driving shaft rotates at a uniform angular speed whereas the driven shaft rotates at a continuously varying angular speed.

The centre piece can be in the shape of a *cross, square or sphere* (having four pins or arms). The four arms of the cross are at right angles.

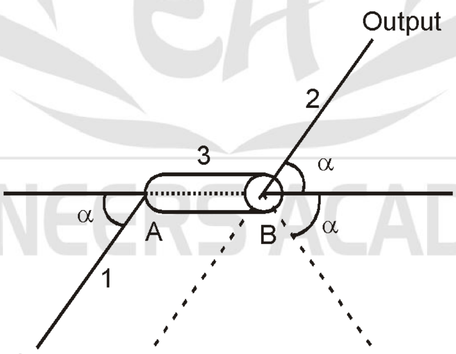
$$\tan \theta = \cos \alpha \tan \phi$$





1.18 Double Hooke's Joint

In a single Hooke's joint, the speed of the driven shaft is not uniform although the driving shaft rotates at a uniform speed. To get uniform velocity ratio, a double Hooke's joint has to be used. In a double Hooke's joint, two universal joints and an intermediate shaft are used.



Thus, to have a constant velocity ratio

- The driving and the driven shafts should make equal angles with the intermediate shaft.
- The forks of the intermediate shaft should lie in the same plane.

Note :

- Universal (Hooke's) joint A and B.
- Intermediate shaft 3.

❍❍❍

PRACTICE SHEET

OBJECTIVE QUESTIONS

1. Instantaneous center of a body rolling with sliding on a stationary curved surface lies

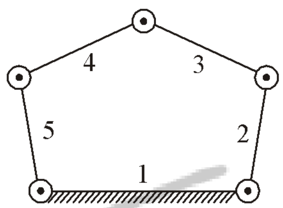
(a) At the point of contact

(b) On the common normal at the point of contact

(c) On the common tangent at the point of contact

(d) At the center of curvature of the stationary surface

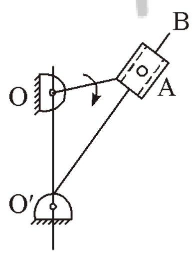
2. The number of degrees of freedom of a five link plane mechanism with five revolute pairs as shown in the figure is:



(a) 3 (b) 1

(c) 2 (b) 4

3. Figure shows a quick return mechanism. The crank OA rotates clockwise uniformly. OA 2 cm, OO′ = 4 cm. The ratio of time for forward motion to that for return motion is



(a) 0.5 (b) 2.0

(c) $\sqrt{2}$ (d) 1

4. ***Assertion (A):*** The elements of higher pairs must be force closed.

Reason (R): This is required in order to provide completely constrained motion.

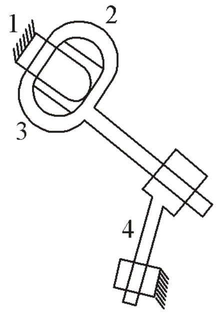
(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not the correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

5. For the planar mechanism shown in figure select the most appropriate choice for the motion of link 2 when link 4 is moved upwards.



(a) Link 2 rotates clockwise

(b) Link 2 rotates counter-clockwise

(c) Link 2 does not move

(d) Link 2 motion cannot be determined

6. The instantaneous centre of rotation of a rigid thin disc rolling on a plane rigid surface is located at

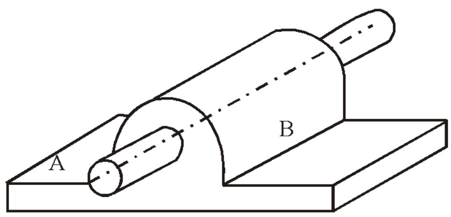
(a) The centre of the disc

(b) An infinite distance on the plane surface

(c) The point of contact

(d) The point on the circumference situated vertically opposite to the contact point

7. A round bar A passes through the cylindrical hole in B as shown in the given figure. Which one of the following statements is correct in this regard?



(a) The two links shown form a kinematic pair

(b) The pair is completely constrained

(c) The pair has incomplete constrained

(d) The pair is successfully constrained

8. ***Assertion (A)*:** Hydraulic fluid is one form of link

***Reason (R)*:** A link need not necessarily be a rigid body but it must be a resistant body.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not the correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

9. The centre of gravity of the coupler link in a 4 bar mechanism would experience

(a) no acceleration

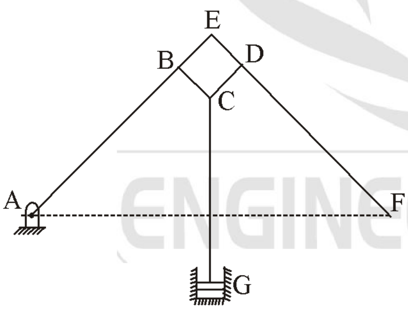
(b) only linear acceleration

(c) only angular acceleration

(d) both linear and angular acceleration

10. Consider the following statements:

***Assertion (A)*:** The given line diagram of watt's indicator mechanism is a type of crank and lever mechanism.



***Reason (R)* :** BCD acts as a lever.

Of these statements :

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not the correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

11. Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

A. Quadratic cycle chain

B. Single slider crank chain

C. Double slider crank chain

D. Crossed slider crank chain

List-II

1. Rapson's slide

2. Oscillating cylinder engine mechanism

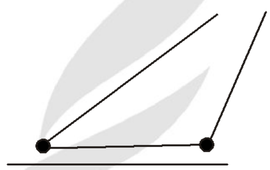
3. Ackermann steering mechanism

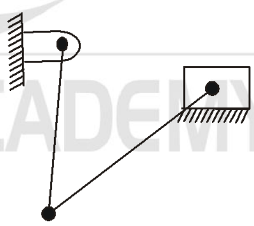
4. Oldham coupling

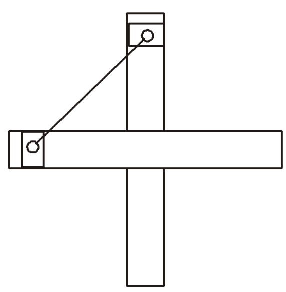
Codes :

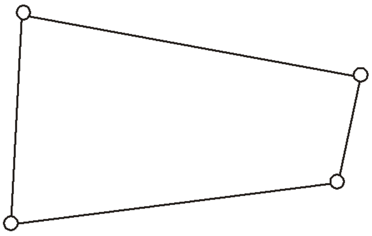
	A	B	C	D
(a)	1	2	4	3
(b)	4	3	1	2
(c)	3	2	4	1
(d)	3	4	2	1

12. Which of the following are examples of a kinematic chain?

1. 

2. 

3. 

4. 

Select the correct answer using the codes given below :

(a) 1, 3 and 4 (b) 2 and 4

(c) 1, 2 and 3 (d) 1, 2, 3, and 4

13. Which of the following pairs are correctly matched? Select the correct answer using the codes given below the pairs.

Mechanism

1. Whithworth quick return motion

2. Oldham's coupling

3. Scotch yoke

Chain from which derived

1. Single slider crank chain

2. Four bar chain

3. Double slider crank chain

(a) 1 and 2 (b) 1, 2 and 3

(c) 1 and 3 (d) 2 and 3

14. Match List-I with List-II and select the correct answer using the codes given below the lists

List-I	**List-II**
A. 4 link, 4 turning pairs	**1.** Complete constrained
B. 3 links, 3 turning pairs	**2.** Successfully constrained
C. 5 links, 5 turning pairs	**3.** Rigid frame
D. Footstep bearing	**4.** Incomplete constrained

Codes :

	A	B	C	D
(a)	3	1	4	2
(b)	1	3	2	4
(c)	3	1	2	4
(d)	1	3	4	2

15. In a single slider four-bar linkage when the slider is fixed, it form a mechanism of

(a) hand pump (b) reciprocating engine

(c) quick return (d) oscillating cylinder

16. Which one of the following pairs is correctly matched?

(a) Governor : Interference

(b) Gears : Hunting

(c) Klein's construction : Acceleration of piston

(d) Cam : Pinion

17. A four-bar chain has

(a) all turning pairs

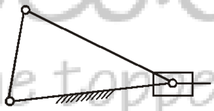
(b) one turning pair and the others are sliding pairs

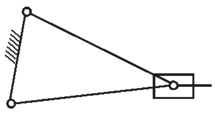
(c) one sliding pair and the others are turning pairs

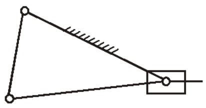
(d) all sliding pairs

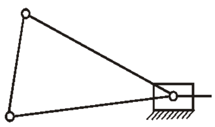
18. Match List-I (Kinematic inversions) List-II (Applications) and select the correct answer using the codes given below the lists

List-I

A. 

B. 

C. 

D. 

List-II

1. Hand pump

2. Compressor

3. Whitworth quick return mechanism
4. Oscillating cylinder engine

Codes :

	A	B	C	D
(a)	1	3	4	2
(b)	2	4	3	1
(c)	2	3	4	1
(d)	1	4	3	2

19. Consider the following pairs of parts

1. Pair of gear in mesh
2. Belt and pulley
3. Cylinder and piston
4. Cam and follower

Among these, the higher pairs are

(a) 1 and 4 (b) 2 and 4
(c) 1, 2 and 3 (d) 1, 2 and 4

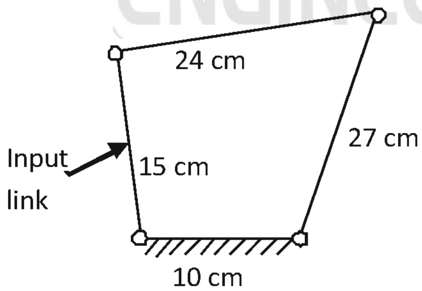
20. Consider the following statements

1. Round bar in a round hole forms a turning pair.
2. A square bar in a square hole forms a sliding pair.
3. A vertical shaft in a footstep bearing forms a successful constrained.

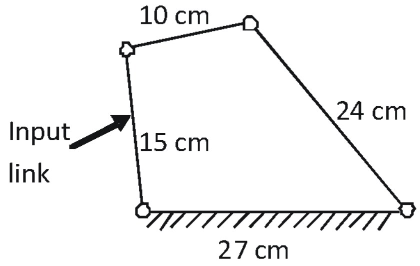
Which of these statements are correct?

(a) 1 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1, 2 and 3

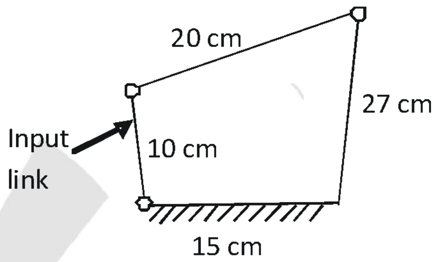
21. In which of the following cases the input link can make a complete rotation.



(1)



(2)



(3)

(a) 1 only (b) 1 and 3
(c) 1 and 2 (d) 1, 2 and 3

22. Match List-I with List-II and select the correct answer using the codes given below the lists

List-I (Type of Mechanism)

A. Scott-Russel mechanism
B. Geneva mechanism
C. Off-set slider-crank mechanism
D. Scotch Yoke mechanism

List-II (Motion achieved)

1. Intermittent motion
2. Quick return motion
3. Simple harmonic motion
4. Straight line motion

Codes :

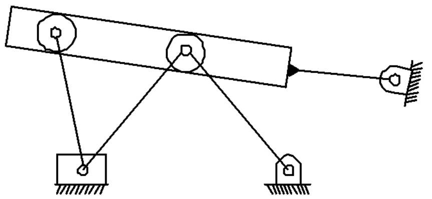
	A	B	C	D
(a)	2	3	1	4
(b)	3	2	4	1
(c)	4	1	2	3
(d)	4	3	1	2

23. If the length of the connecting rod (coupler) and the crank are 'r' units each, then the stroke length of the slider crank mechanism is

(a) r unit (b) 2r unit

(c) 3r unit (d) 4r unit

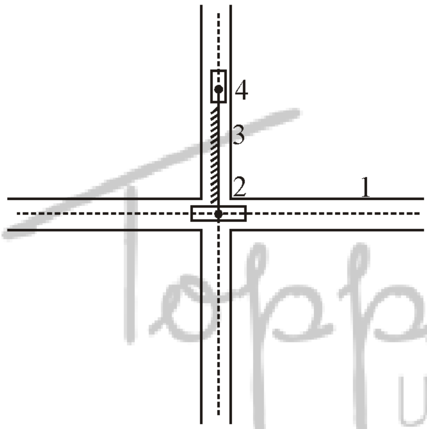
24. For the mechanism shown below. The number of degrees of freedom is



(a) 3 (b) 1

(c) 5 (d) 0

25. For the given inversion of the double-slider crank chain, link 3 is fixed which is of 5 cm in length. By rotating the slider (link 2) through 30° in clock wise direction, the distance between the mid point of the link 1 and the center of rotation of link 4 for this instant is



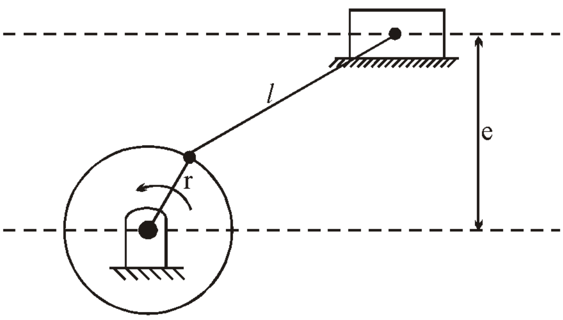
(a) 2.5 cm (b) 3.54 cm

(c) 4.33 cm (d) 5 cm

***Common Data Questions :* 26 and 27**

The figure shown an offset slider-crank mechanism that has an offset 'e'

r = 20 cm, l = 80 cm, e = 60 cm



26. The time ratio of the mechanism is

(a) 1 (b) 1.74

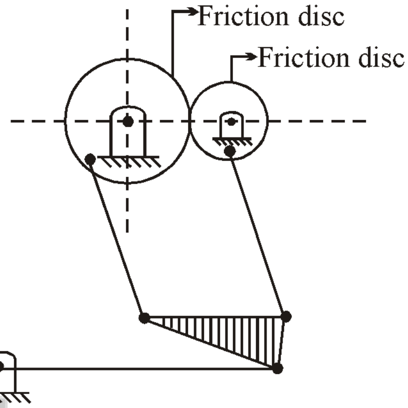
(c) 1.84 (d) 5.76

27. Stroke length of the slider is

(a) 20 cm (b) 40 cm

(c) 60 cm (d) 80 cm

28. The degree of freedom for the mechanism is



(a) 0 (b) 1

(c) 2 (d) 3

29. The relative motion in higher pair is

(a) sliding

(b) turning

(c) combination of sliding and turning

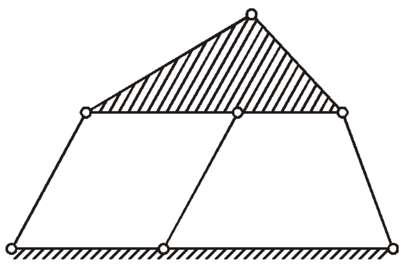
(d) rotary

30. If the fixed link is changed in a kinematic chain, what will be the relative motion of other links?

(a) Will change (b) Will remain same

(c) Will not occur (d) None

31. The number of degrees of freedom for below mentioned arrangement is

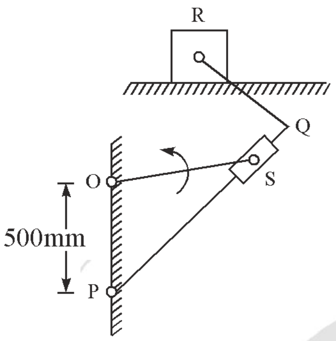


(a) 0 (b) 1

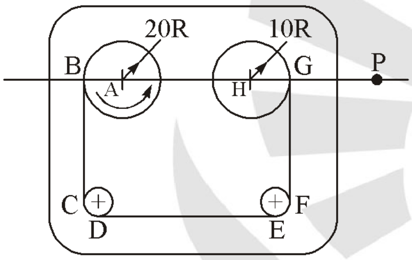
(c) 2 (d) 3

***Statement Linked Questions* 32 and 33**

A quick return mechanism is shown below. The crank OS is drive at 2 rev/s in counter clockwise direction.



32. For the audio cassette mechanism shown in figure given below. Where is the instantaneous centre of rotation (point) of the two spools?



(a) Point P lies to the left of both the spools but at infinity along the line joining A and H

(b) Point P lies in between the two spools on the line joining A and H, such that PH = 2AP

(c) Point P lies to the right of both the spools on the line joining A and H, such that AH = HP

(d) Point P lies at the intersection of the line joining B and C and the line joining G and F

33. Match the following with respect to special mechanisms.

Type of Joint	**Motion constraint**
P. Revolute	**1.** Three
Q. Cylindrical	**2.** Five
R. Spherical	**3.** Four
	4. Two
	5. Zero

Codes :

	P	**Q**	**R**
(a)	1	3	1
(b)	5	4	3
(c)	2	3	1
(d)	4	5	3

34. Which of the following statement is true for links

(a) Tensile loads, belts, ropes, chains are as links only when they are in tension

(b) Liquids are treated as links when they transfer compressive force

(c) Springs are not treated as links in kinematic analysis

(d) All of the above

35. A universal joint is case of

(a) Turning pair (b) Sliding pair

(c) Rolling pair (d) Lower pair

36. Which among the following is a lower pair?

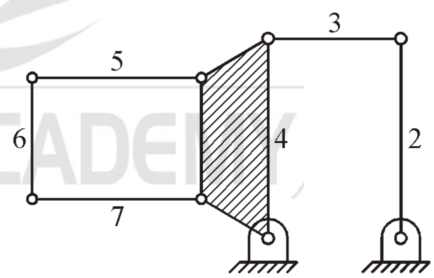
(a) Pair of friction disc

(b) Ball and roller bearing

(c) Piston and cylinder

(d) Gear

37. The number of degrees of freedom for the below mentioned mechanism is



(a) 0 (b) 1

(c) –1 (d) 2

38. For kinematic chains $\frac{2(j+2)}{3}$ applied to higher pair

(a) Each higher pair must be taken equivalent to two lower pairs

(b) Each higher pair equivalent to one additional link

(c) Each higher pair must be taken equivalent to two lower pairs and one additional link

(d) Each higher pair is equivalent to one lower pair and two additional links

39. Minimum requirement of kinematic chain are

(a) 3 links and 2 turning pairs

(b) 4 links and 4 turning pairs

(c) 3 links and 3 turning pairs

(d) 2 links and 3 turning pairs

40. Grubler's criterion for determining the degrees of freedom (n) having plane motion is

(a) $n = 3(l - 1) - 2j$

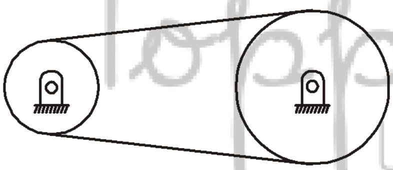
(b) $n = \frac{2}{3}(l - 1) - 2j$

(c) $n = 4(l - 1) - 2j$

(d) None of the above

where n = 1

41. The number of degrees of freedom for below mentioned belt and pulley drive is



(a) 0 (b) 2

(c) 1 (d) 3

42. If l = number of links and P = number of pair which constitute a kinematic chain, then there is a relation between number of joints and number of links which is given by the expression

(a) $P = l - 2$ (b) $l - 4P - 2$

(c) $P = 2l - 3$ (d) $l = 2P - 4$

43. Which one is a spherical pair?

(a) Ball bearing and roller bearing

(b) Ball and socket joint

(c) Bolt and nut

(d) Crank shaft is in journal of engine

44. The lower pair is a

(a) Turning pair (b) Closed pair

(c) Open pair (d) Sliding pair

45. An example of turning pair is

(a) Piston and cylinder

(b) Ball and socket joint

(c) Shaft with collars at both ends fitted in a circular hole

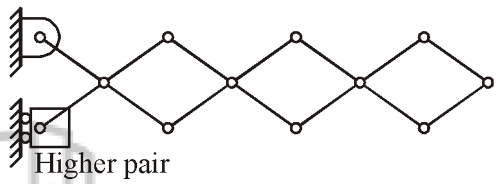
(d) Bolt and nut

46. Motion between two elements having surface in contact is

(a) Sliding pair (b) Rolling pair

(c) Lower pair (d) Higher pair

47. The number of degrees of freedom for below mentioned arrangement is



(a) 0 (b) 2

(c) 1 (d) –1

48. If there are l number of links in a mechanism then number of possible inversions is equal to

(a) l (b) $l - l$

(c) $l + 3$ (d) $l - 2$

49. A piston and cylinder in a slider crank mechanism form a

(a) Cylindrical pair (b) Spherical pair

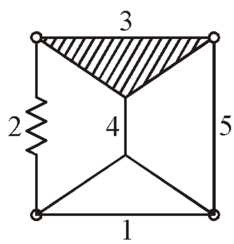
(c) Higher pair (d) Sliding pair

50. A shaft in a bearing is a

(a) Lower pair (b) Higher pair

(c) Rolling pair (d) Spherical pair

51. In the below mentioned arrangement, the removal of spring (without affecting the degree of freedom), can be replaced by



(a) Single link (b) Binary link

(c) Ternary link (d) None of these

52. For kinematics chains constituted by lower pair the relation between the number of link l and the number of joint j is

(a) $l = \frac{2}{3}(j+2)$ (b) $l = \frac{2}{3}(j+2)^2$

(c) $l = \frac{3}{2}(j+2)$ (d) $l = \frac{5}{2}(j+2)$

53. A quartenary joint is equivalent to

(a) Two binary joints

(b) Three binary joints

(c) Four binary joints

(d) All of above

54. Which of the following is inversion of slider crank mechanism?

(a) Reciprocating internal combustion engine

(b) Crank and slotted lever mechanism

(c) Whitworth quick return mechanism

(d) (a), (b) and (c)

55. As per equation $l = \frac{2}{3}(j + 2)$ to determine whether the given chain is kinematic or not, higher pair is treated equivalent to

(a) Two lower pairs and two additional links

(b) One lower pair and two additional links

(c) Two lower pairs and one additional link

(d) Three lower pairs and two additional links

56. A quartenary joint is comparable to

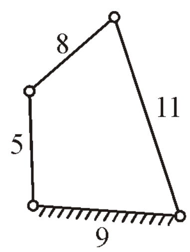
(a) Two binary joints

(b) Three binary joints

(c) Four binary joints

(d) None of the above

57. The arrangement shown below represents



(a) Double rocker mechanism

(b) Double crank mechanism

(c) Crank-rocker mechanism

(d) None of these

58. Double slider crank chain traces a

(a) Elliptical path (b) Straight line path

(c) Parabolic path (d) Circular path

59. When does a kinematic chain becomes a mechanism?

(a) If the first two links fixed

(b) If all links are fixed

(c) If any one link is fixed

(d) None of the links are fixed

60. Kinematic pairs are those which have two elements which

(a) Permit relative motion

(b) Act as support

(c) Have line contact

(d) Are held together

61. A simple mechanism has

(a) 2 links (b) 4 links

(c) 5 links (d) 6 links

62. In case of lower pairs

(a) There is surface contact between the two elements while in the motion

(b) There is line contact between the two elements while in the motion

(c) Contact is at upper end

(d) None of the above

63. Cross head and guides is an example of

(a) Lower pair (b) Turning pair

(c) Sliding pair (d) Surface pair

64. In case of higher pairs

(a) There is contact only at higher point of the two elements while in motion

(b) There is surface contact between the two elements

(c) There is no contact between two elements

(d) There is only line or point contact between the two elements while in motion

65. For 6 links in a mechanism number of pairs would be

(a) 12 (b) 6

(c) 3 (d) 5

66. ***Assertion (A)*: The Ackermann Steering gear is commonly used in all automobiles.

***Reason (R)*: It has the correct inner turning angle θ for all positions.

(a) Both A and R are true and R is the correct explanation of A

(b) Both A and R are true but R is not the correct explanation of A

(c) A is true but R is false

(d) A is false but R is true

❍❍❍

ANSWERS AND EXPLANATION

1. ***Ans. (b)***

In a pure rolling the I-centre lies at the point of contact at the given instant.

In sliding motion, the I-centre lies at infinity in a direction perpendicular to the path of motion of slider. As for three centers in line theorem, in both rolling and sliding motion the I-center lies in between point of contact and in the direction of the centre of sliding i.e. perpendicular to the sliding direction.

2. ***Ans. (c)***

Grubler's equation

$$F = 3(N - 1) - 2P_1 - 1P_2$$

F = degrees of freedom

N = total number of links in a mechanism

P_1 = number of pairs having one degree of freedom

P_2 = number of pairs having two degree of freedom (Higher pairs)

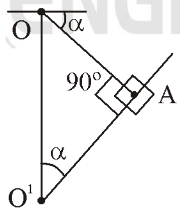
Above mechanism have 5 joint pairs which have one degree of freedom = (P_1) = 5.

There is No class II pairs (P_2) = 0, Number of links N = 5.

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

3. ***Ans. (b)***

$$\sin\alpha = \frac{OA}{OO^1}$$



$\Rightarrow \quad \alpha = 30^\circ$

$$QRR = \frac{180 + 2\alpha}{180 - 2\alpha}$$

$\Rightarrow \quad QRR = 2$

4. ***Ans. (d)***

5. ***Ans. (b)***

Link 2 rotates counter-clockwise. Identify the I centre 24 direction of the velocity of I_{24} gives the direction of rotation of link 2.

6. ***Ans. (c)***

If the two links form a higher kinematic pair with pure rolling. Then their instantaneous center lies at the point of contact itself.

7. ***Ans. (c)***

8. ***Ans. (a)***

Link need not necessarily be a rigid body but it must be a resistant body so that it is capable of transmitting motion from one member to another without appreciable deformation in it. For eg: in hydraulic lifts it transmits motion.

9. ***Ans. (d)***

The centre of gravity of the coupler link in a 4-bar mechanism would experience both linear and angular acceleration.

10. ***Ans. (a)***

11. ***Ans. (c)***

Quadratic cycle chain → Ackermann steering.

Single slider crank chain → Oscillating cylinder engine mechanism.

Double slider cranks chain → Oldham coupling.

Crossed slider crank chain → Rapson's slide.

12. ***Ans. (d)***

For kinematic chain, $l = 2p - 4$

Where, l = No. of link

p = No. of pair

Here p = 4

$\therefore \quad l = 4$

13. ***Ans. (c)***

Oldham's coupling → Double slider crank chain.

14. ***Ans. (d)***

If $l = (2p - 4)$ Complete constrained

$l > (2p - 4)$ Rigid frame

$l < (2p - 4)$ Incomplete constrained

15. ***Ans. (a)***

16. ***Ans. (c)***

Governor	Hunting
Gear	Interference
Klein's construction	Acceleration of piston
Cam	Follower

17. ***Ans. (a)***

18. ***Ans. (c)***

Kinematic inversion	**Application**
1. Frame is fixed	Compressor
2. Crank is fixed	Whitworth quick return mechanism
3. Connecting rod is fixed	Oscillating cylinder engine
4. Slider is fixed	Hand pump

19. ***Ans. (d)***

Higher Pair : When a pair has a point or line contact between the links, it is known as a higher pair. The contact surfaces of the two links are dissimilar.

Wheel rolling on a surface, cam-follower, tooth gear, ball and roller bearing etc.

20. ***Ans. (d)***

21. ***Ans. (a)***

According to the Grashof's criterion for a planar four bar linkage, the sum of the shortest and longest link length cannot be greater than the sum of the remaining two link length if there is to be continuous relative rotation between two members.

$\Rightarrow \quad \ell + s \leq p + q$

Where, ℓ = length of the largest link

s = length of the shortest link

p, q = length of the other two links

If this inequality is not satisfied, no link will make a complete revolution relative to another. Again if this inequality is satisfied, this will leads three different kinds of mechanisms.

(a) A double-crank mechanism where 's' in frame (fixed link).

(b) Two different crank rocker mechanism when 's' is the crank and any one of the adjacent links is the frame (fixed link).

(c) One double rocker mechanism when 's' is the coupler [i.e. opposite to the frame (fixed link)].

As in figure 1

$$10 + 27 < 24 + 15$$

And the smallest link is fixed, it will give rise to a double-crank mechanism i.e. both the links adjacent to the fixed link can full rotation with respect to the fixed link.

22. ***Ans. (c)***

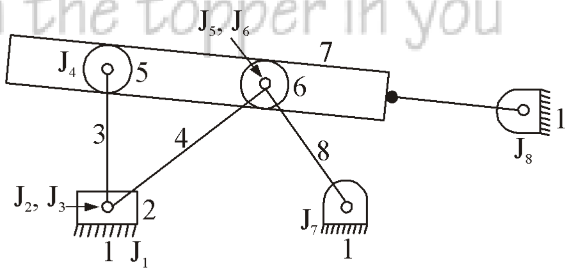
Straight line motions (Exact)

Approximate straight line motions

- Paucellier mechanism
- The watt mechanism
- Hart mechanism
- The Grasshopper mechanism
- Scott–Russel mechanism
- The Tchebicheff straight mechanism
- The Robot's straight mechanism

23. ***Ans. (b)***

24. ***Ans. (b)***



l = no. of links = 8

j = no. of simple hinges = no. of joints having one degree of freedom = 8

h = no. of higher pairs = no. of joints having two degrees of freedom = 2

F_r = no. of reductant degrees of freedom = 2

Both the links 5 and 6 have a reductant degree of freedom. As they can rotate without causing any movement in the rest of the mechanism.

So F_e = Effective degrees of freedom

$= 3(l - 1) - 2j - h - F_r$ .... (Kutzbach Equation)

$= 3(8 - 1) - 2 \times 8 - 2 - 2$

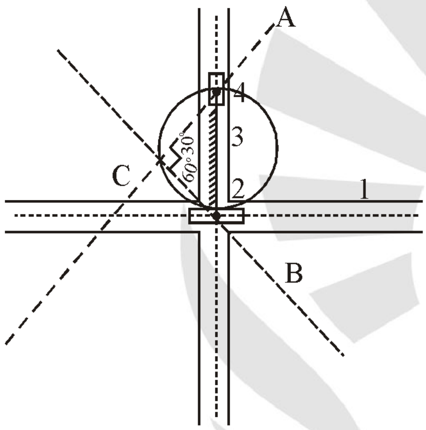
$= 21 - 16 - 4 = 1$

25. ***Ans. (c)***

The mid point of link 1 rotates in a circle with the length of link '3' on diameter.

Length of link

$$3 = AB = 5 \text{ cm}$$



As points A and B are on the diameter of a circle.

$\angle ACB = 90°$

Also $\angle CAB = 30°$

and $\angle CBA = 60°$

Now from ΔABC, $\sin 60° = \dfrac{AC}{AB}$

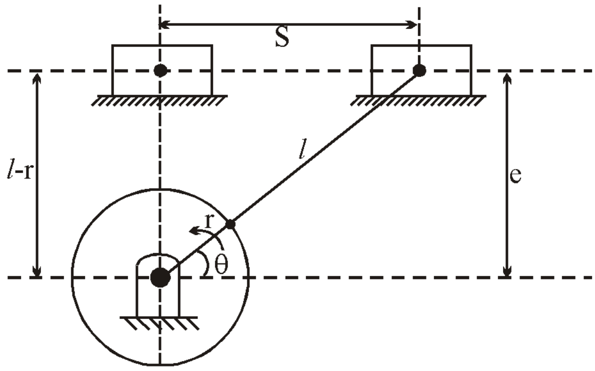
$\Rightarrow \quad AC = AB \sin 60°$

$= 4.33$ cm

26. ***Ans. (c)***

27. ***Ans. (d)***

The given figure shows the slider crank mechanism in its limiting position.



From geometry,

$$\sin\theta = \frac{e}{r+l} = \frac{60}{20+80} = \frac{60}{100}$$

$\Rightarrow \quad \theta = 36.87°$

Now time ratio

$$= \frac{360° - (90° + 36.87°)}{(90° + 36.87°)}$$

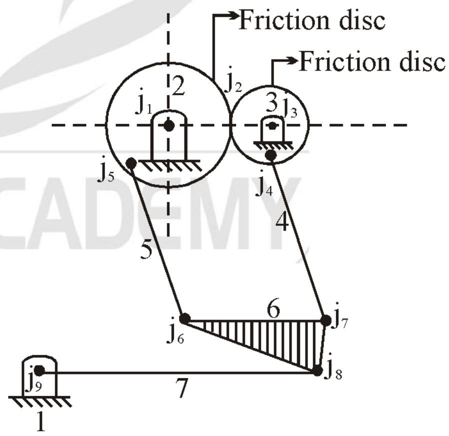
$$\simeq 1.84$$

Also from geometry

$$S = \sqrt{(r+l)^2 - (l-r)^2} = \sqrt{4.r.l}$$

$$S = \sqrt{4 \times 20 \times 80} = 80 \text{ cm}$$

28. ***Ans. (a)***



n = 7

j = 9 (since the discs are rolls without slipping, the higher pair is replaced by a lower pair joint)

$F = 3(7 - 1) - 2 \times 9 = 0$

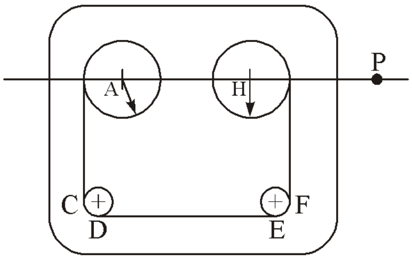
29. ***Ans. (c)***

30. ***Ans. (b)***

31. ***Ans. (a)***

32. ***Ans. (c)***

Consider the three bodies the bigger spool (Radius 20), smaller spool (Radius 10) and the frame. They together have three I centers, I centre of big spool with respect to the frame is at its centre A. that of the small spool with respect to the frame is at its centre H. The I centre for the two spools P is to be located.



As for the three centers in line theorem all the three centers should lie on a straight line implies on the line joining of A and H more over as both the spools are rotating in the same direction, P should lie on the same side of A and H. Also it should be close to the spool running at higher angular velocity. Implies close to H and it is to be on the right of H. Whether P belongs to bigger spool or smaller spool its velocity must be same. As for the radii of the spools and noting that the velocity of the tape is same on both the spools

$$\omega_H = 2\omega_A$$

$\therefore$ $AP \cdot \omega_A = HP\omega_H$

and $AP = AH + HP$

$\Rightarrow$ $HP = AH$

33. ***Ans. (c)***

For revolute joint, degree of freedom is 1 and constrained DOF = 5.

For cylindrical joint, degree of freedom is 2 and constrained DOF = 4.

For spherical joint, degree of freedom is 3 and constrained DOF = 3.

[Degree of constraints = 6 – Degree of freedom]

34. ***Ans. (d)***

35. ***Ans. (d)***

36. ***Ans. (c)***

37. ***Ans. (d)***

Number of links = 7

Number of lower pair = 8

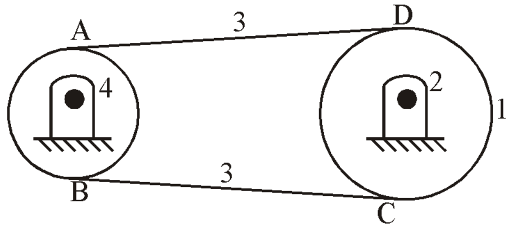
$$D.O.F = 3(7 - 1) - 2(8)$$
$$= 18 - 16 = 2$$

38. ***Ans. (c)***

39. ***Ans. (b)***

40. ***Ans. (a)***

41. ***Ans. (c)***



Four links are marked as shown. We have two turning pairs at 2 and 4. Points of contact A, B, C and D form 4 higher pairs.

$$D.O.F = 3(n - 1) - 2p_1 - p_2$$
$$= 3(4 - 1) - 2(2) - 4 = 1$$

42. ***Ans. (d)***

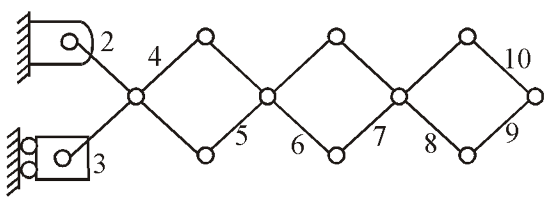
43. ***Ans. (b)***

44. ***Ans. (d)***

45. ***Ans. (c)***

46. ***Ans. (c)***

47. ***Ans. (c)***



No. of loops = 4

No of links = 10

$$F = n - (2(\text{no of loops}) + 1)$$
$$= 10 - 9 = 1$$

48. ***Ans. (a)***

49. ***Ans. (d)***

50. ***Ans. (a)***

51. *Ans. (b)*

52. *Ans. (a)*

53. *Ans. (b)*

54. *Ans. (d)*

55. *Ans. (c)*

56. *Ans. (b)*

57. *Ans. (c)*

Since $5 + 11 < 8 + 9$

So it is class-I mechanism. Also link adjacent to shortest link is fixed, so becomes a crank-rocker mechanism.

58. *Ans. (a)*

59. *Ans. (c)*

60. *Ans. (a)*

61. *Ans. (b)*

62. *Ans. (a)*

63. *Ans. (c)*

64. *Ans. (d)*

65. *Ans. (d)*

$$l = 2p - 4$$

66. *Ans. (c)*

Ackermann steering fullfils fundamental equation for gearing at middle and two extreme positions not in all positions.

❍❍❍