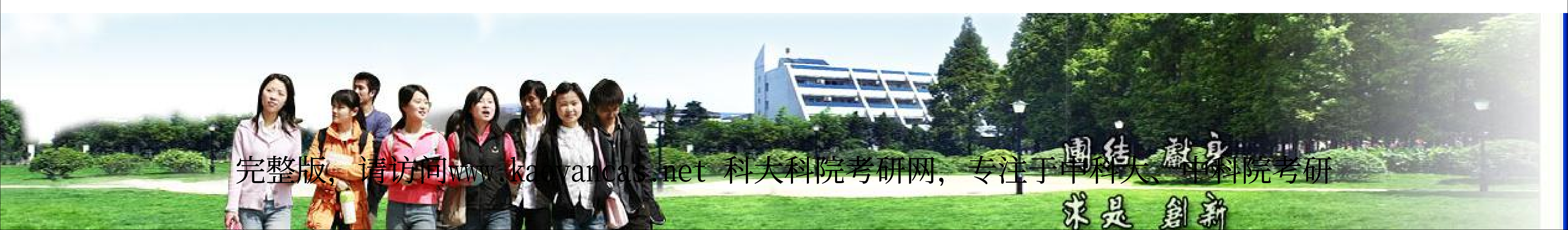
南京理工大学
Nanjing University of Science and Technology

Theory of Machines and Mechanisms

(机械原理)



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Chapter1 Introduction

Chapter2 Structural Analysis of Planar Mechanisms

Chapter3 Kinematic Analysis of Mechanisms

Chapter4 Planar Linkage Mechanisms

Chapter 5 Cam Mechanisms

Chapter 6 Gear Mechanisms

Chapter 7 Gear Trains

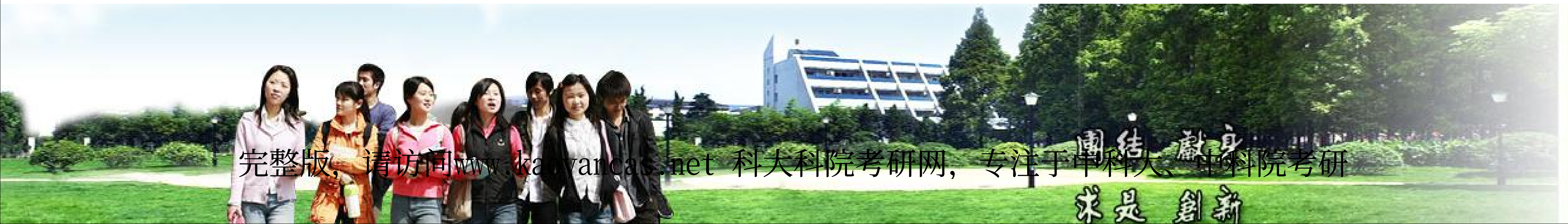
Chapter 8 Other Mechanisms in Common Use

Chapter 9 Balancing of Machinery

Chapter 10 Motion of Mechanical Systems and Its Regulation

Chapter 11 Efficiency of Machine

Chapter 4
Planar Linkage Mechanisms



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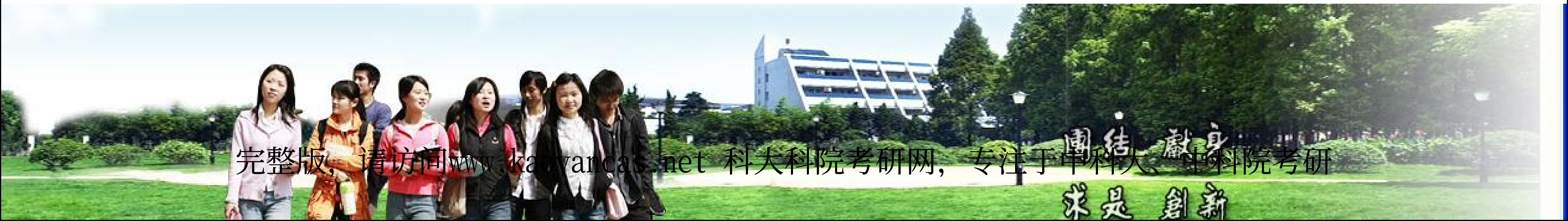
本章重点：　平面四杆机构的类型、基本知识和设计。

本章难点：　平面四杆机构的设计。



4.1 Characteristics of Planar Linkage Mechanisms

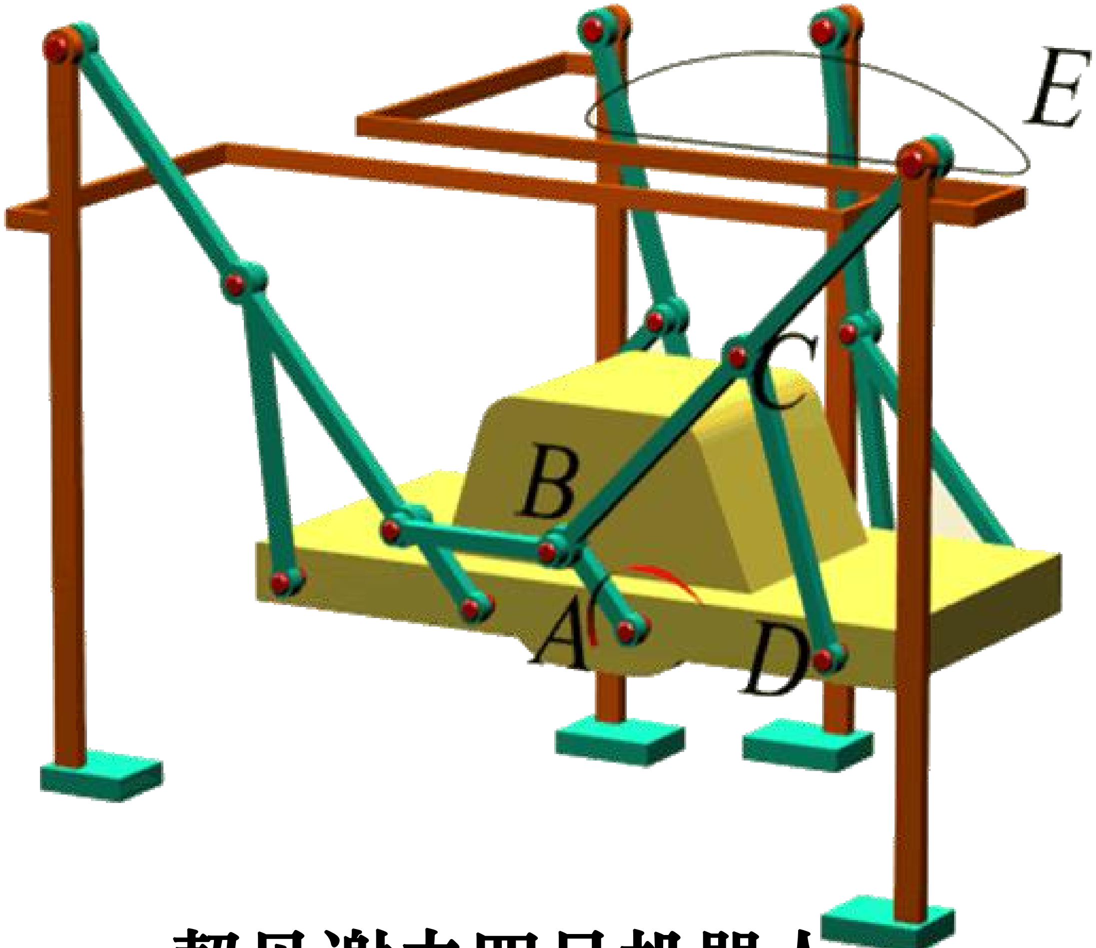
4.2 The Types of Four-bar Linkages

4.3 Characteristics Analysis of Four-bar Linkages

4.4 Dimensional Synthesis of Four-bar Linkages

4.1 Characteristics of Planar Linkage Mechanisms

all kinematic pairs→lower pairs



契贝谢夫四足机器人

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Advantages:

1.The main advantage is their better ability to trap lubricant between enveloping surface.(便于润滑、寿命长)The contact pressure is lower.

2.The lower pairs are easy to manufacture.

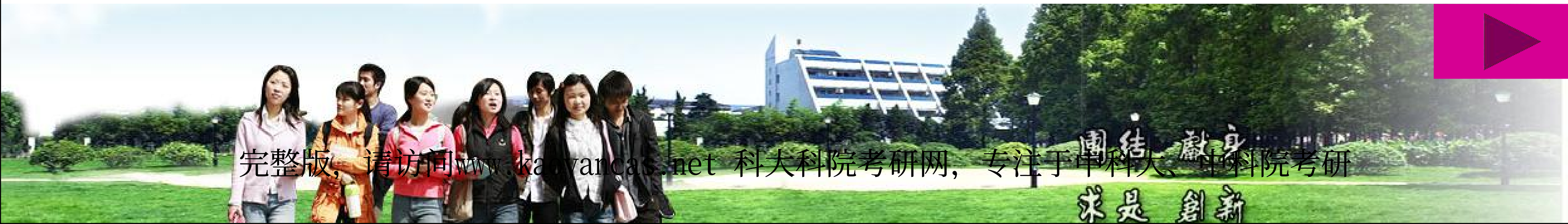
Disadvantages:

1.It is difficult to perform precision motion

2.Low speed

3.Difficult to balance

So,the linkage is preferred for low speed and heavy load situation.

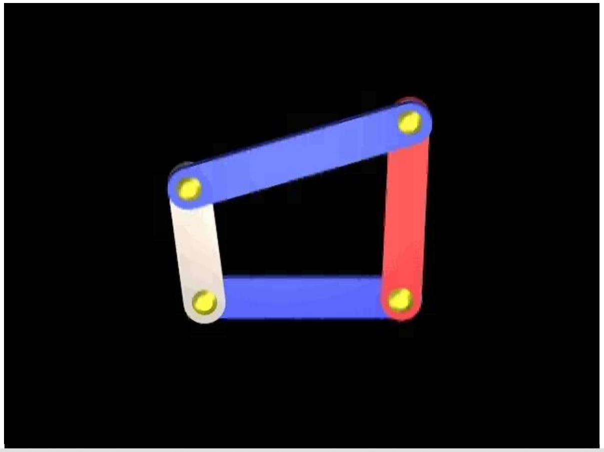


4.2 The Types of Four-bar Linkages

4.2.1 The Basic Form of Four-bar Mechanism

Revolute Four-bar Mechanism铰链四杆机构

所有运动副均为转动副的机构



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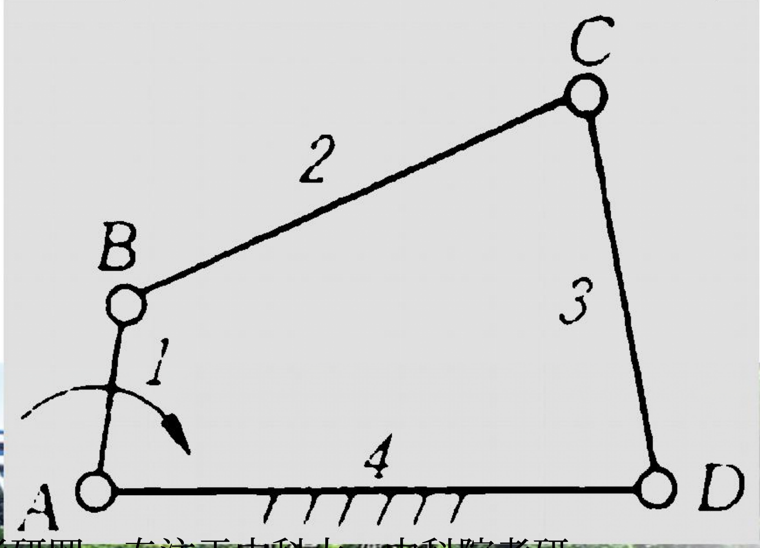
side links(连架杆)——1 &3

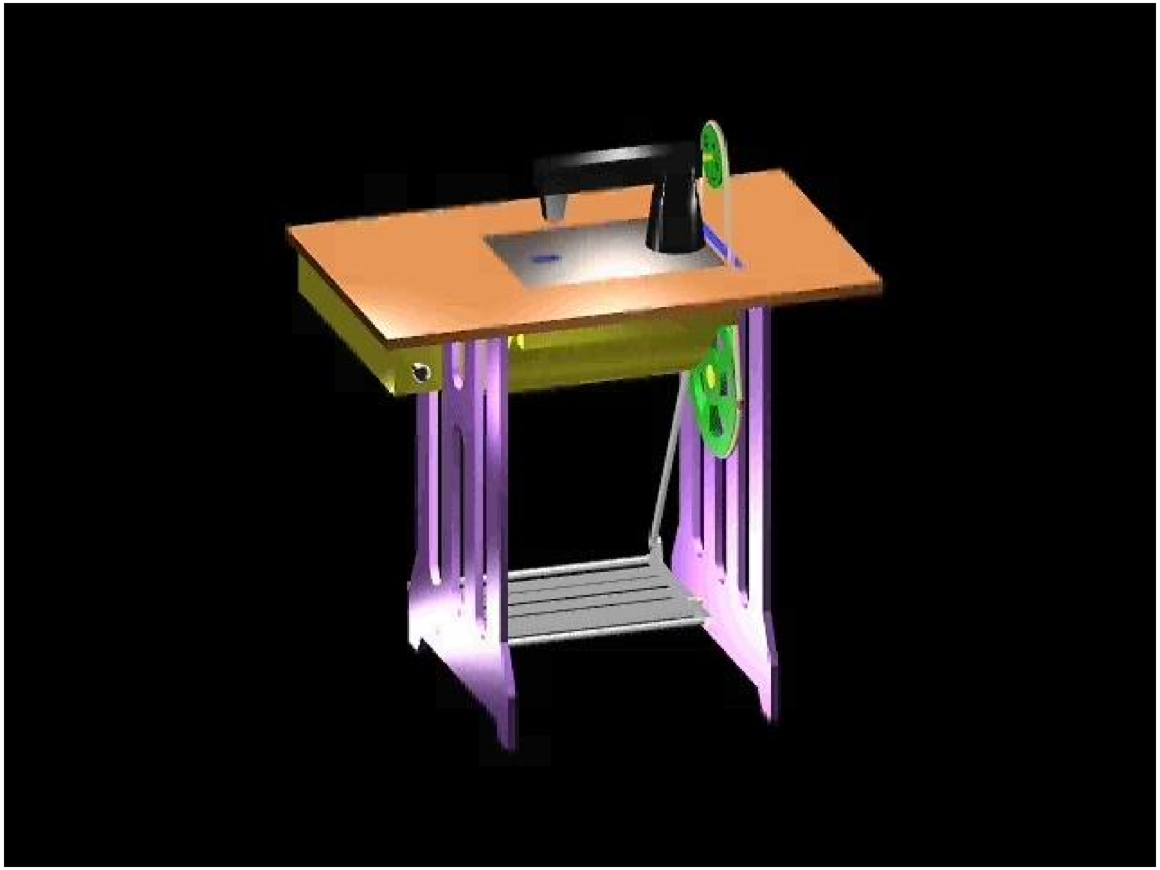
coupler（连杆）-----2

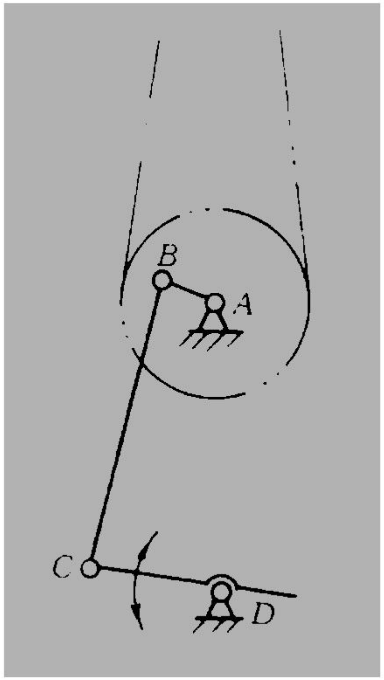
crank（曲柄）1

rocker（摇杆）3

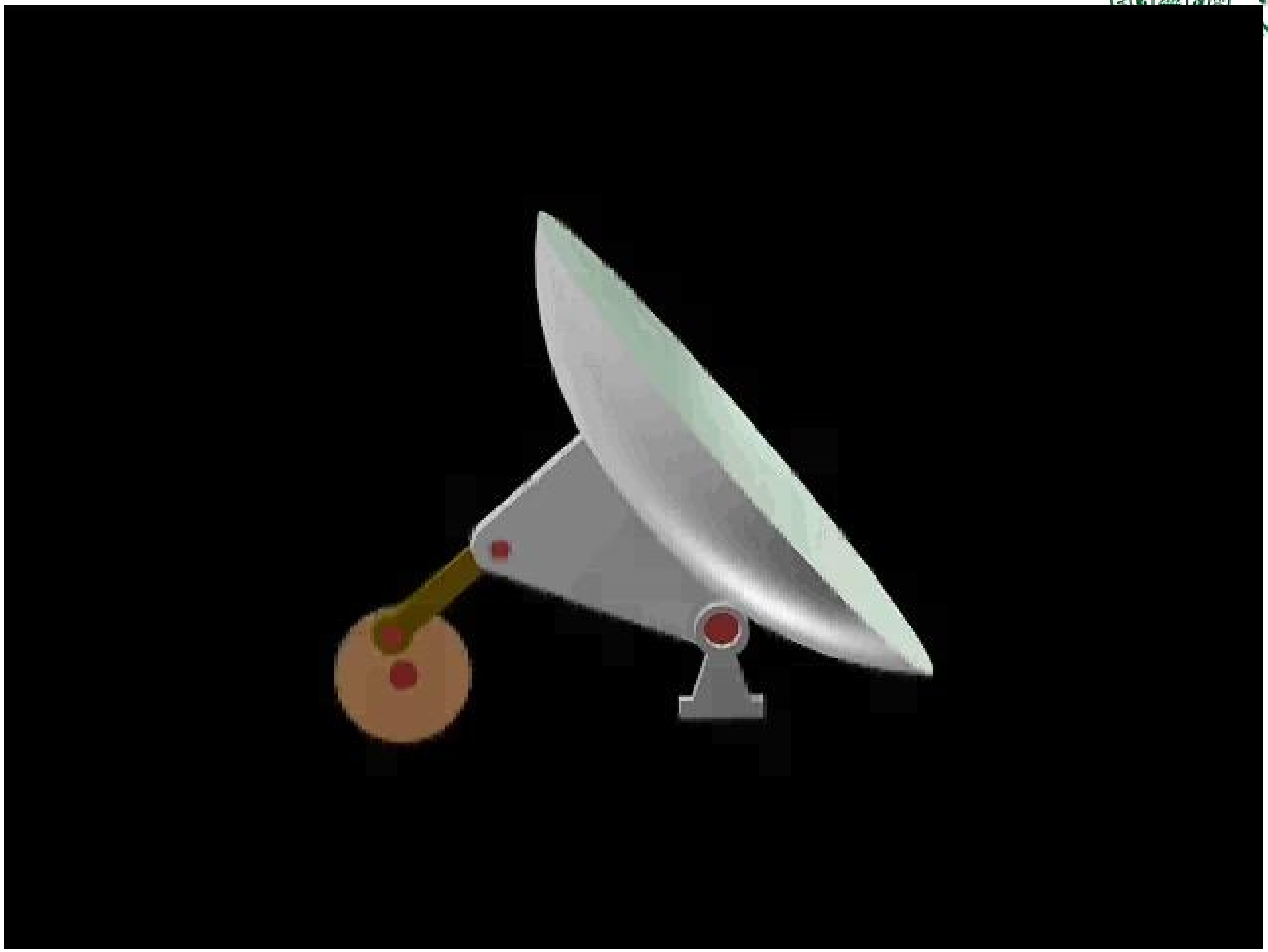


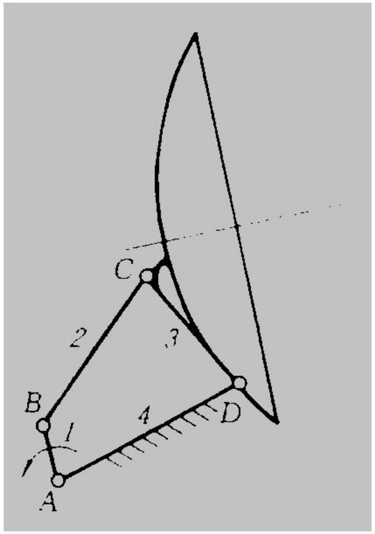
(a) Crank-rocker mechanism



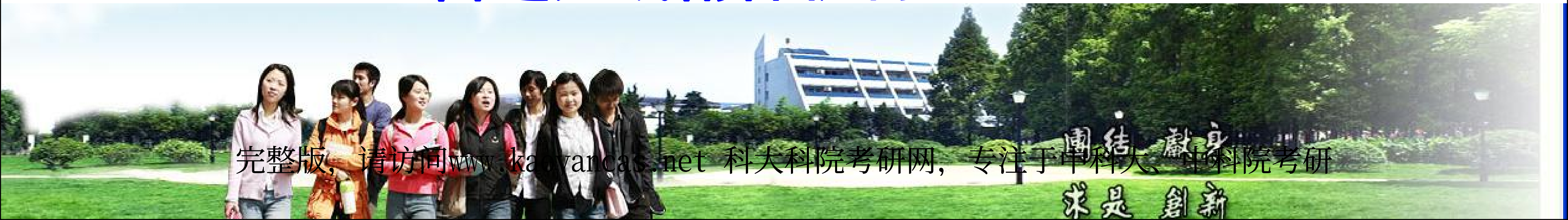


Foot operated sewing machine





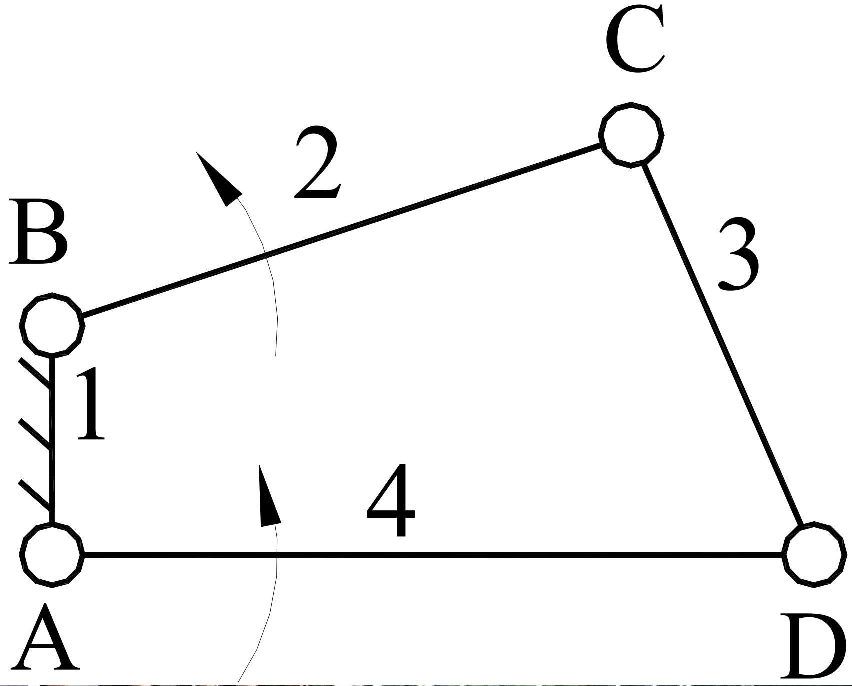
雷达天线俯仰机构



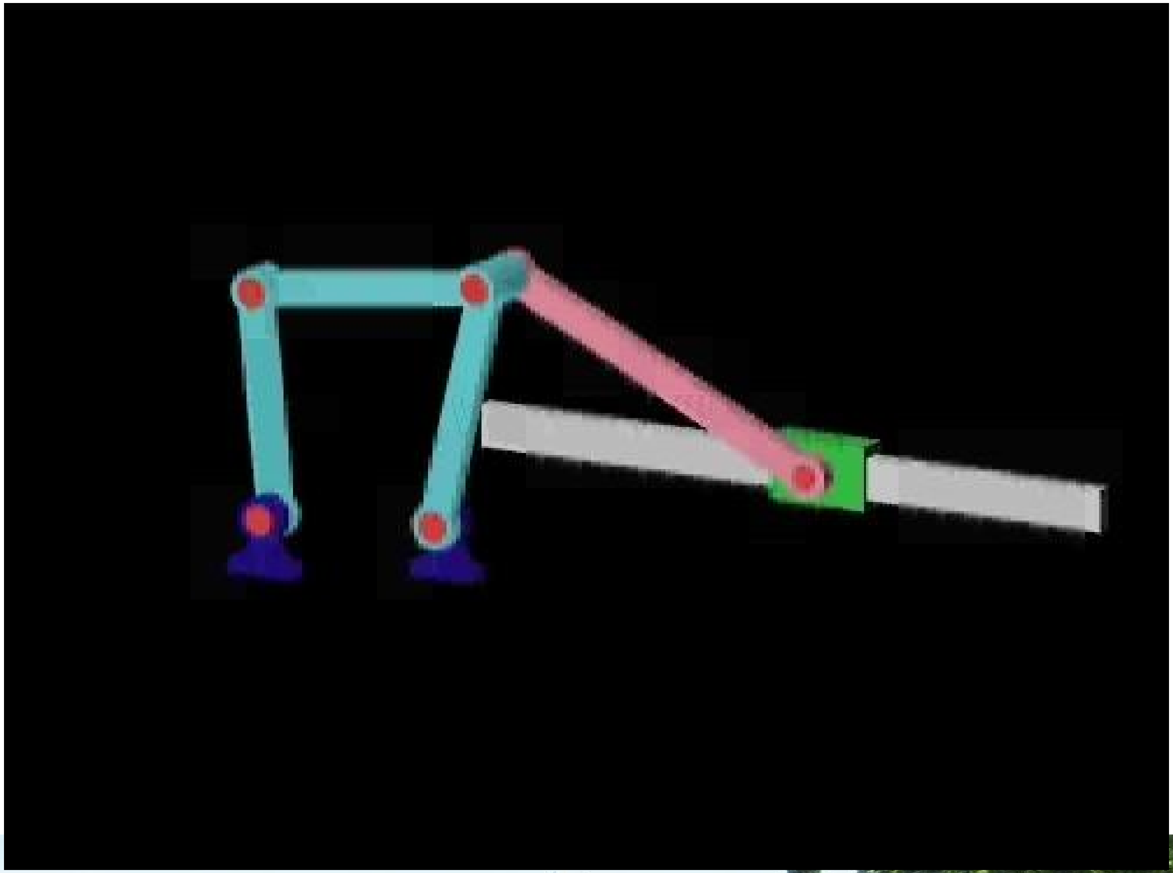
(b) Double-crank mechanism

If one crank rotates at a constant speed, the other crank will rotate in the same direction at a varying(变化的) speed.

当主动曲柄匀速转动时，从动曲柄作变速转动。

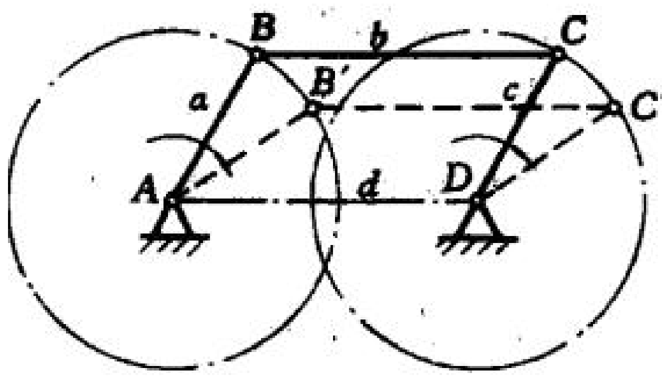


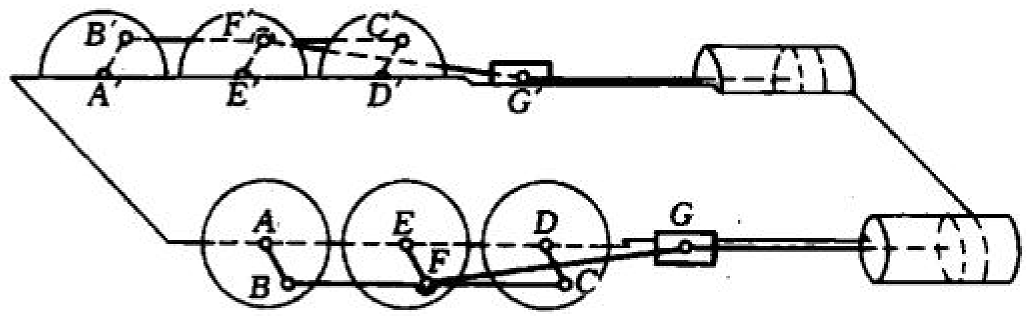
Unbalanced throw screen mechanism
惯性筛机构

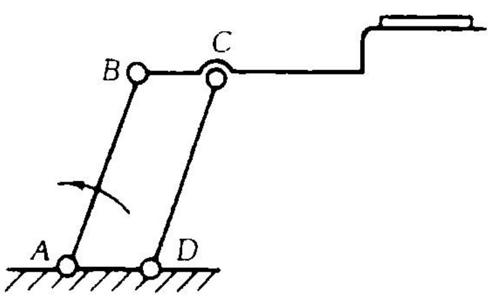


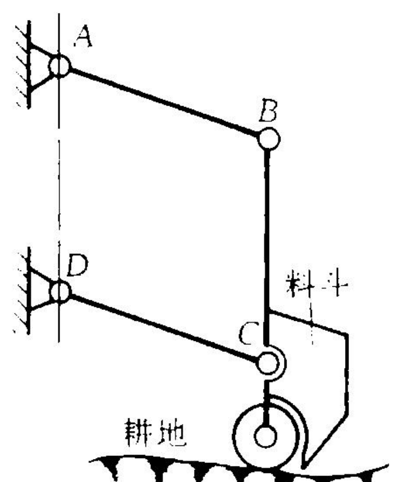
平行四边形机构：Parallel-crank Mechanism

正平行四边形机构如天平称、机车联动机构、摄影平台升降机构和播种料斗机构等。两曲柄等速转动









Antiparallel-crank Mechanism

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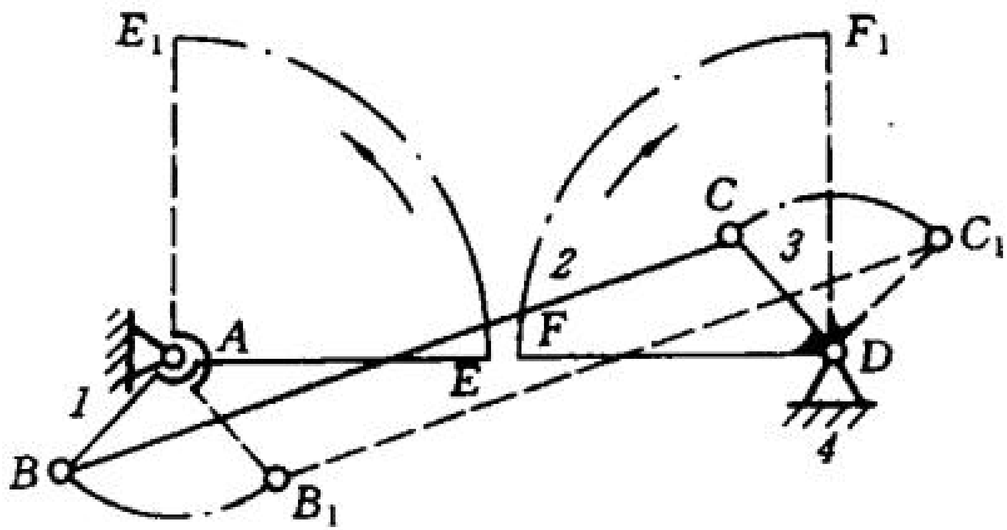
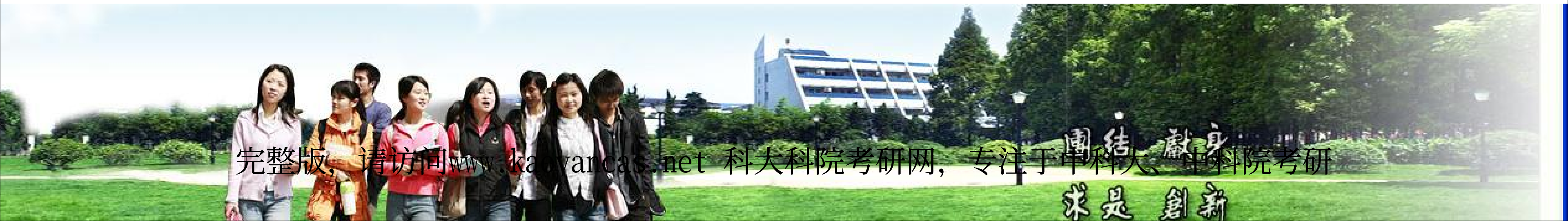
反平行四边形机构：两对杆长度相等，但不平行。

当以长边为机架时，两曲柄等速反向转动。用于车门开闭机构，如图所示。



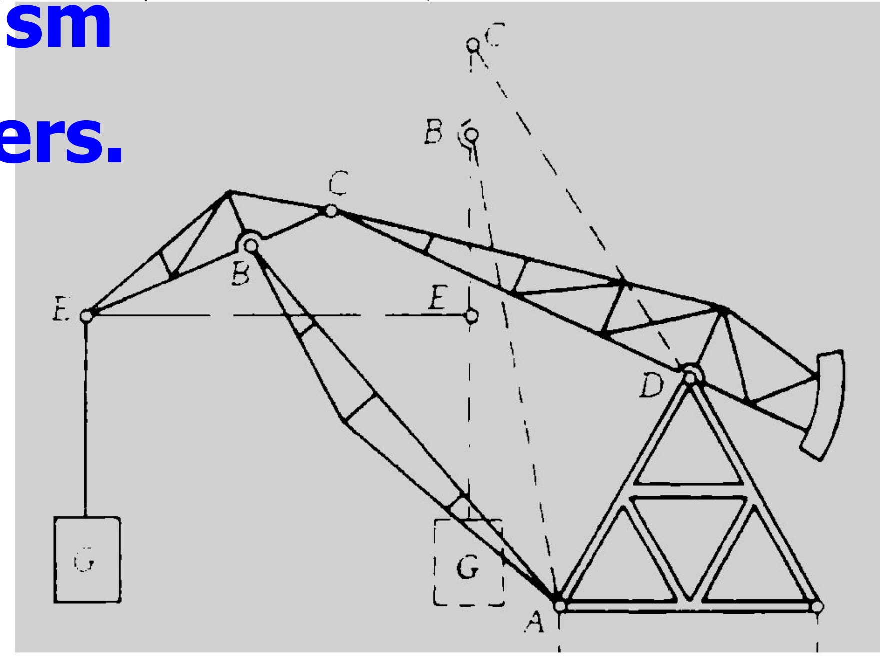
车门开闭机构动画



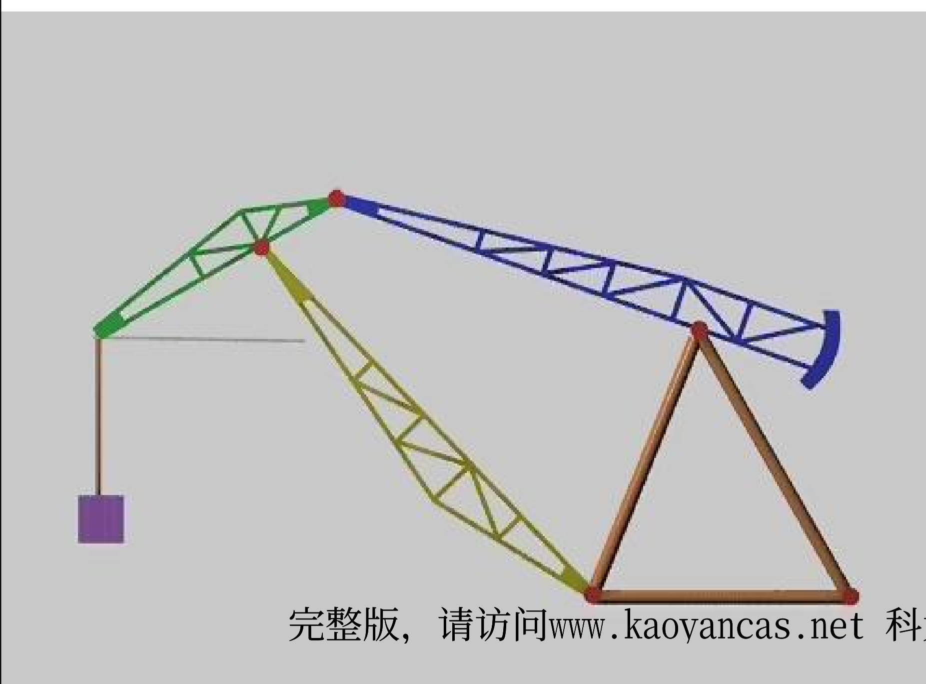
(c)Double-rocker mechanism

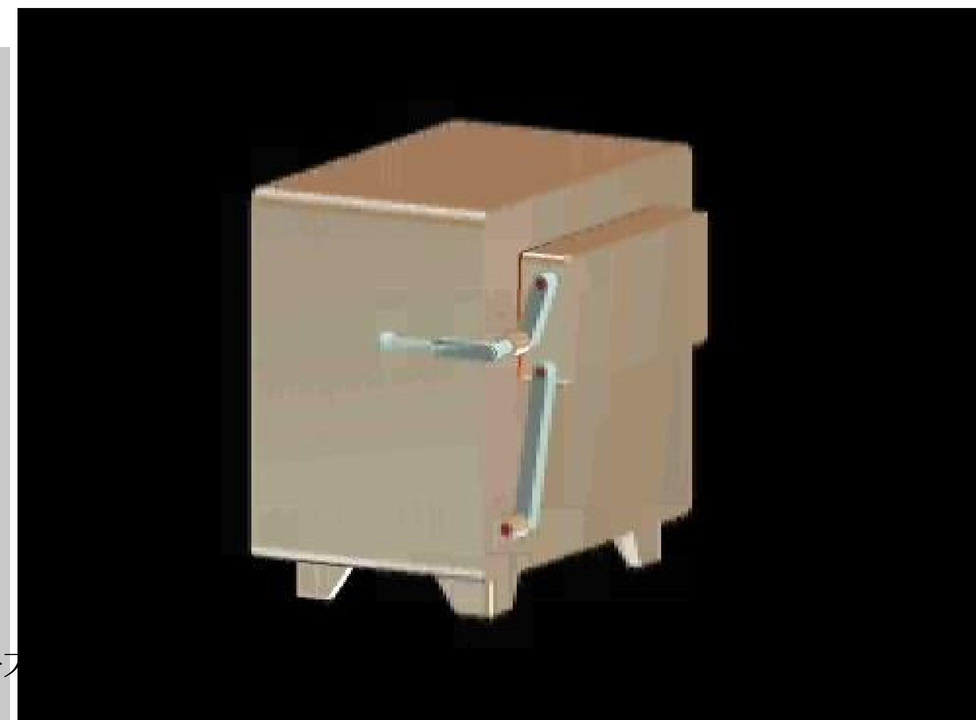
Both side links are rockers.

两连架杆都是摇杆。



用于鹤式起重机和炉门开关机构等。



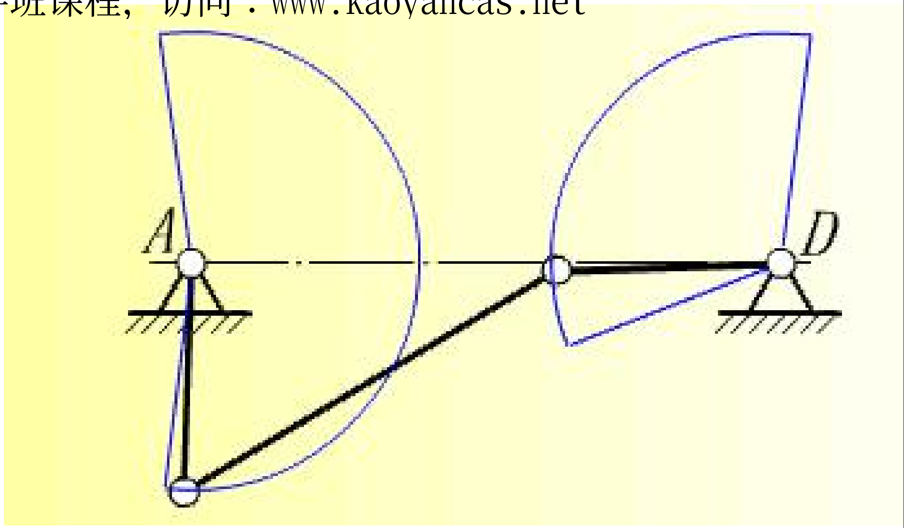


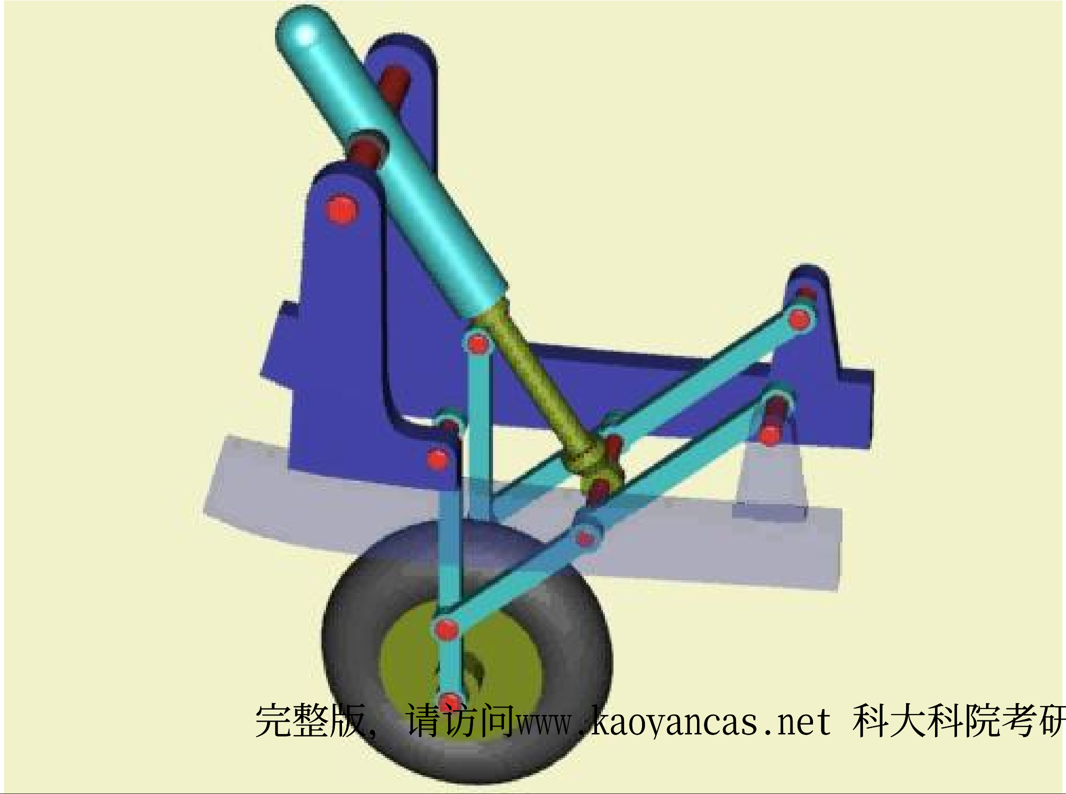
等腰梯形机构也是双摇杆机构

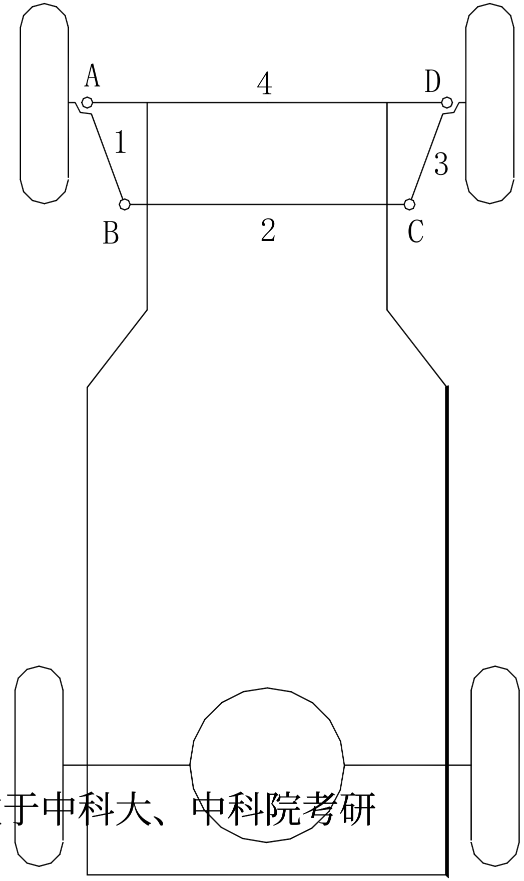
应用：

转向机构——车辆的前轮转向

飞机起落架





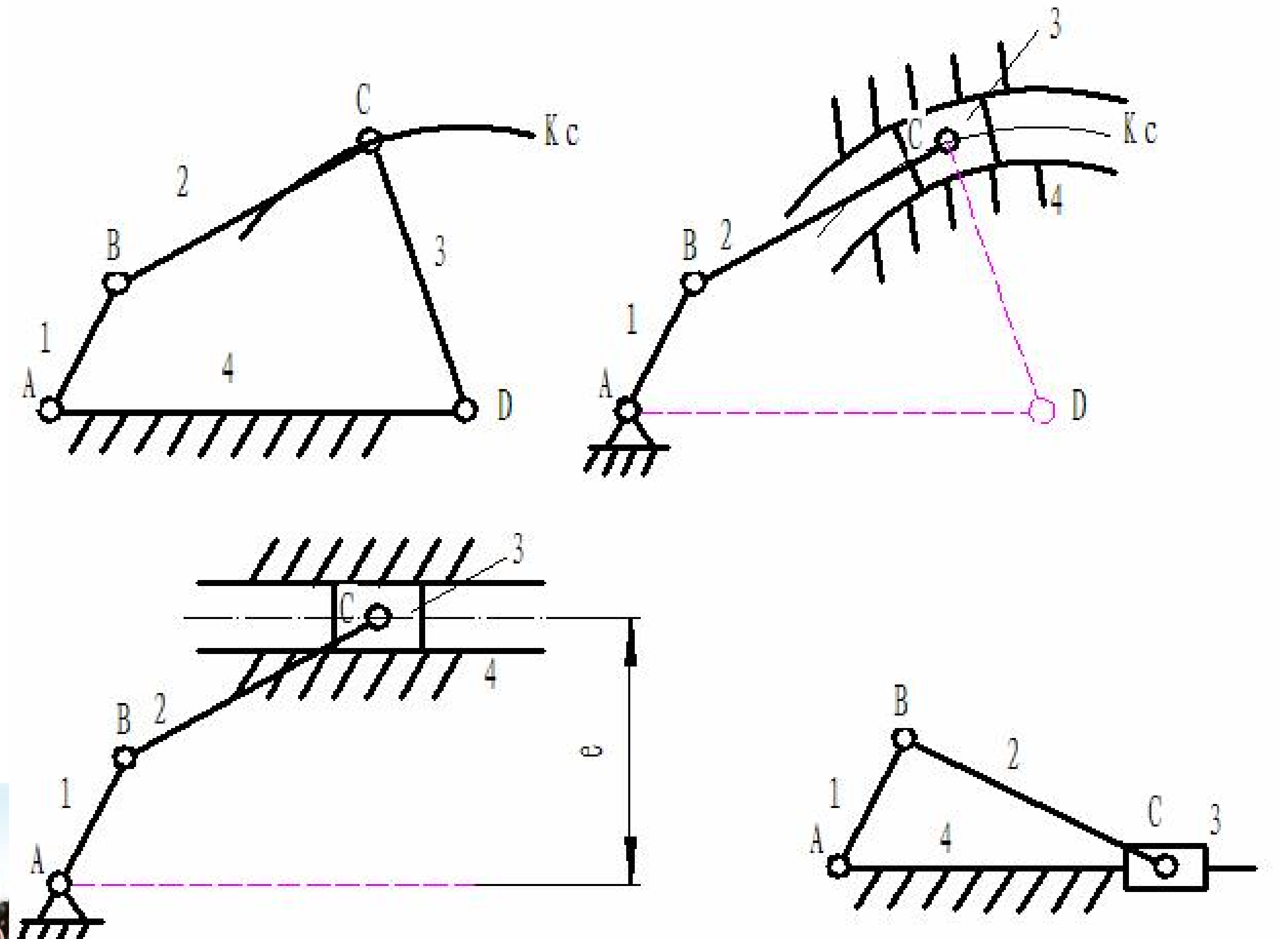


4.2.2 Variation (变异) of Revolute Four-bar Mechanisms

((1))Replacing a revolute pair with a sliding pair

Slider-crank mechanism

曲柄滑块机构（偏距e）



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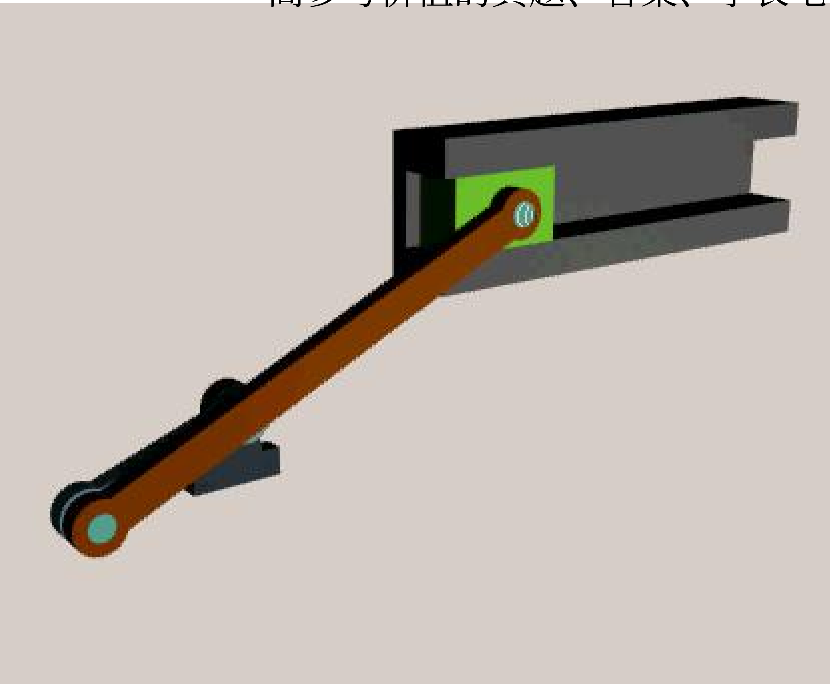
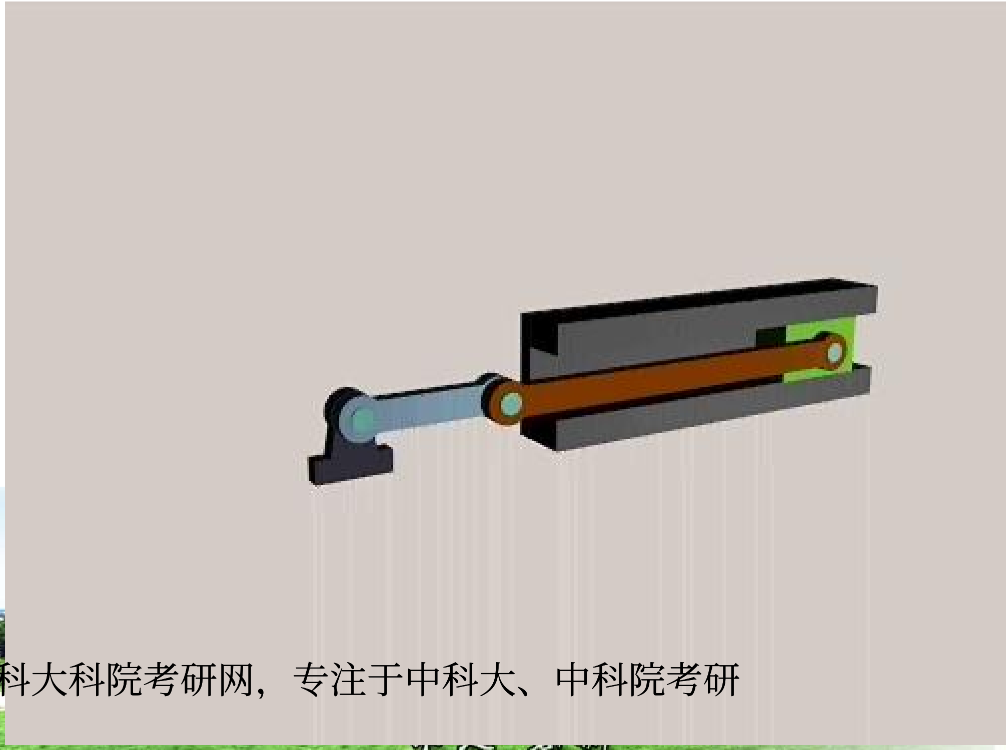
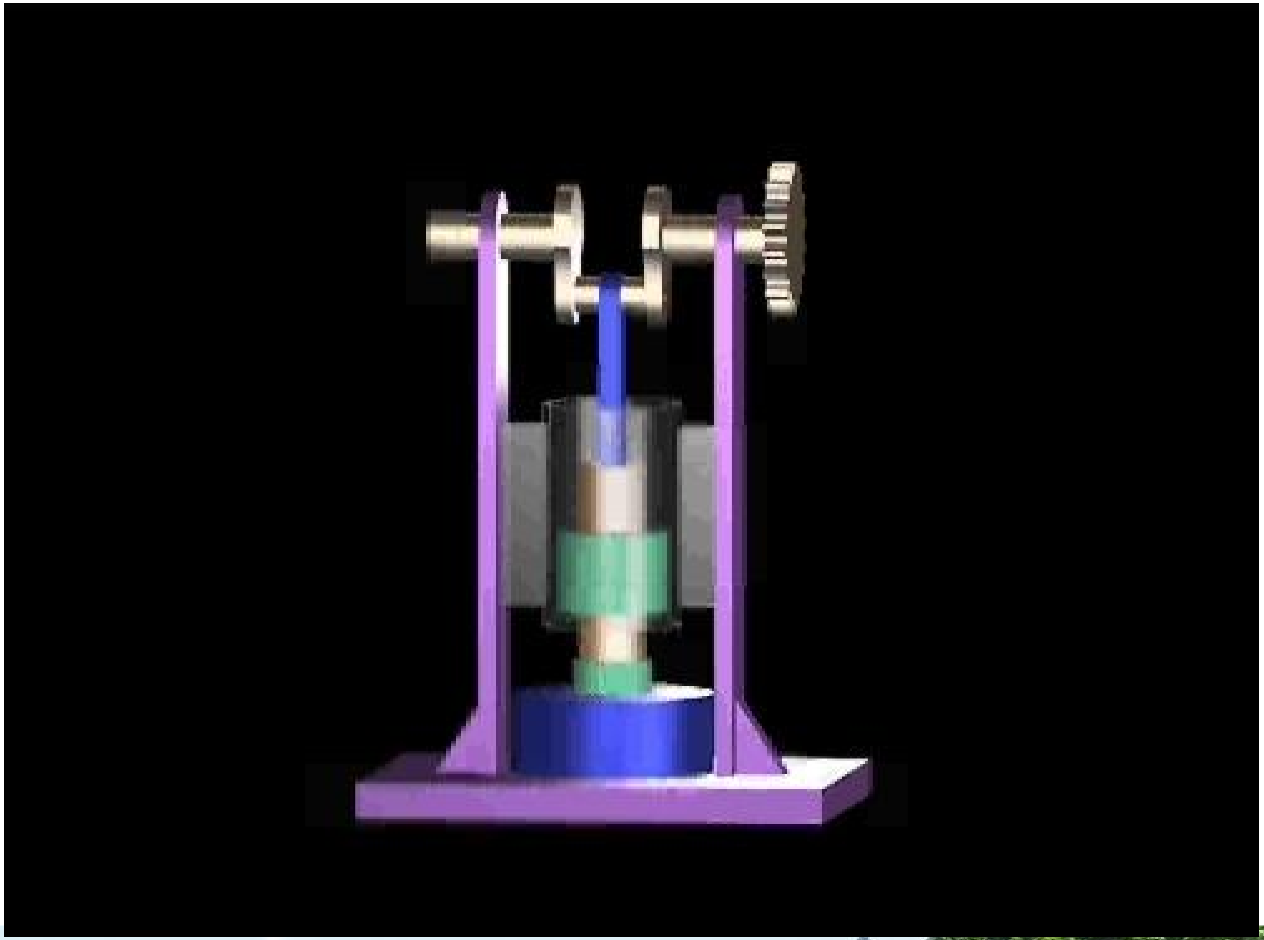


e≠0,
Offset slider-crank mechanism
偏置曲柄滑块机构

e=0,
Centric slider-crank mechanism
对心曲柄滑块机构



用于冲床、内燃机、空压机、曲柄压力机等机械中。



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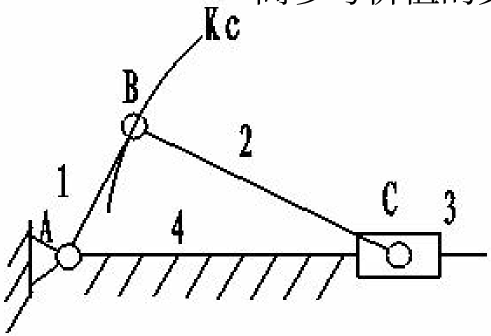
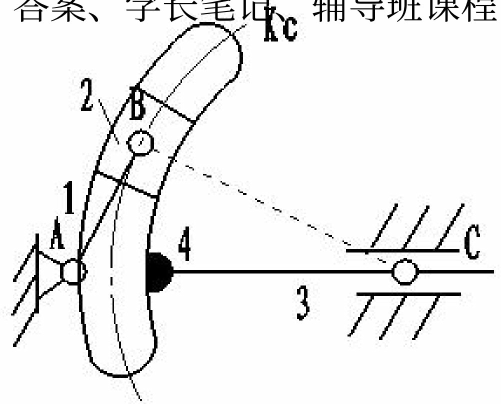




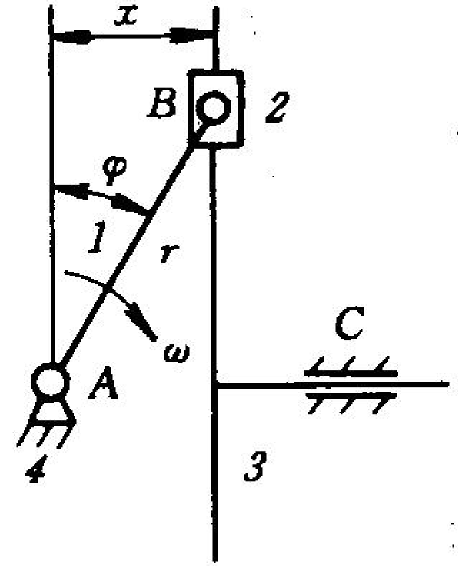
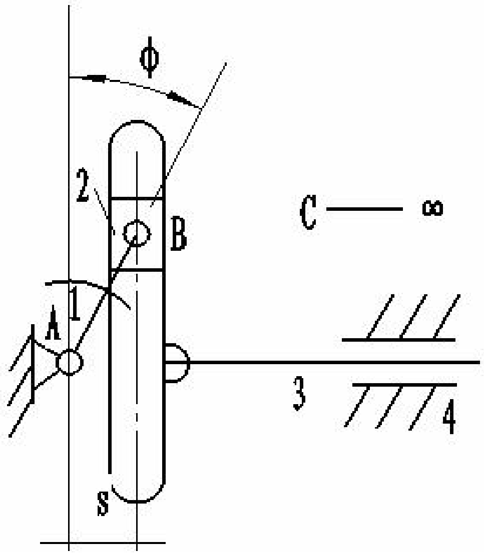
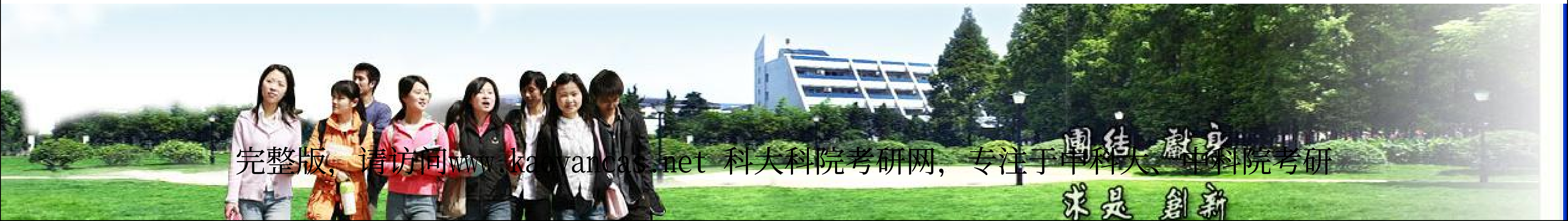
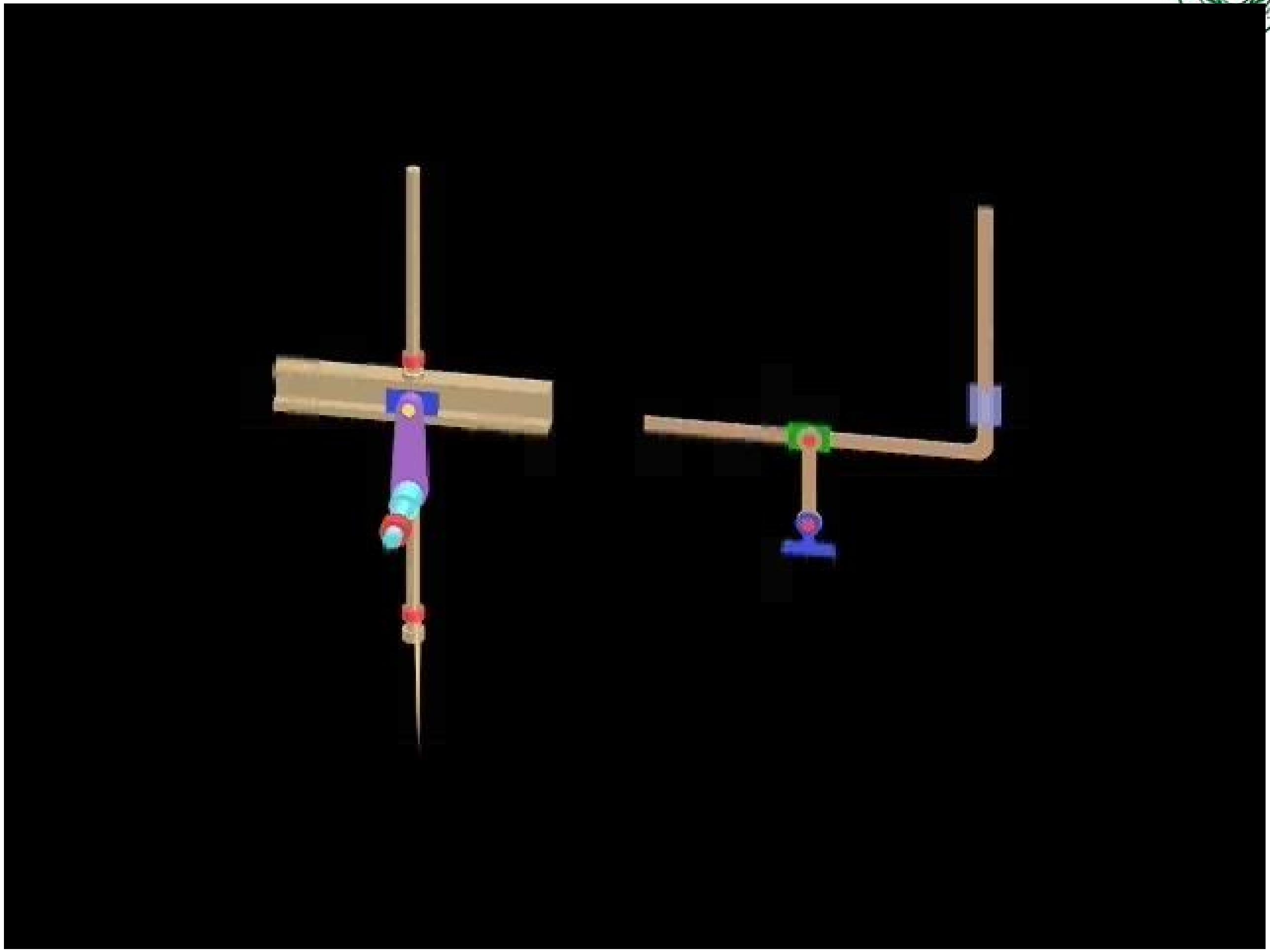


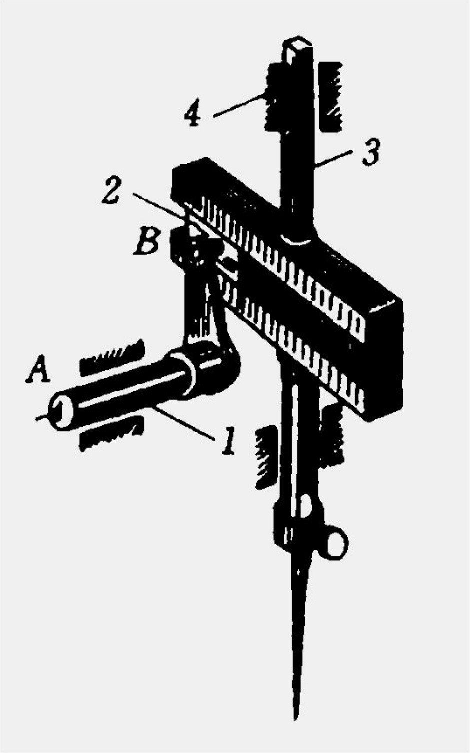
Fig. 4-6



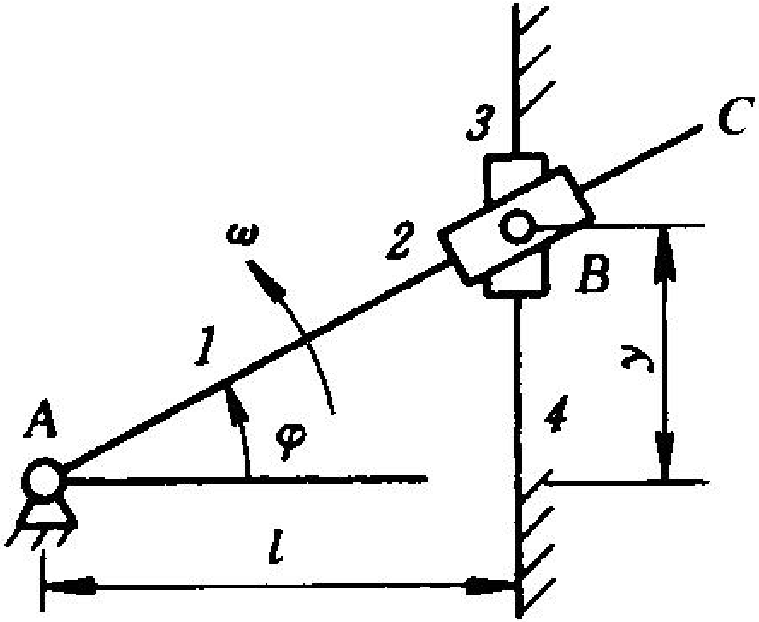
$$S = l_{AB}\sin\phi \longrightarrow$$ Sinusoid Generator正弦机构

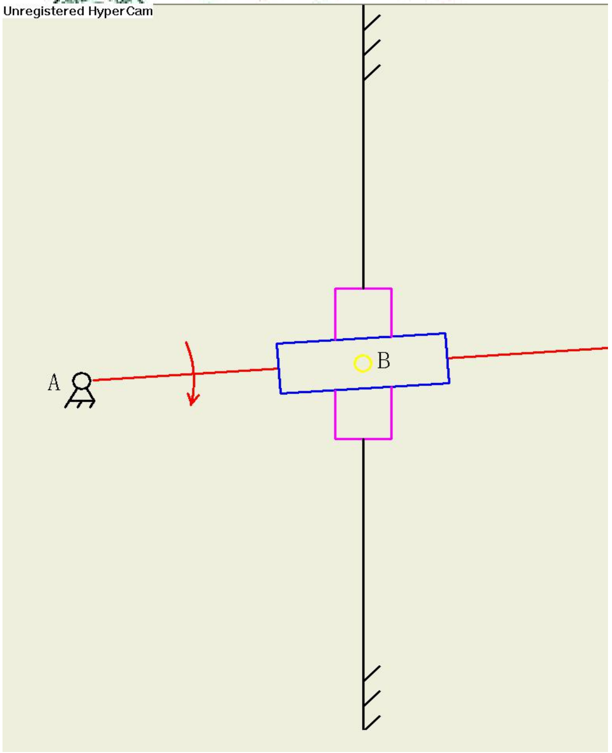




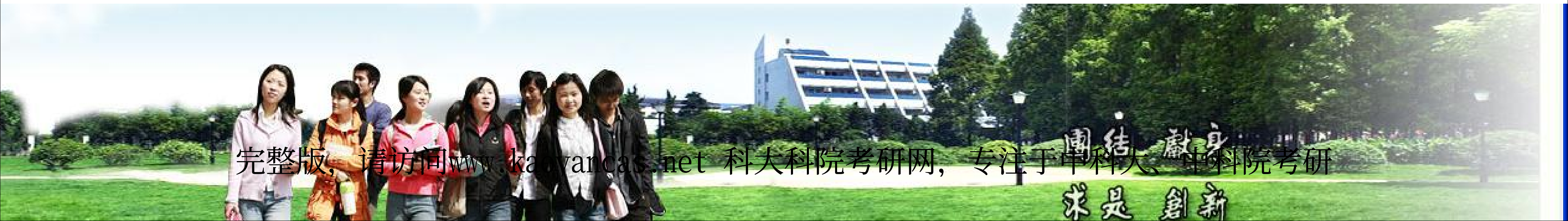


缝纫机的刺布机构





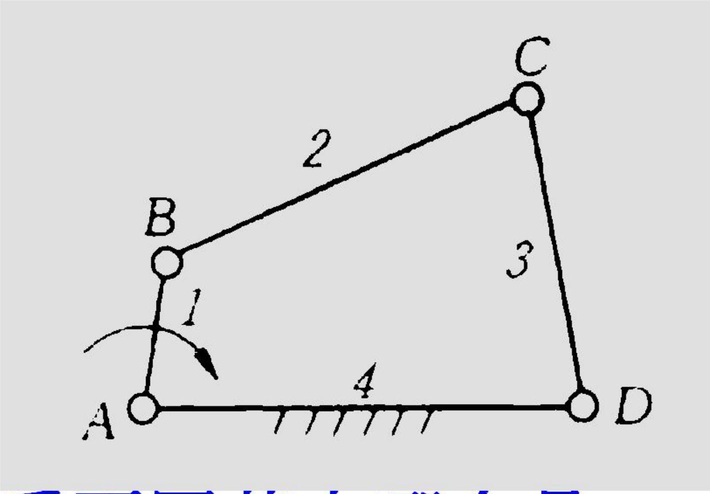
$y = l \tan \varphi$ ⟶ Tangent generator正切机构



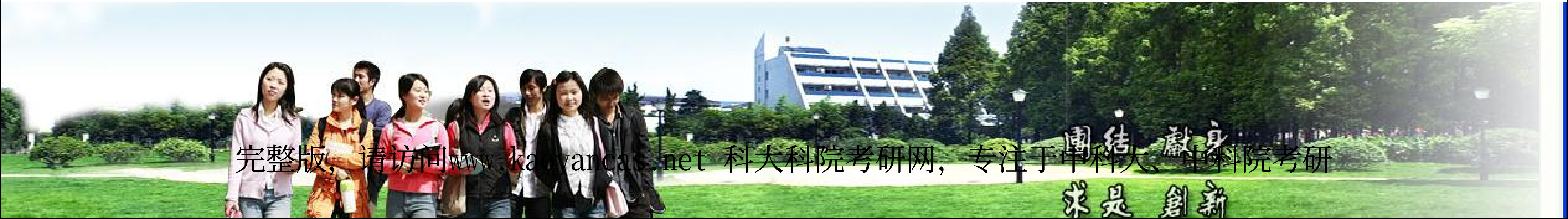
(2)Taking different links as frame.-----inversions 机架变换

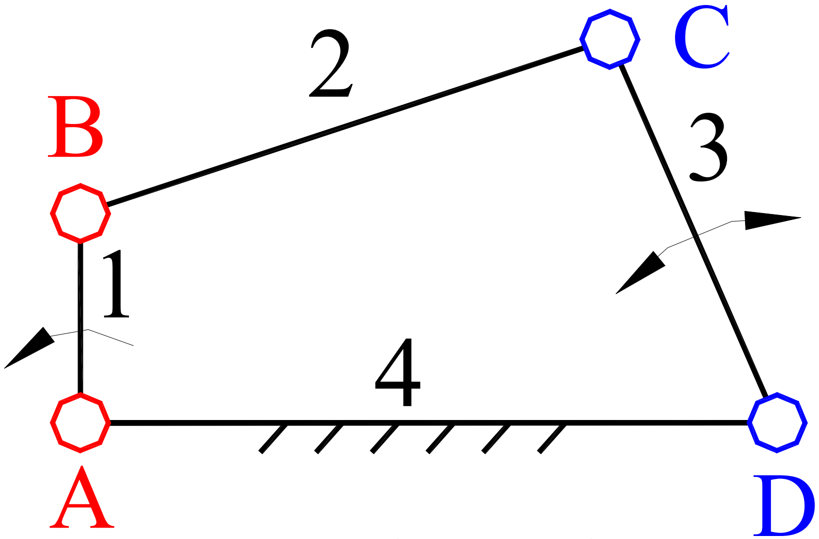
Fully rotating revolute: A &B （整转副）

Partially rotating revolute :C&D （摆动副）

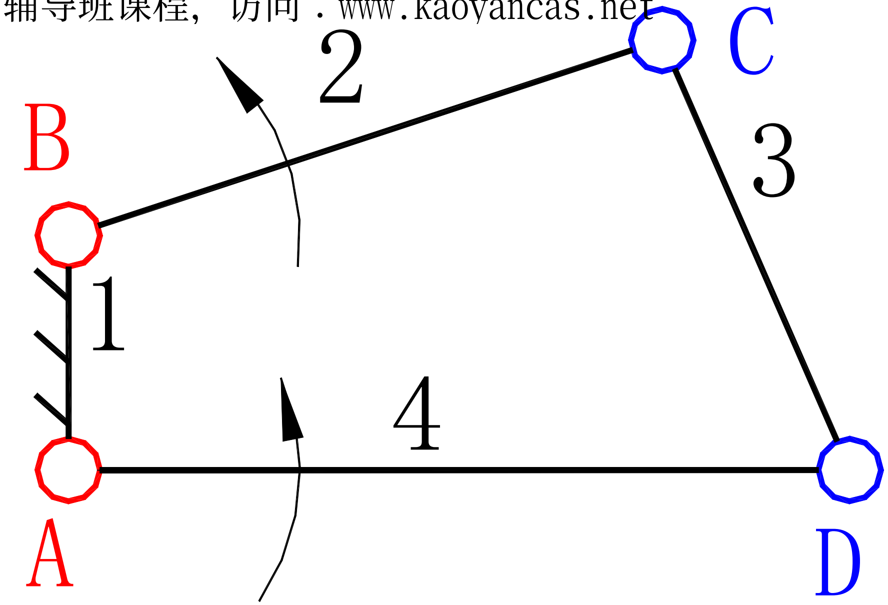


机构中任意两构件间的相对运动关系不因其中哪个是机架而变化。So,inversion of a mechanism in no way changes the type of revolute and the relative motion between its links.

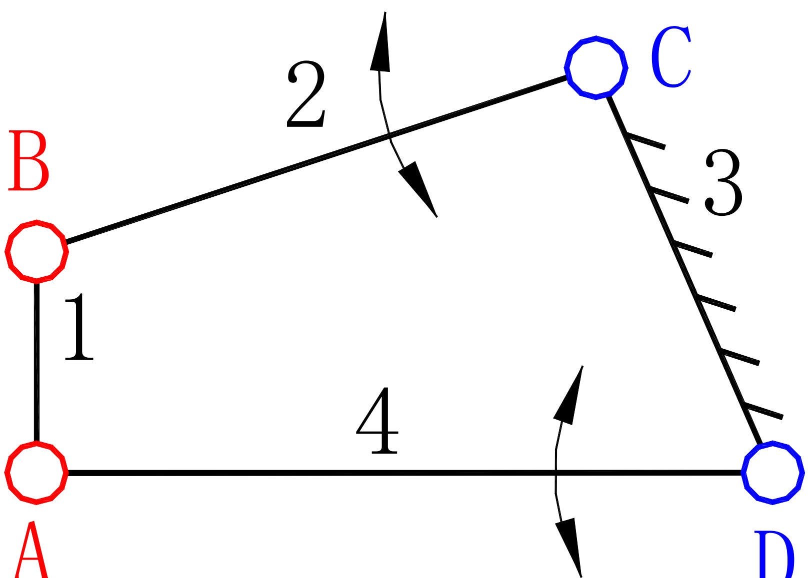




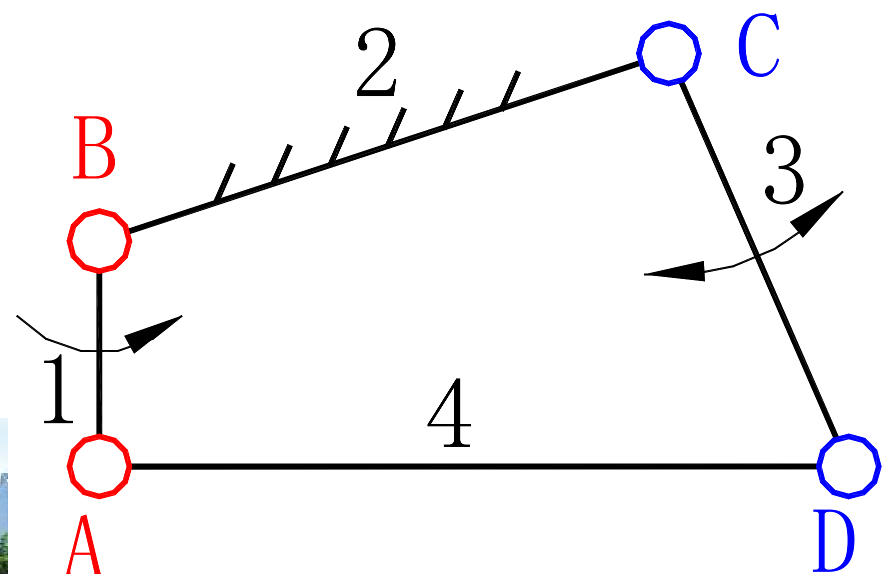
Crank-rocker



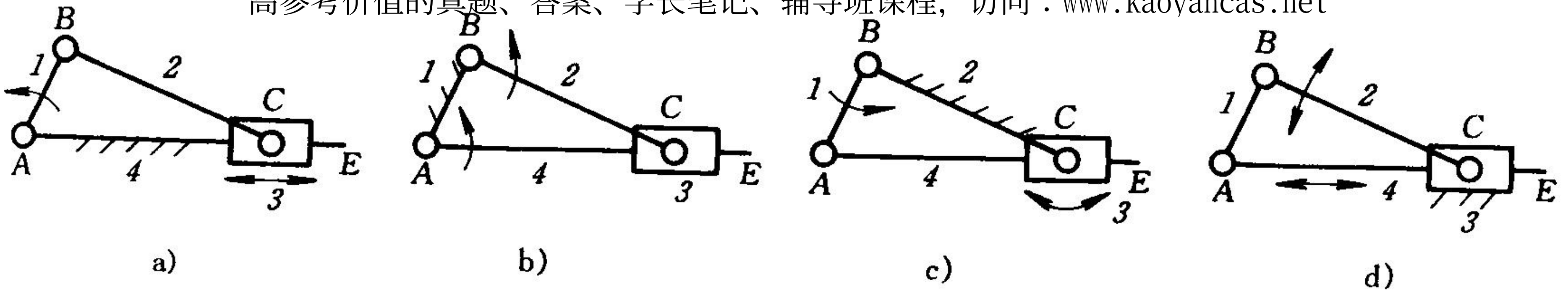
Double-crank



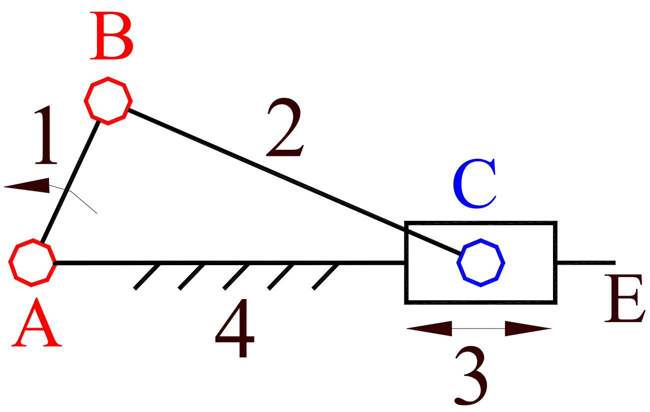
Double-rocker

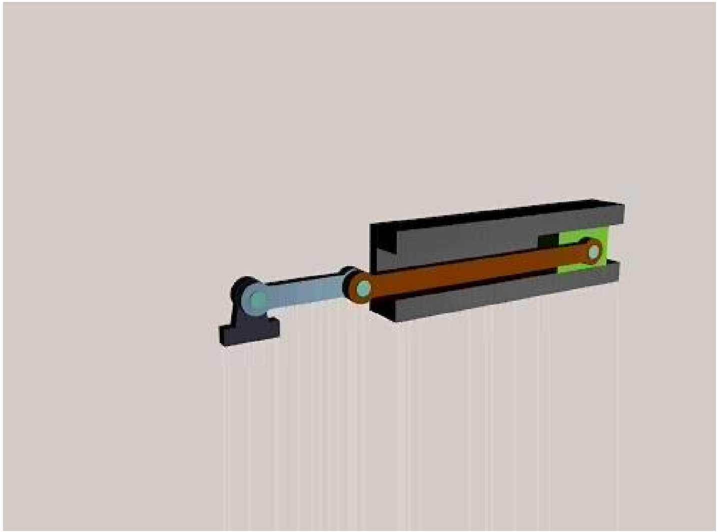


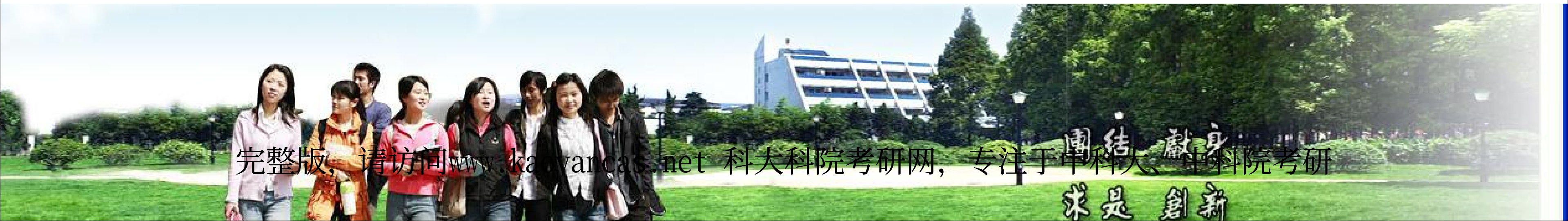
Crank-rocker

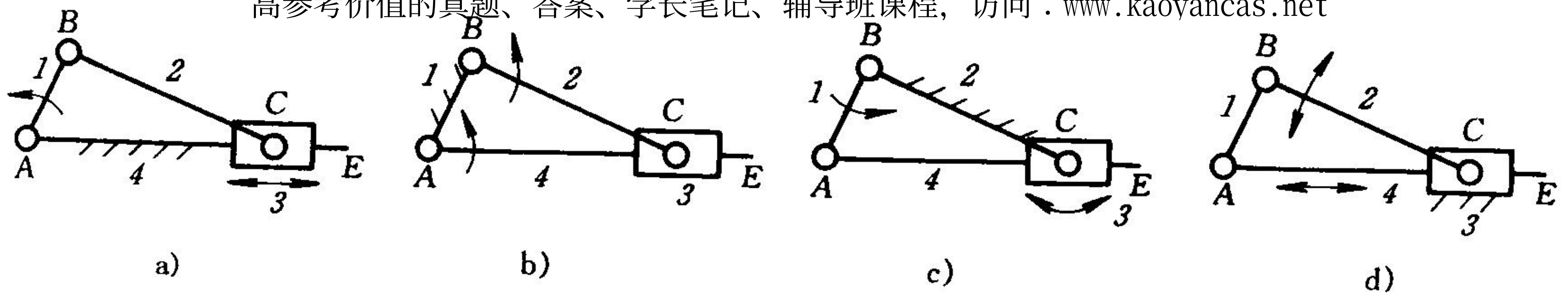


a）slider-crank mechanism曲柄滑块机构

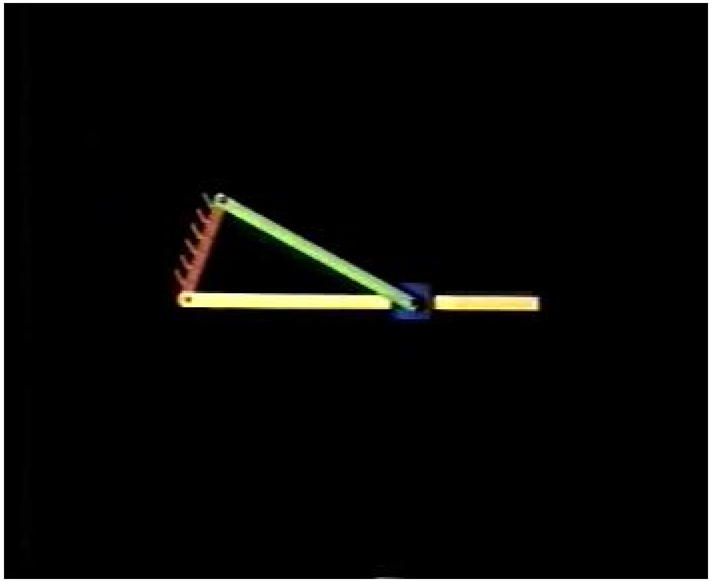


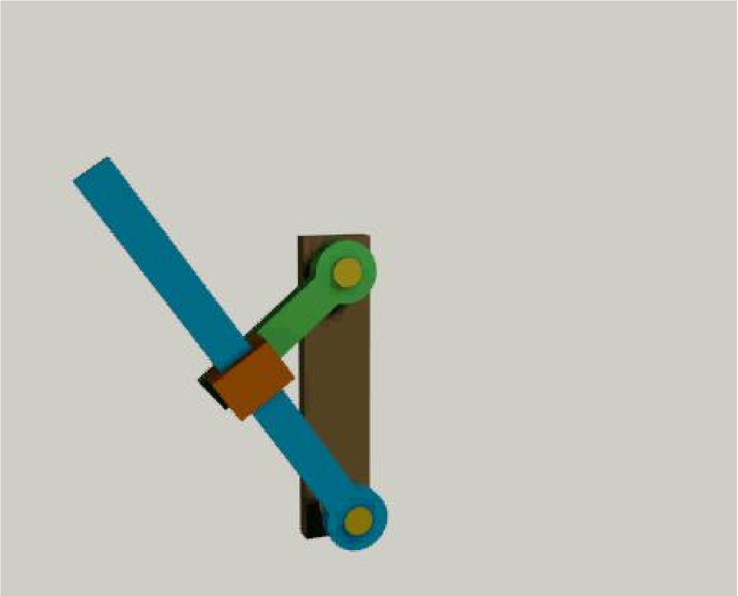






b) guide-bar mechanism导杆机构

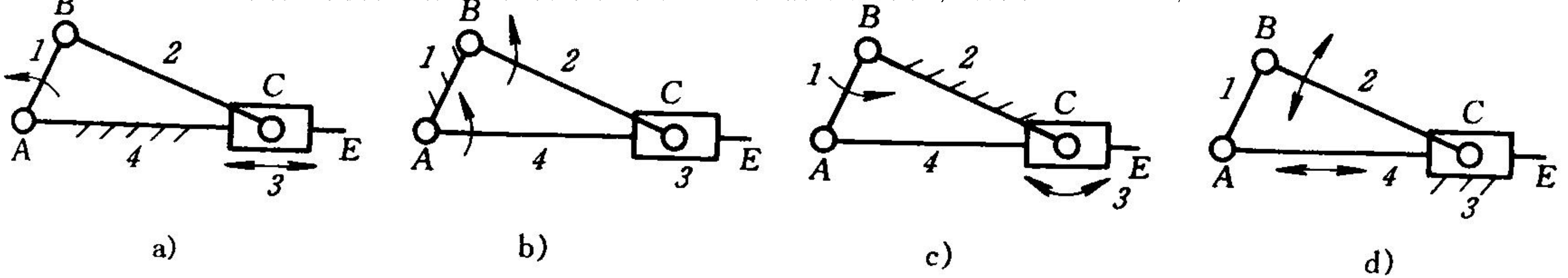




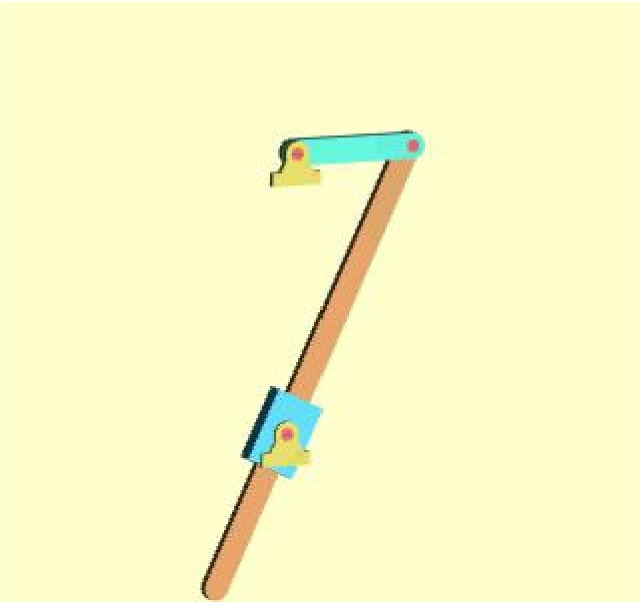
If $l_{BC}<l_{AB}$

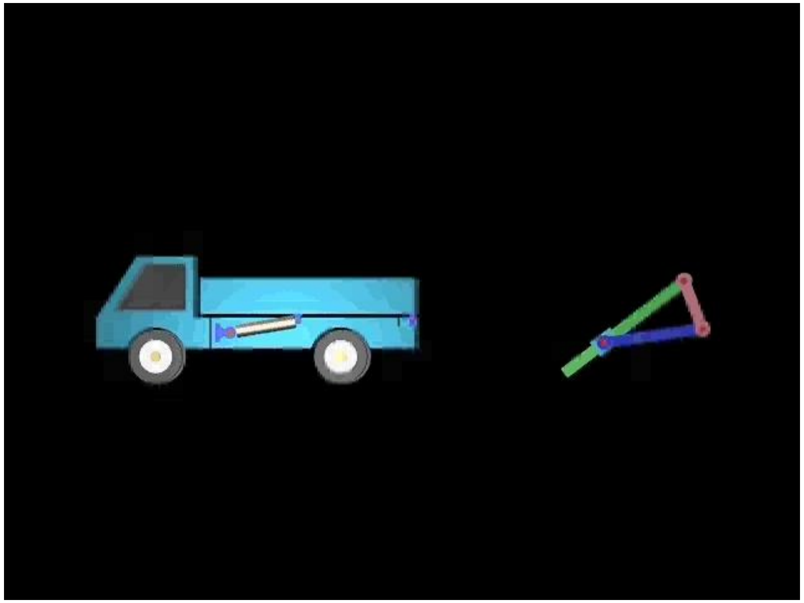
Rotating guide-bar mechanism 转动导杆机构

Oscillating guide-bar mechanism 摆动导杆机构

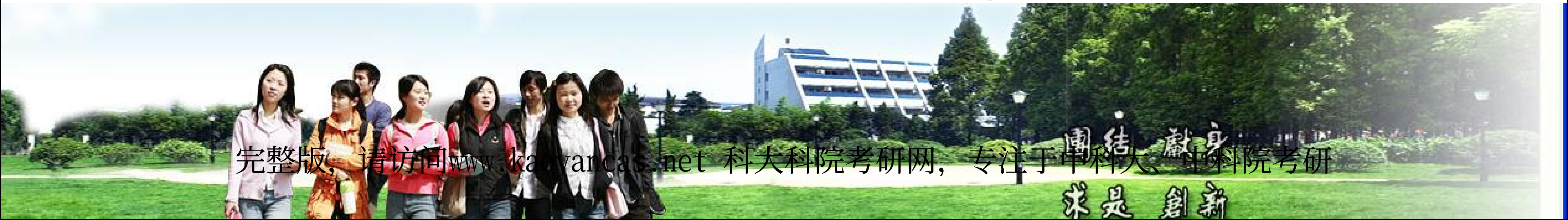


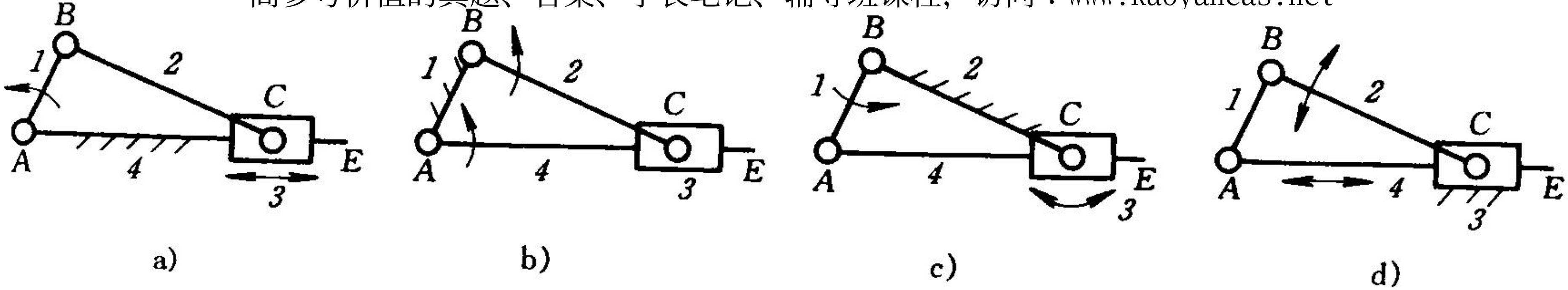
c)crank and oscillating block mechanism摇块机构



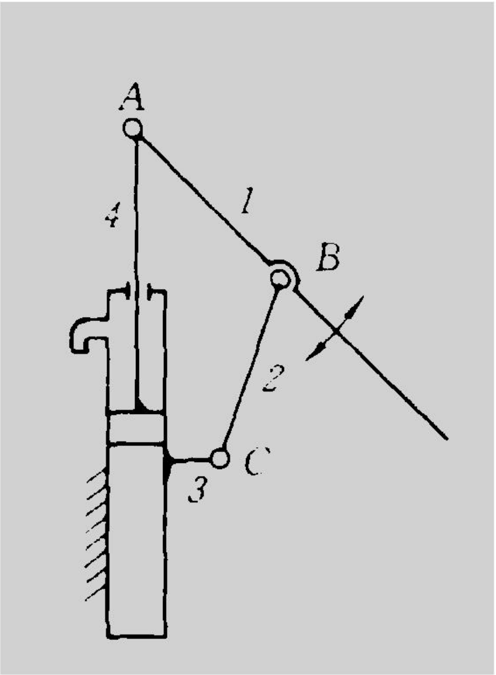


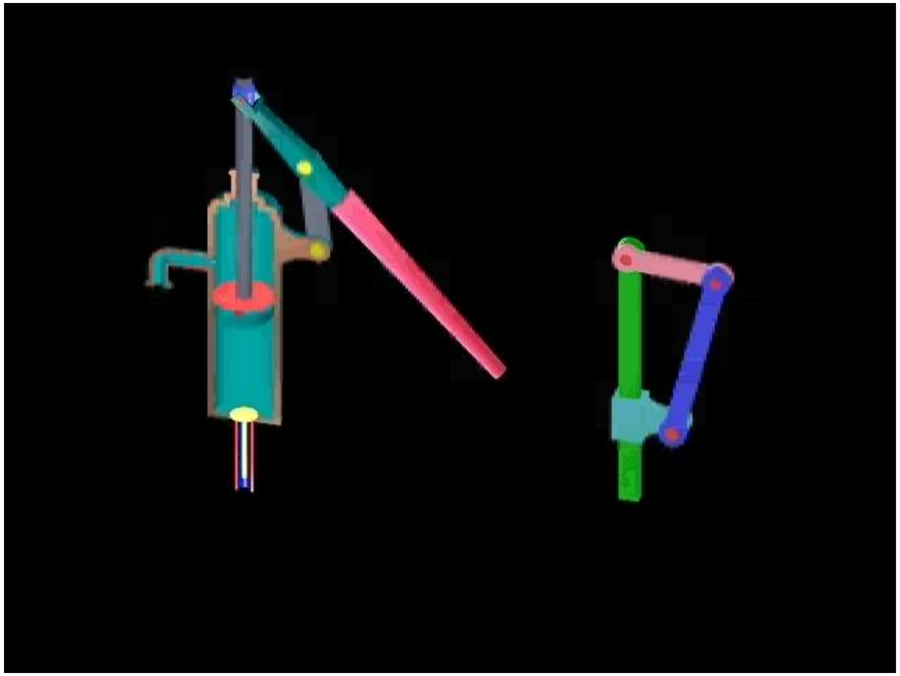
Self-tipping vehicle自卸车辆



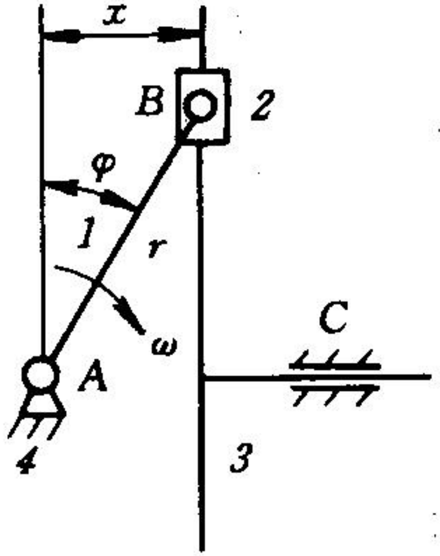


d)translating sliding-rod mechanism
移动导杆机构或定块机构

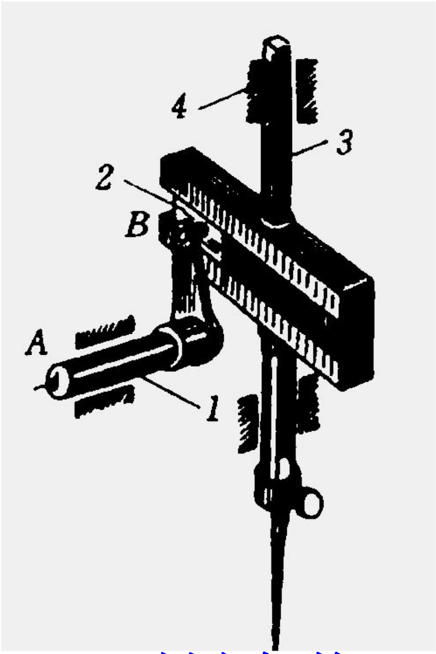




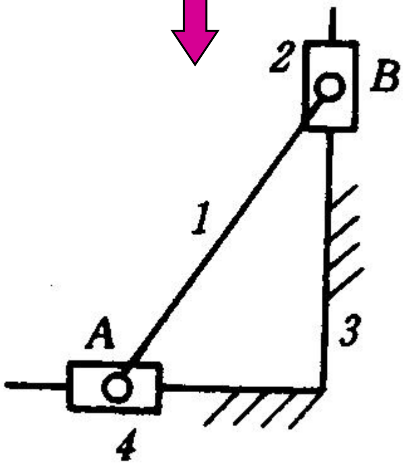
含有两个移动副的情况：



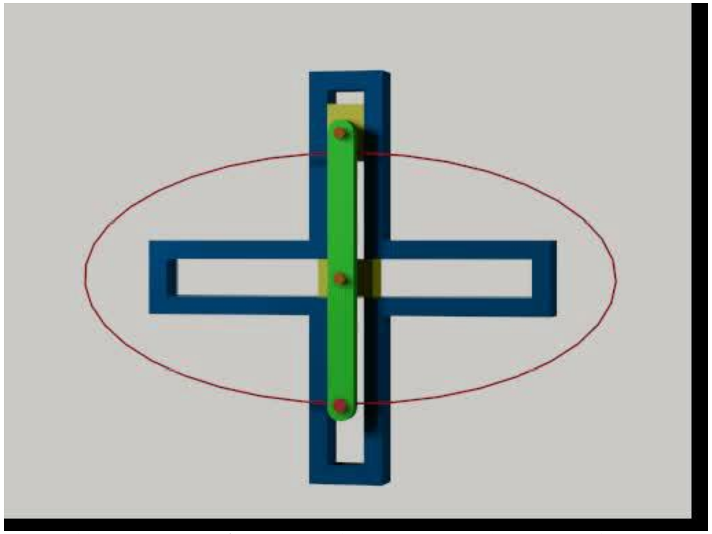
正弦机构



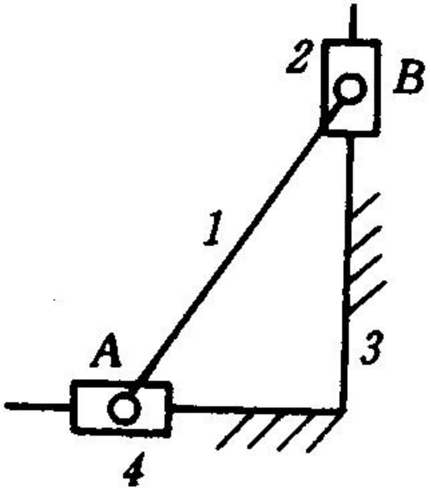
刺布机构



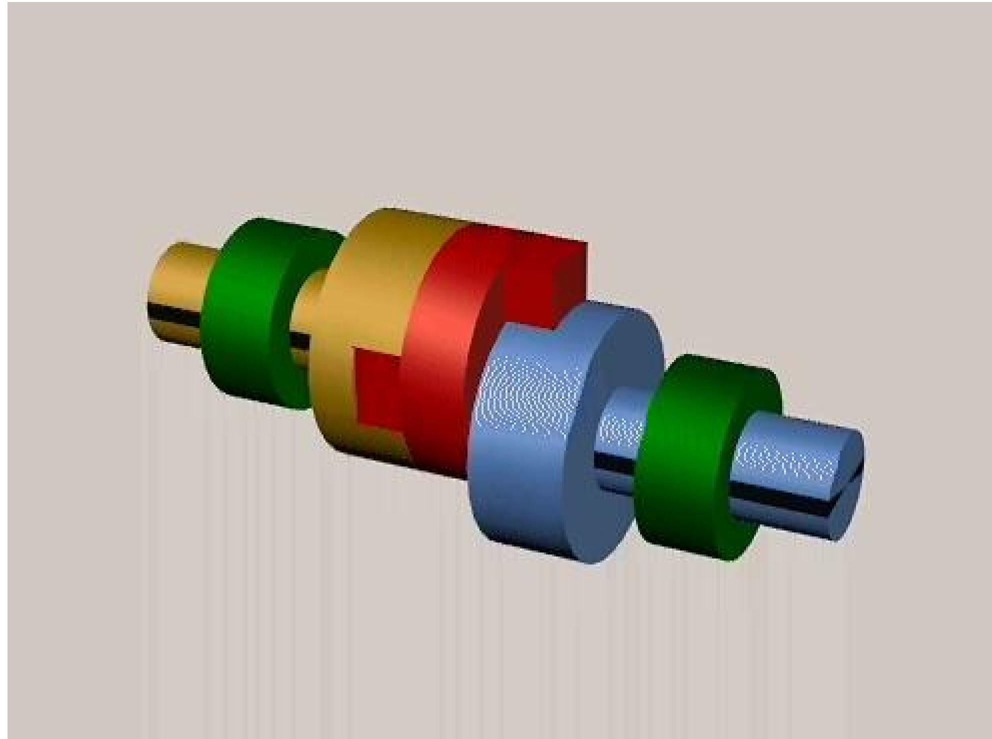
双滑块机构

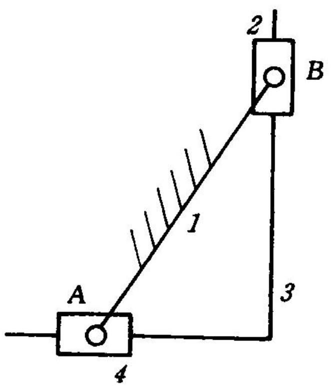


Elliptic trammel椭圆规



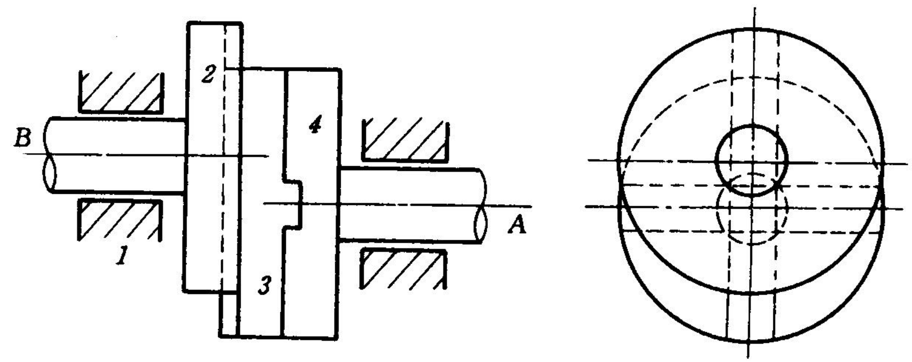
双滑块机构





双转块机构

Double rotating block

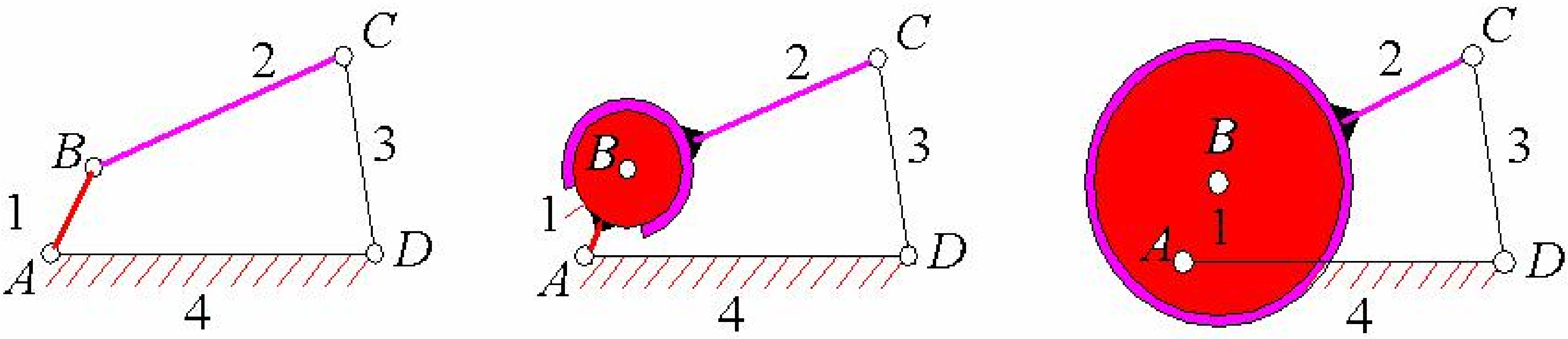


十字滑块机构

Oldham coupling

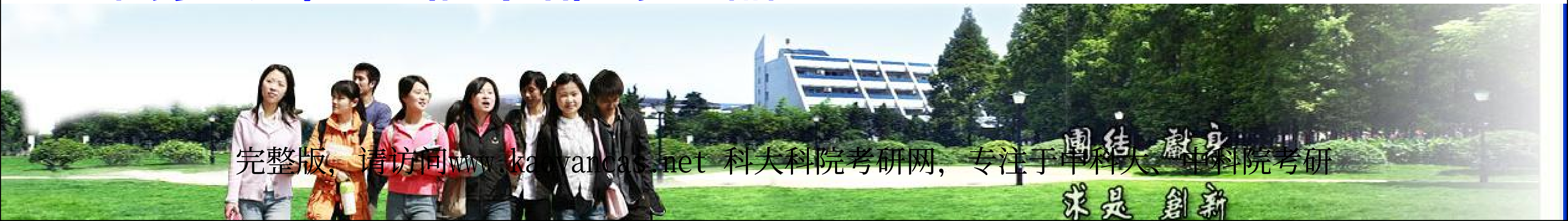
(3)Enlarging a revolute pair

Note:Enlarging a revolute pair in no way changes the motion relationship between any links.



Crank1---eccentric偏心轮

偏心轮机构多用于曲柄销承受较大冲击，曲柄较短，需要装在直轴中部的机器



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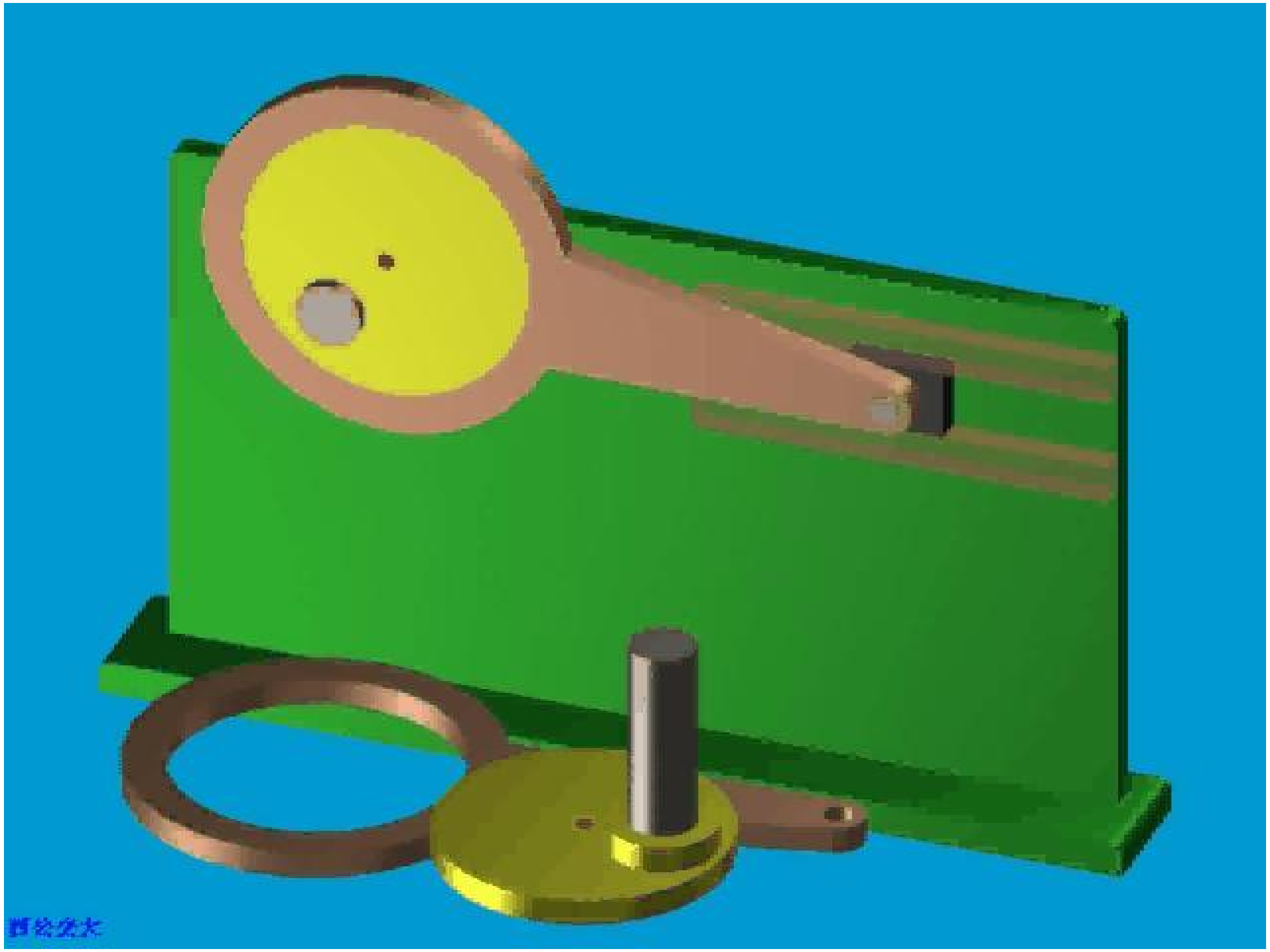


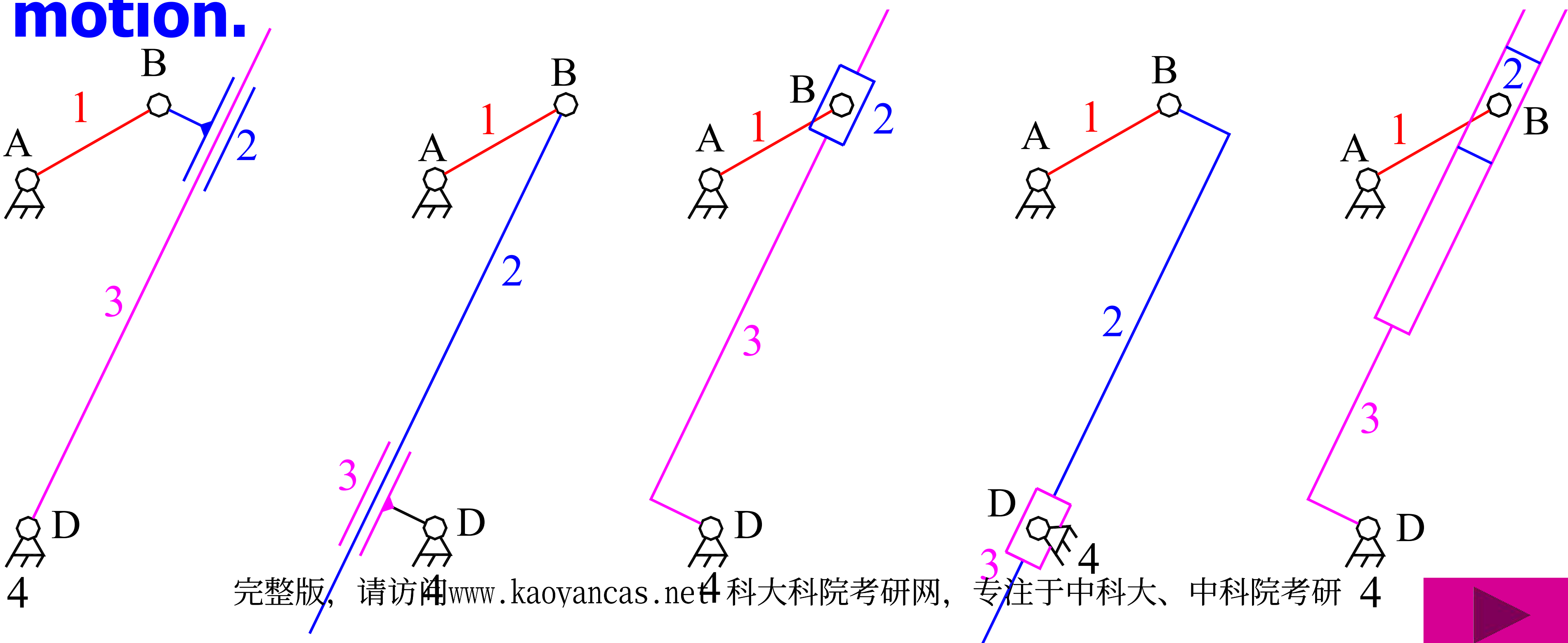
团结 献身
求是 创新

(4)Interchanging guide-bar and sliding block

变换导杆和滑块

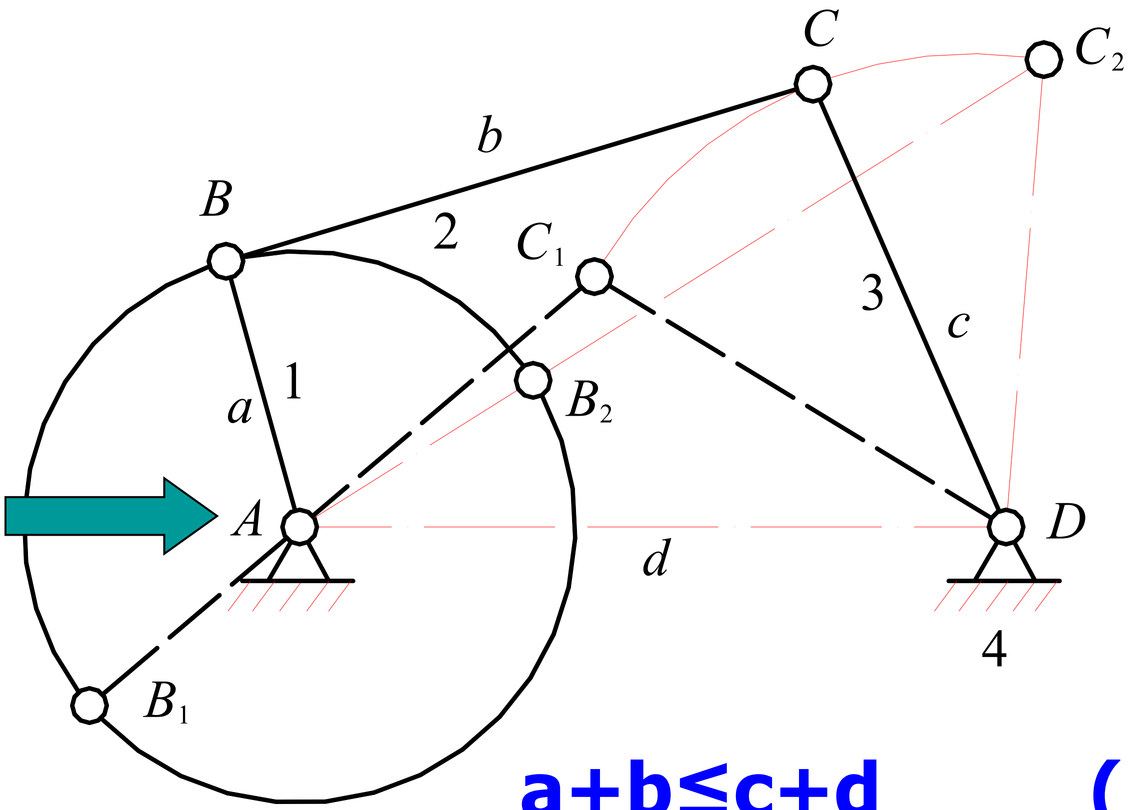
Any link in a sliding pair can be drawn as a guide-bar, and the other link as a sliding block.

The centre line of any sliding pair can be translated(平移) without changing any relative motion.



4.3 Characteristics Analysis of Four-bar Linkages

4.3.1 Conditions for having a crank



a+b≤c+d (1)

d<c+b-a → a+d≤c+b (2)

c<d+b-a →a+c≤b+d (3)

即：

$a+d \le b+c$ (1)

$a+b \le c+d$ (2)

$a+c \le b+d$ (3)

(1)+(2) 得 $2a+b+d \le 2c+b+d$ 即 $a \le c$

(1)+(3) 得 $a \le b$ (2)+(3) 得 $a \le d$

Grashof Criterion:the Condition for having a crank

两构件作整周相对转动的条件（曲柄存在的条件）

1. The crank must be shortest link.
2. The sum of the shortest and the longest links must be less than the sum of the remaining two links 最短构件与最长构件的长度之和小于等于其它两构件长度之和。（杆长之和的条件）

铰链四杆机构类型判定：
（根据是否符合杆长之和条件）

- 如不满足杆长之和条件 $l_{\max} + l_{\min} > l_b + l_c$

Double rocker mechanism

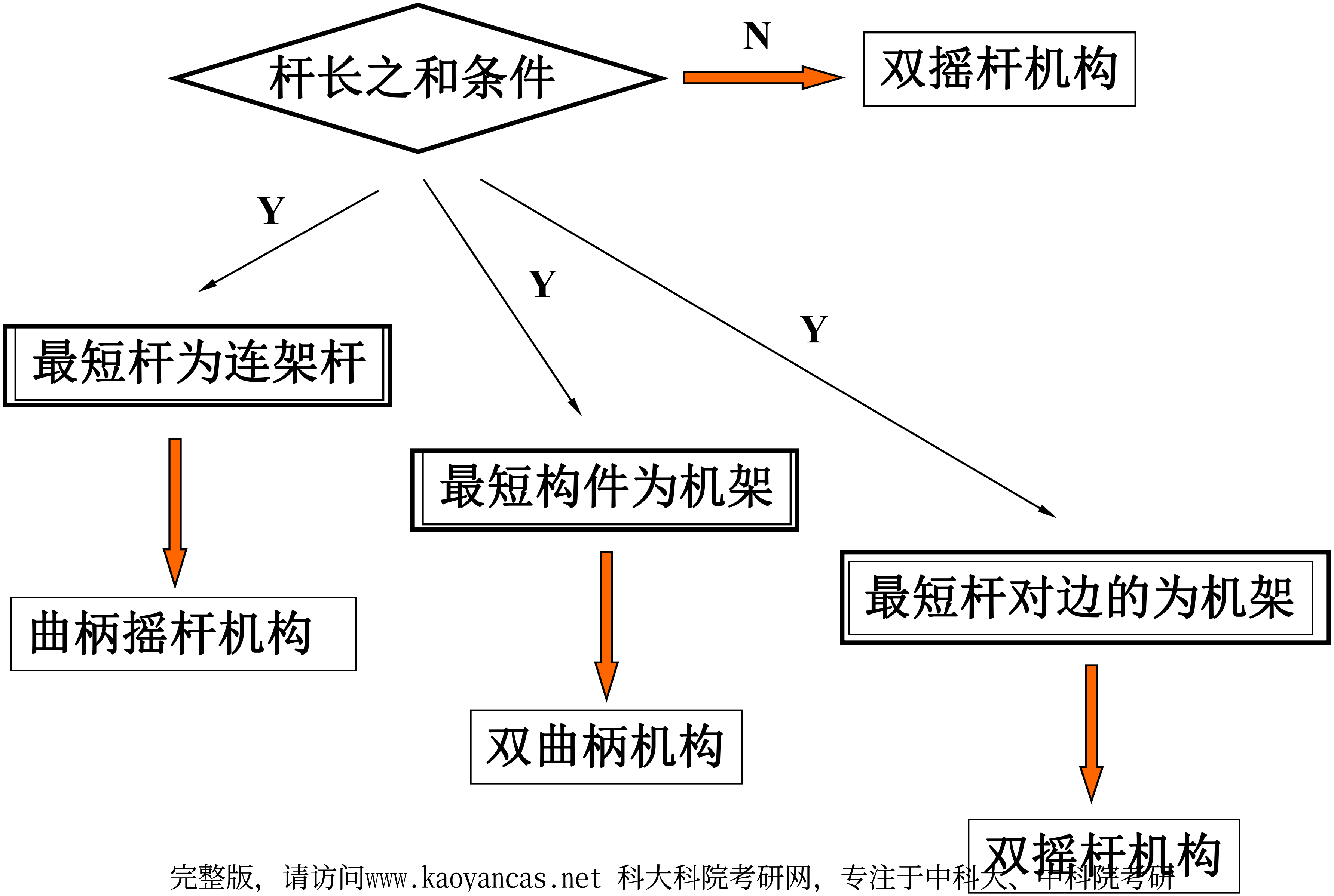
- 如满足杆长之和条件 $l_{\max} + l_{\min} \le l_b + l_c$

If the link opposite to the shortest Link is the frame ——**Double Rocker mechanism**

The shortest link is the frame ——**Double crank mechanism**

If the link adjacent to the shortest Link is the frame ——**Crank-rocker mechanism**

铰链四杆机构类型判定：


杆长之和条件
N
双摇杆机构
Y
Y
Y
最短杆为连架杆
最短构件为机架
最短杆对边的为机架
曲柄摇杆机构
双曲柄机构
双摇杆机构

if $l_{\max} + l_{\min} = l_b + l_c$

The centre lines of the four links can become collinear(共线).

At these positions, the output behavior may become indeterminate(不确定的). These positionsAB$_1$C$_1$D are called change-points.

AB$_2$C$_2$D

Parallel-crank mechanism

AB$_2$C'$_2$D

antiParallel-crank mechanism

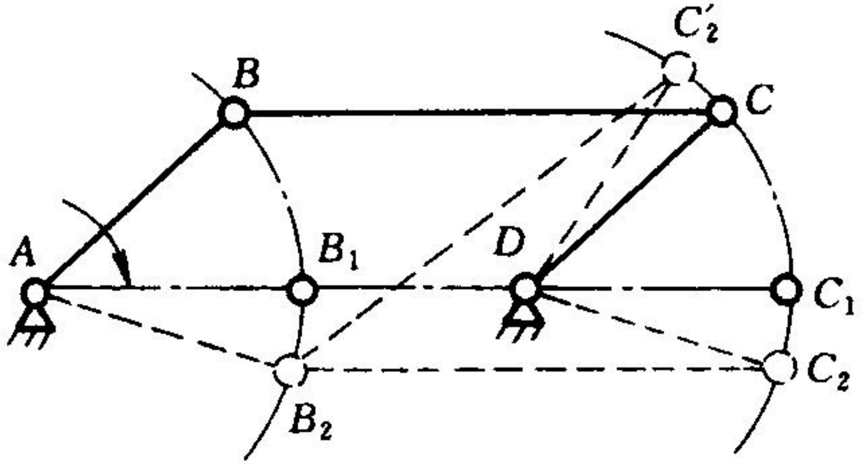
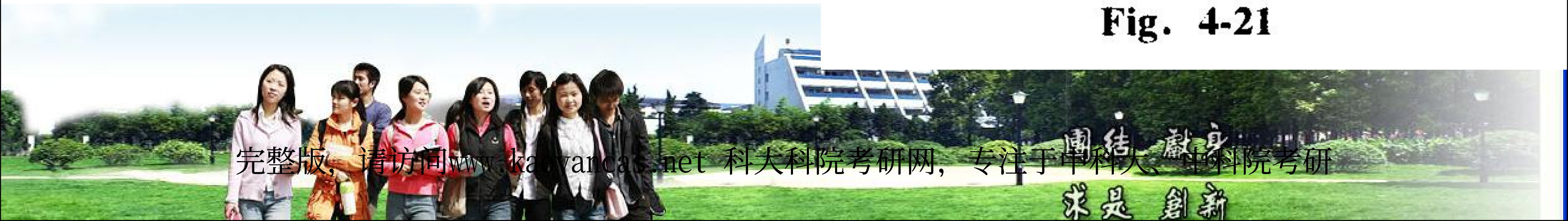
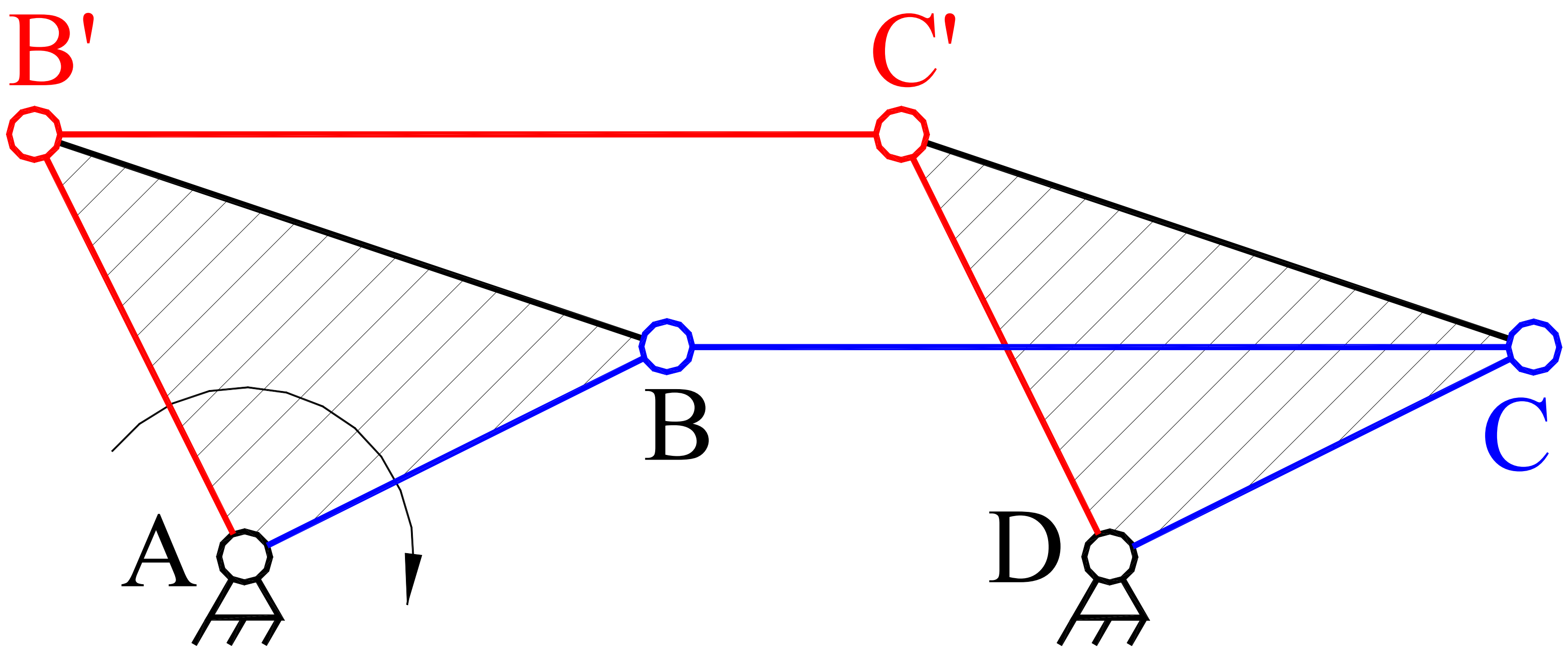


Fig. 4-21

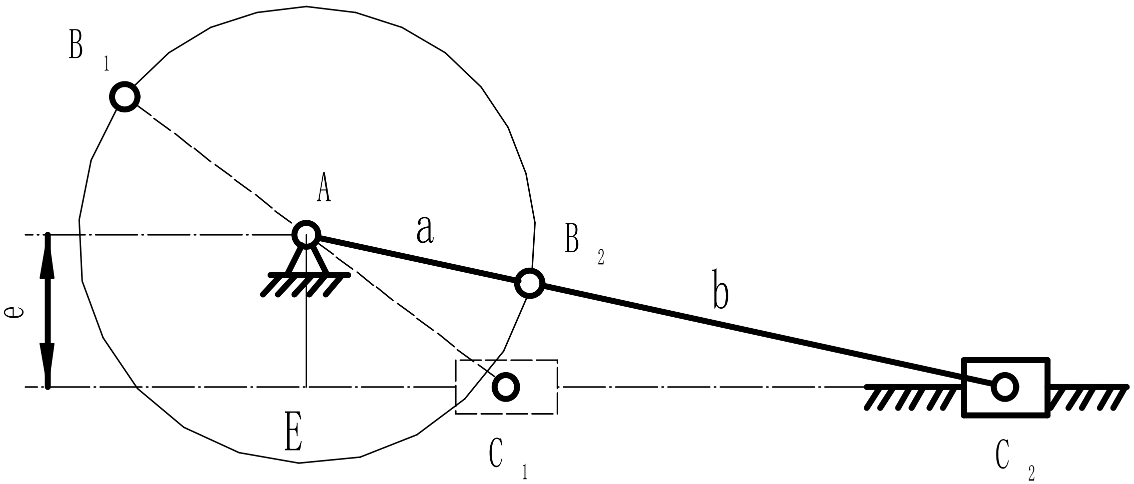


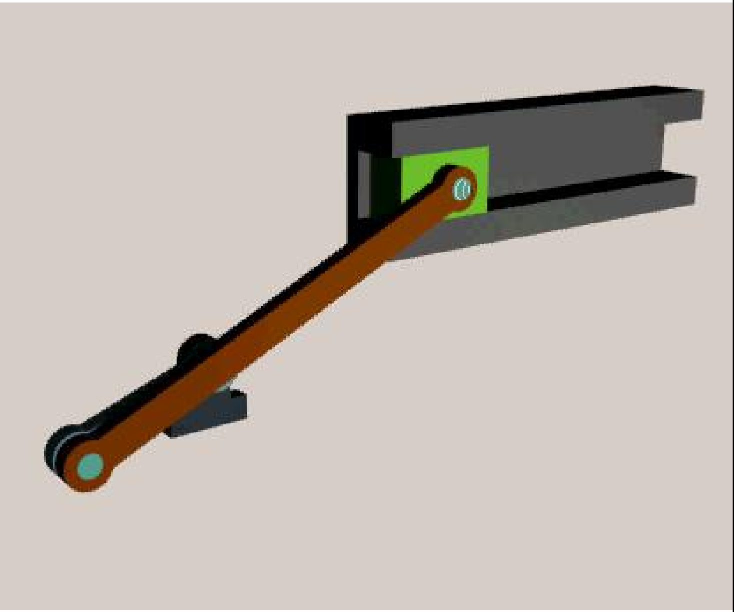
the change-points are handled by inertia of flywheel fixed with the driven crank or providing the duplicate(复制的) linkage 90° out of phase(相位).



Slider-Crank Mechanisms

----conditions for having a crank





直角△ AC_1E：$AC_1 > AE$　　b-a>e

直角△ AC_2E：$AC_2 > AE$　　a+b>e

即曲柄存在的条件:b>a+e　　偏置

b>a　　对心

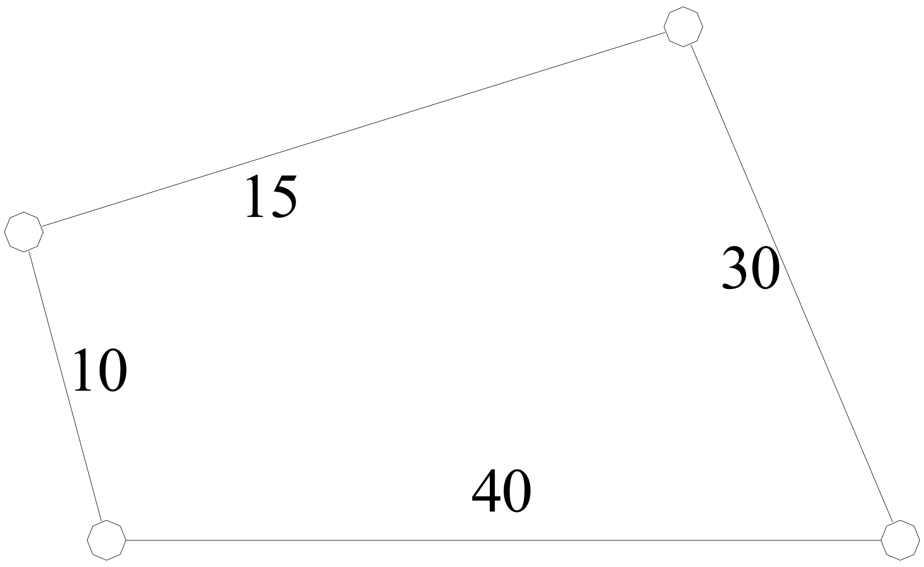
示 例：

(1) $10+40 \nleq 15+30$

不满足曲柄存在条件

↓

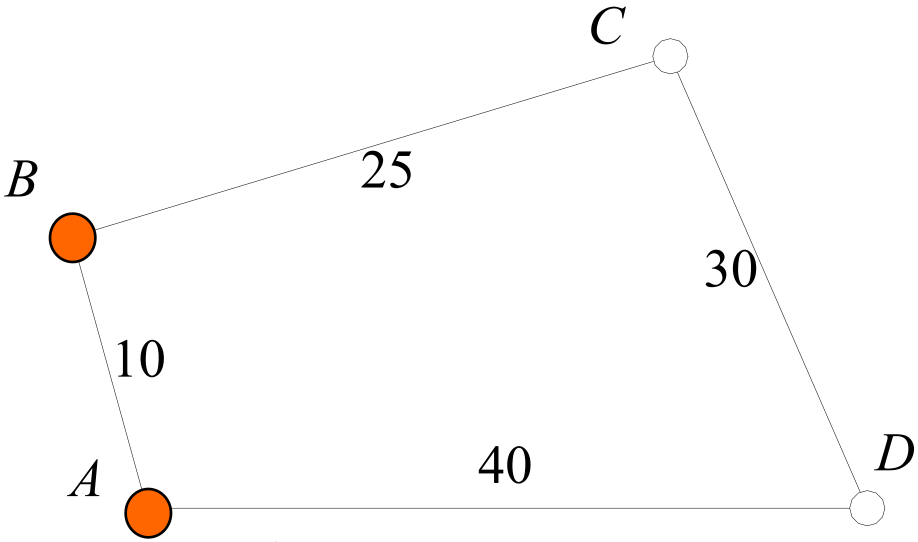
双摇杆机构



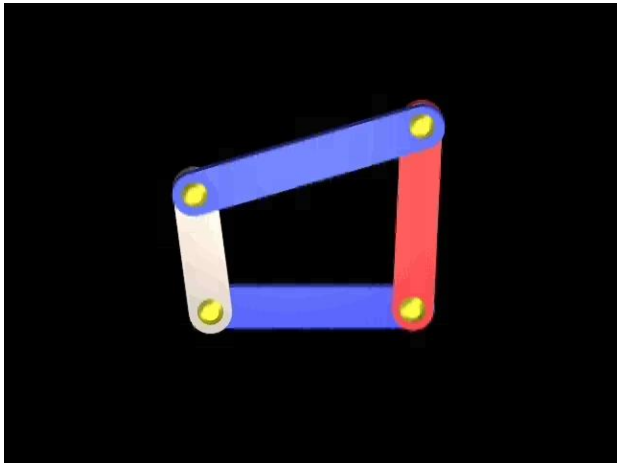
(2) $10+40 < 25+30$

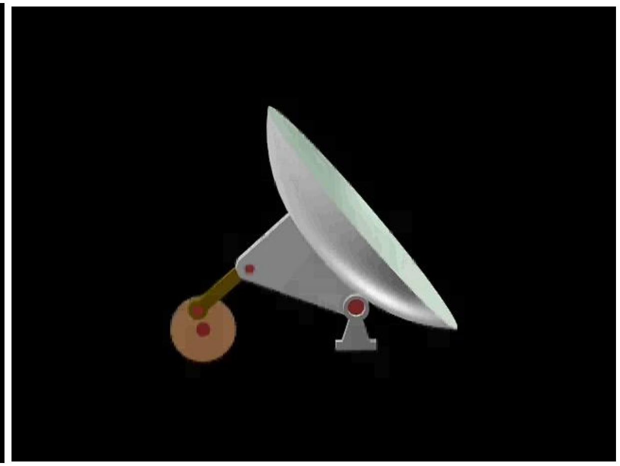
满足曲柄存在条件

根据机架不同来判定



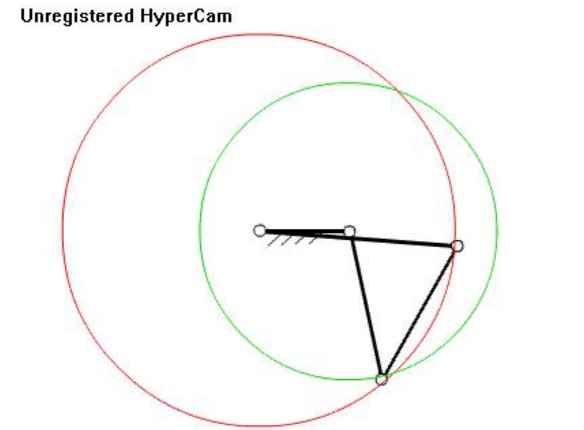
(1) 曲柄摇杆机构



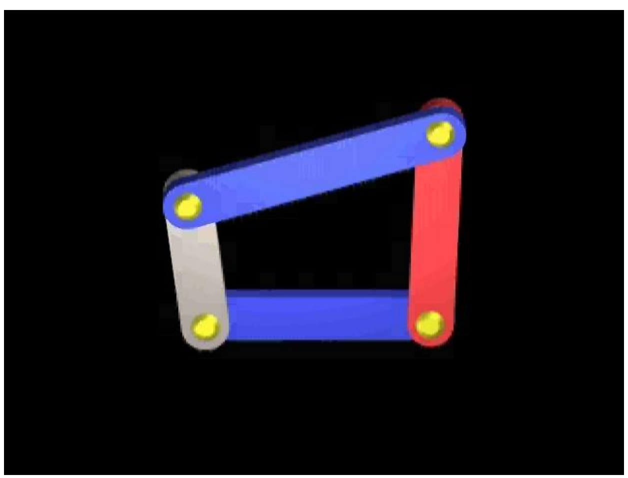


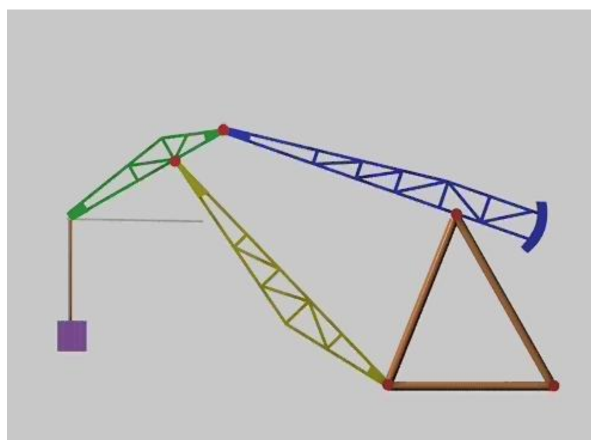
雷达俯仰机构

(3) 双曲柄机构

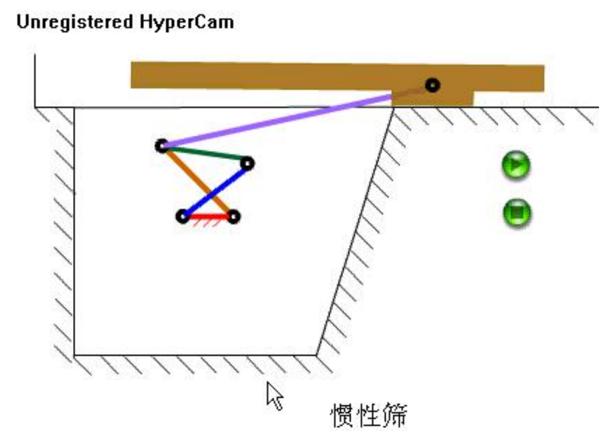


(2) 双摇杆机构



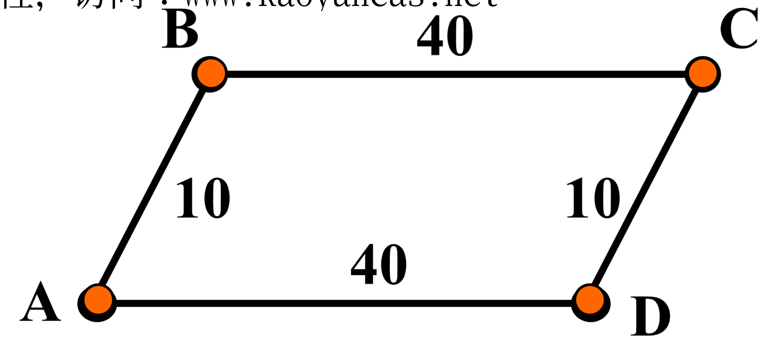


鹤式起重机



惯性筛

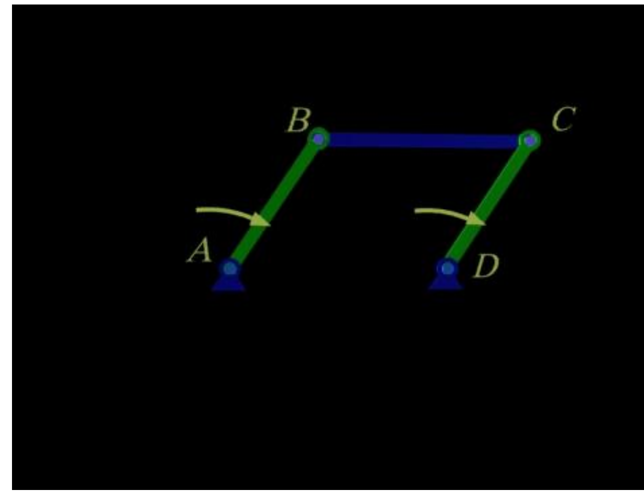
(3) $10+40=10+40$



满足周转副存在条件

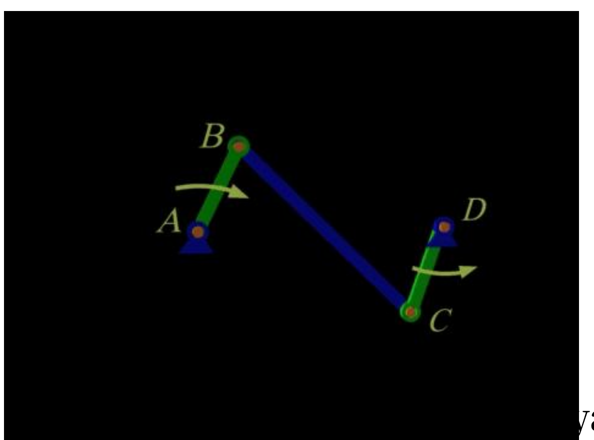
↓

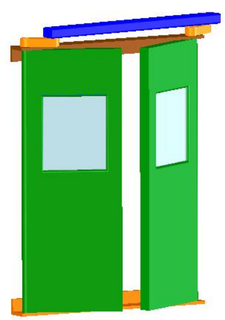
双曲柄机构



↓ 当两曲柄长度相等

平行四边形机构





4.3.2 Pressrue Angle α压力角 and Transmission Angle γ传动角

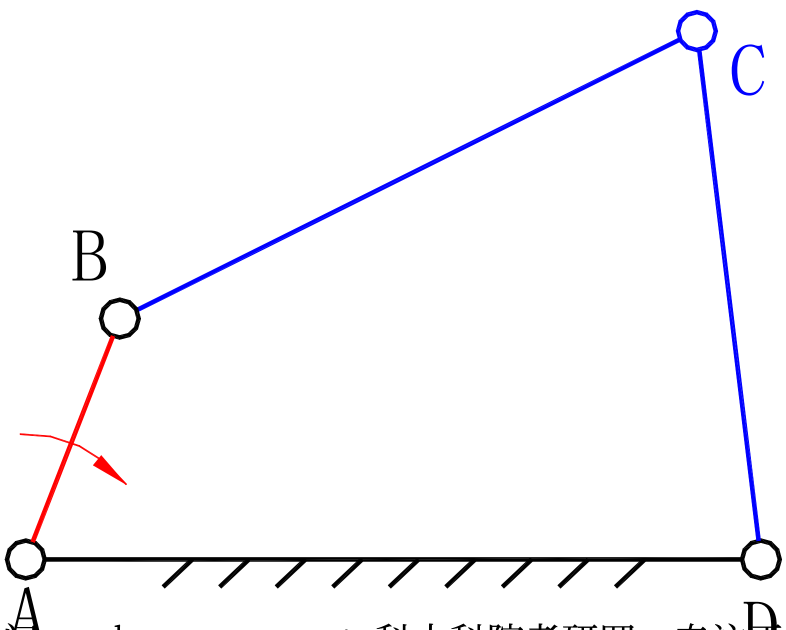
crank-rocker mechanism:

input link-AB

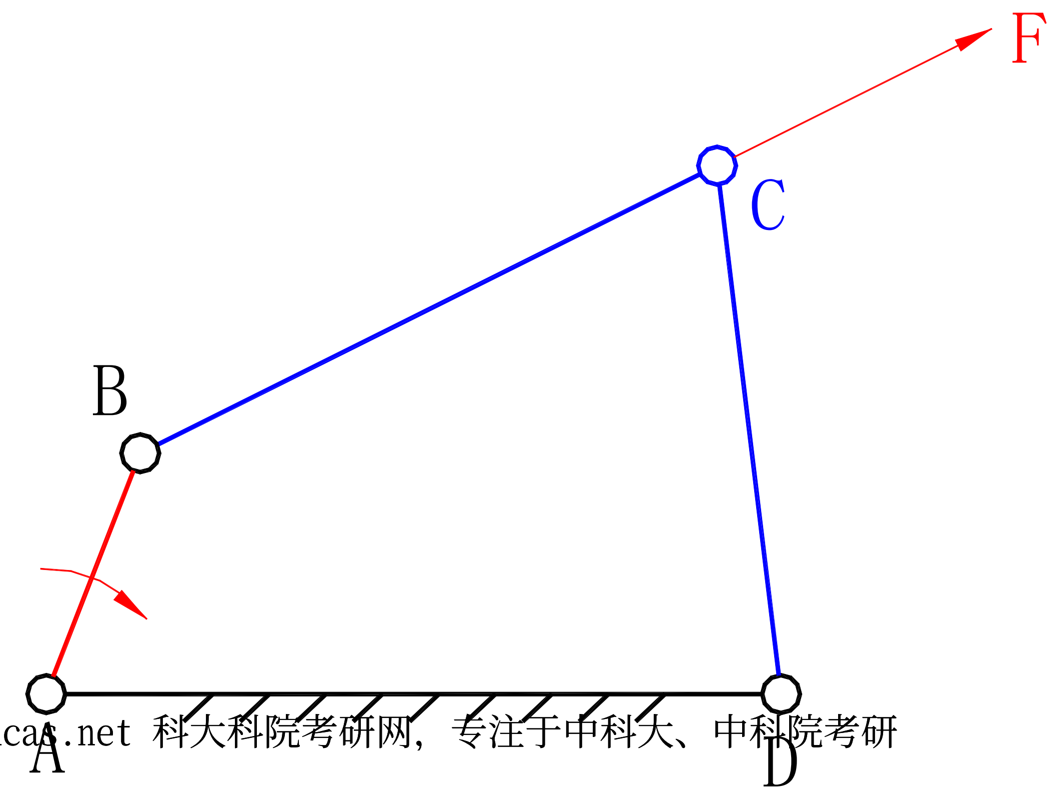
output link-CD

neglect the friction force & gravity force

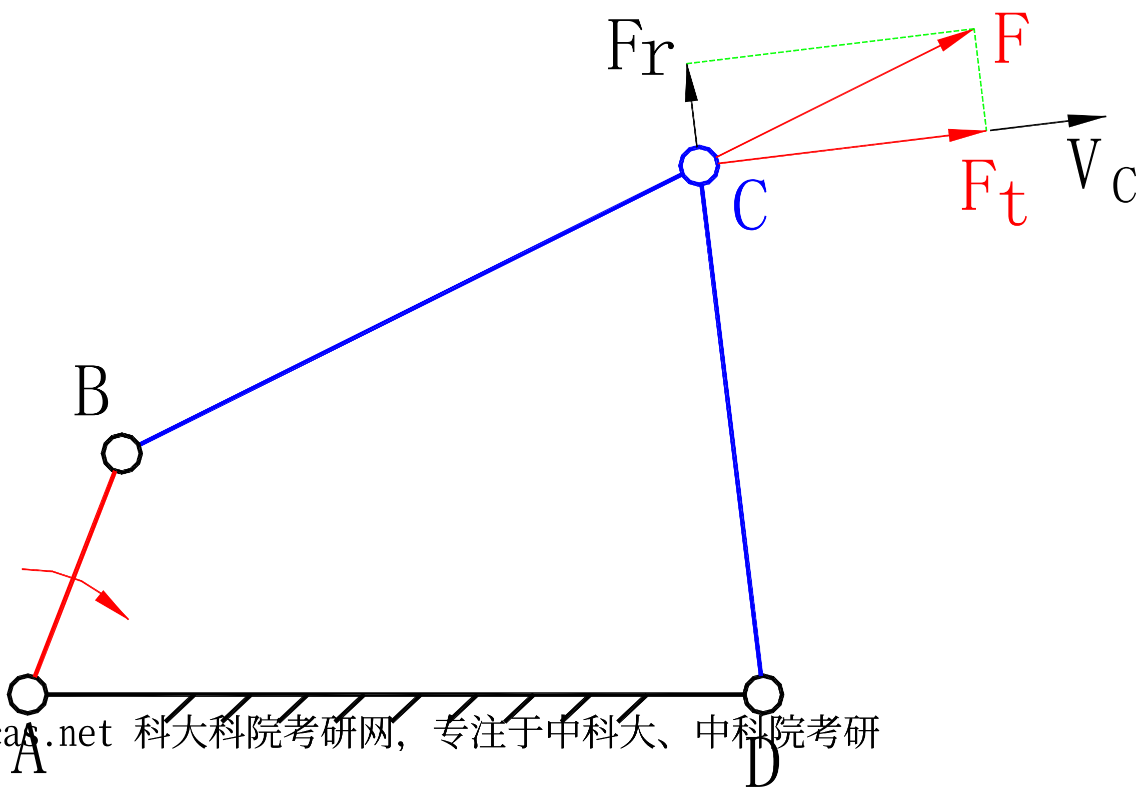
不考虑摩擦力和重力



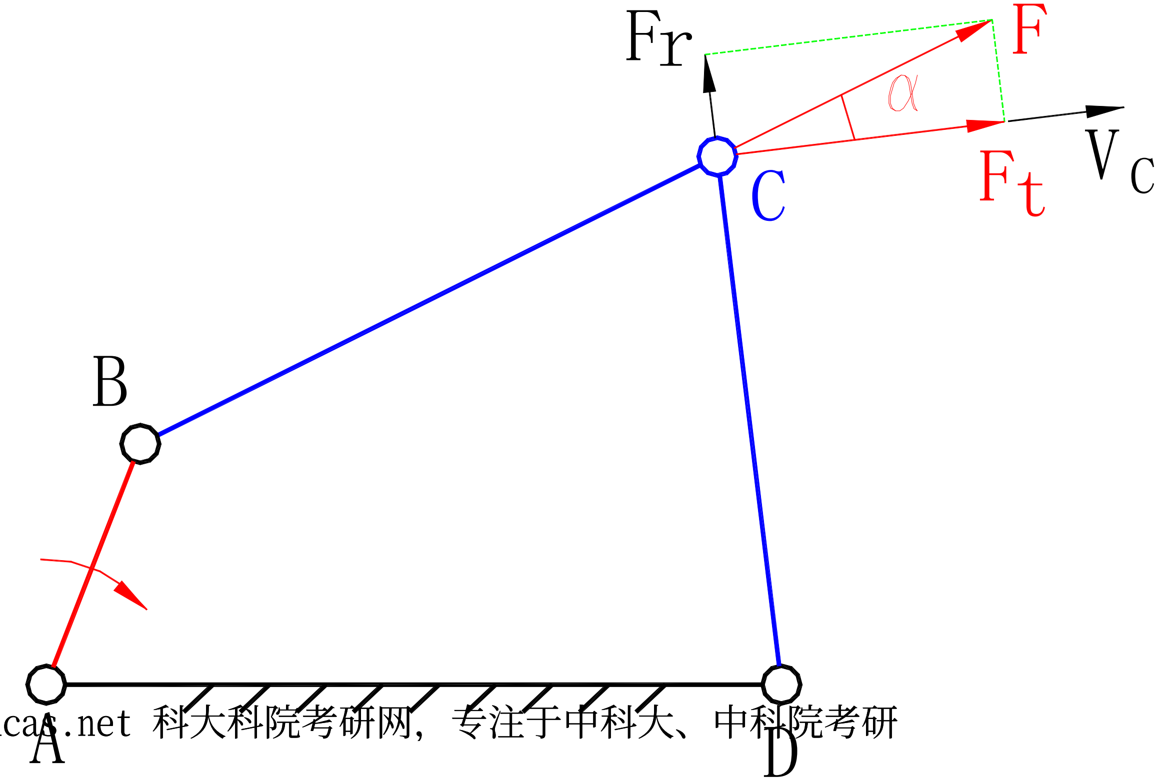
the force applied to the CD→F, direction: along to BC



the velocity of point C→V_c ,
direction:vertical to CD



The acute angle(锐角) between the directions of the force *F* and the velocity of the point receiving(受到) the force on the follower is defined as the pressure angle(压力角) α of the mechanism at that position.



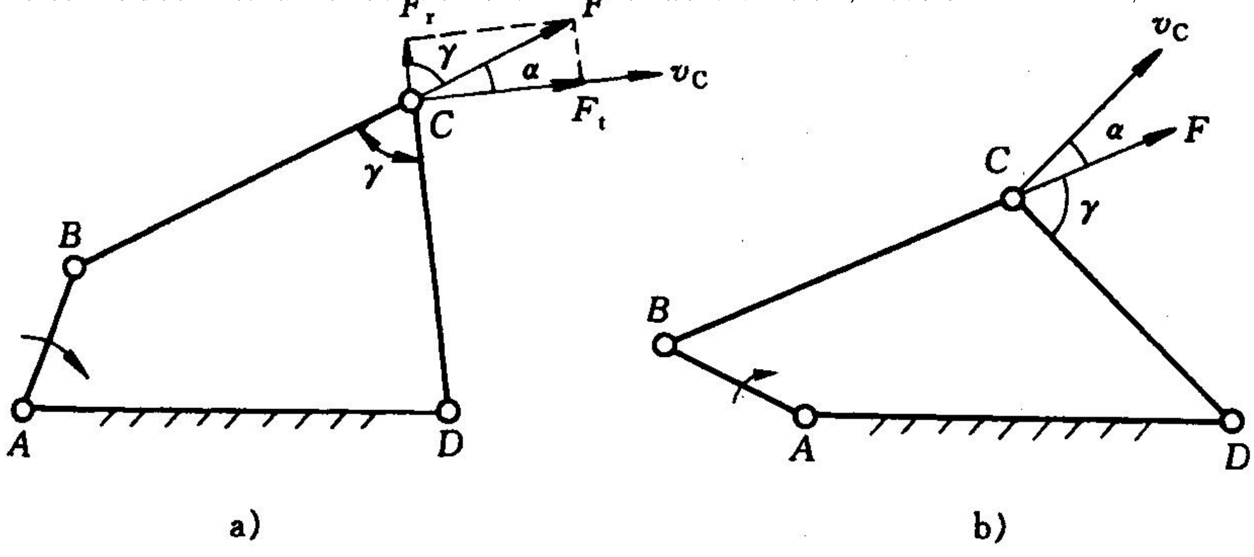
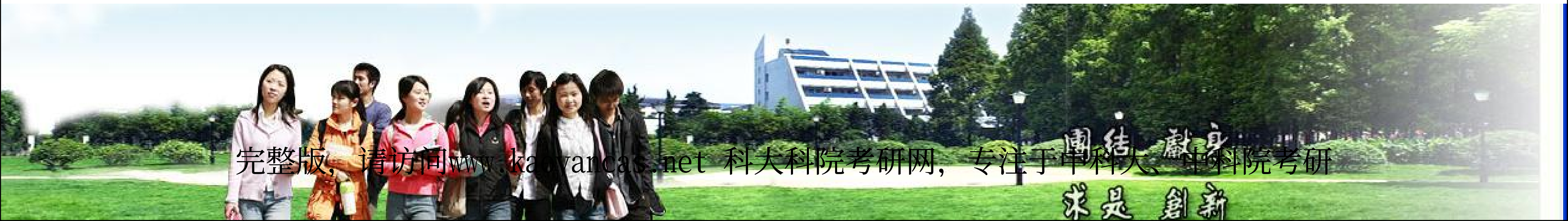


Fig. 4-23

$$F_t = F\cos\alpha = F\sin\gamma$$ ——有效分力

$$F_n = F\sin\alpha = F\cos\gamma$$ ——无效分力

α越小，Ft越大，对机构传递越有利（效率高，不易自锁）



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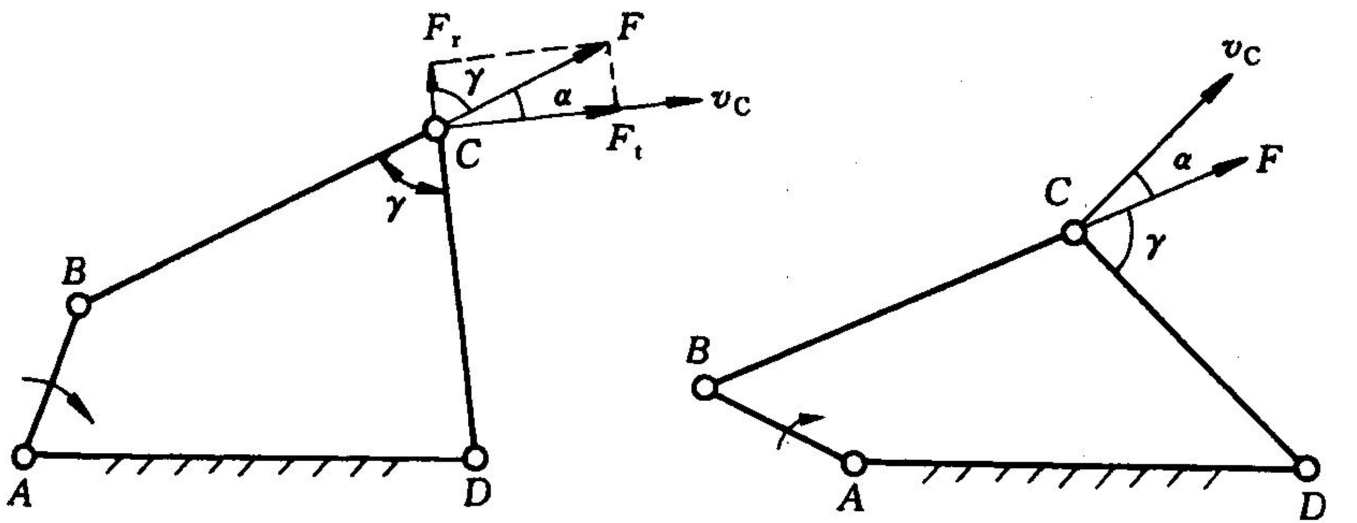
传动角γ：The complement of the pressure angle α is transmission angle γ压力角余角

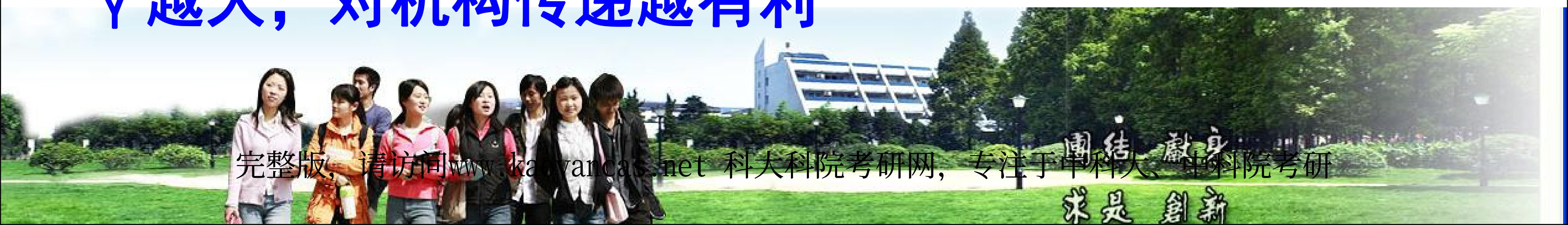
$$\alpha + \gamma = 90^{\circ}$$



$\angle BCD < 90^{0}$时，$\gamma = \angle BCD$ $\angle BCD > 90^{0}$时，$\gamma = 180^{\circ} - \angle BCD$

平面连杆机构经常用γ衡量机构的传动质量（易于测量）

γ越大，对机构传递越有利

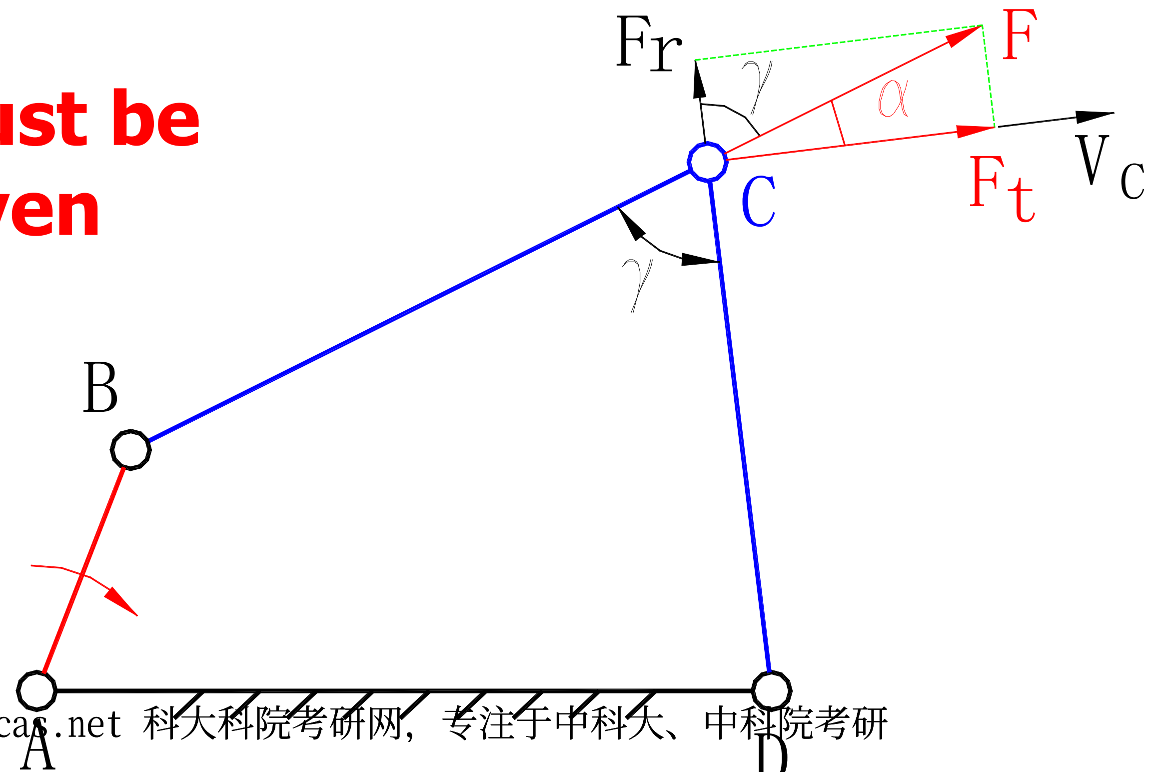


α 越小，γ 越大，F_t越大，对机构传递越有利（效率高，不易自锁）

机构不停地在运动，α 和 γ 不停在变化，为使机构不出现冲击

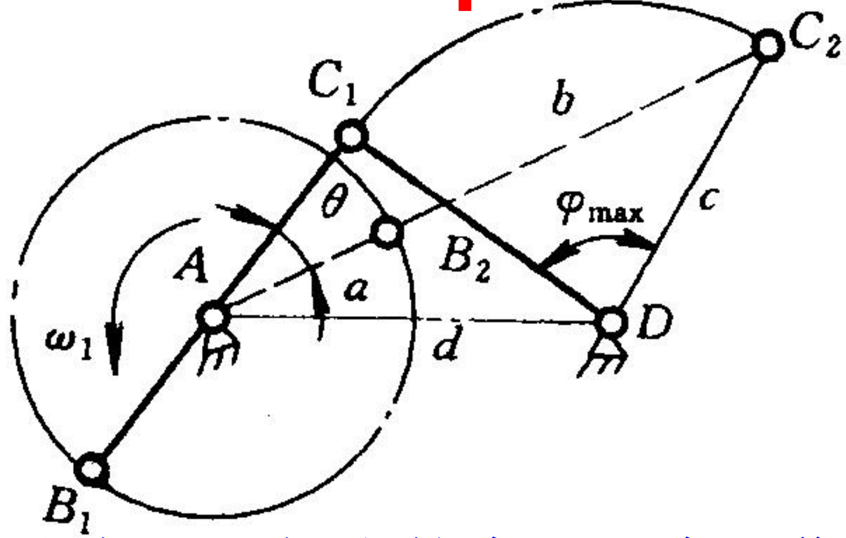
$$\alpha \le [\alpha] = 40^\circ \qquad \gamma \ge [\gamma] = 50^\circ$$

Note: α and γ must be drawn on the driven link!!



4.3.3 Toggle (肘节) Positions and Dead-points

1.the limiting position C_1D,C_2D



如果曲柄 **AB**为主动件,转到极限位置时,只用很小的力，可克服作用在**CD**上很大的力。

→**toggle position.** (杠杆增力位置)

如果摇杆**CD**为主动件，曲柄的压力角 $\alpha = 90^\circ \quad (\gamma = 0^\circ)$

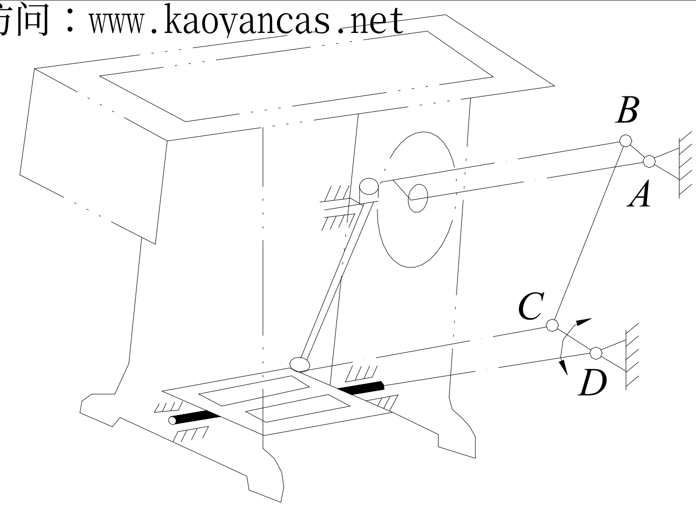
加在AB上的力通过铰链中心A, 使从动件AB运动的有效分力等于0

曲柄AB不能运动→dead-point

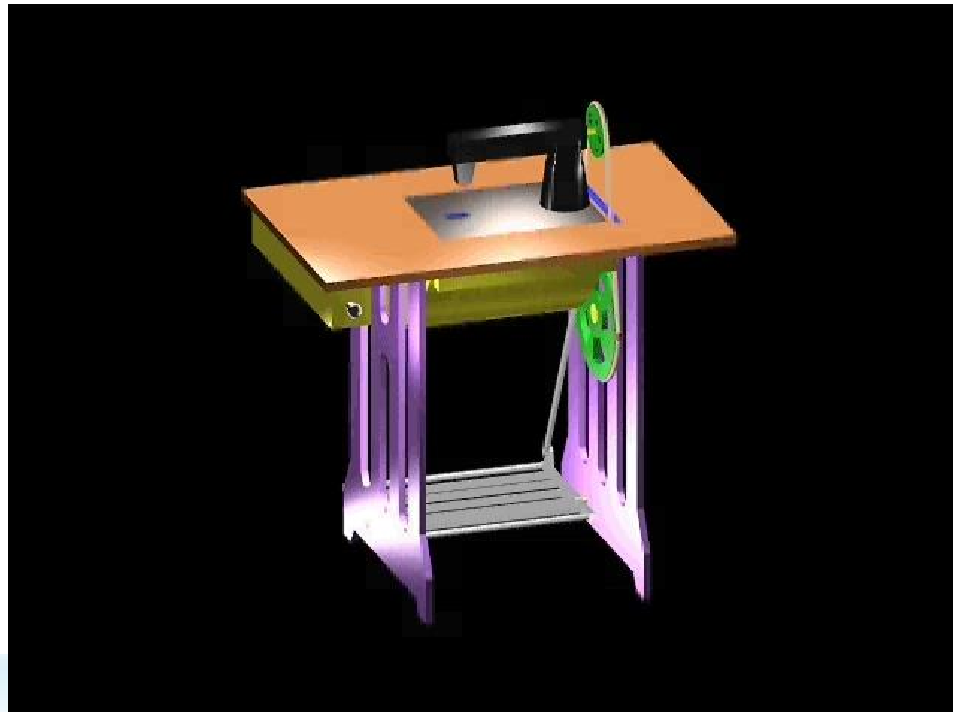
2. 死点位置的不利影响及克服

①运动不确定性

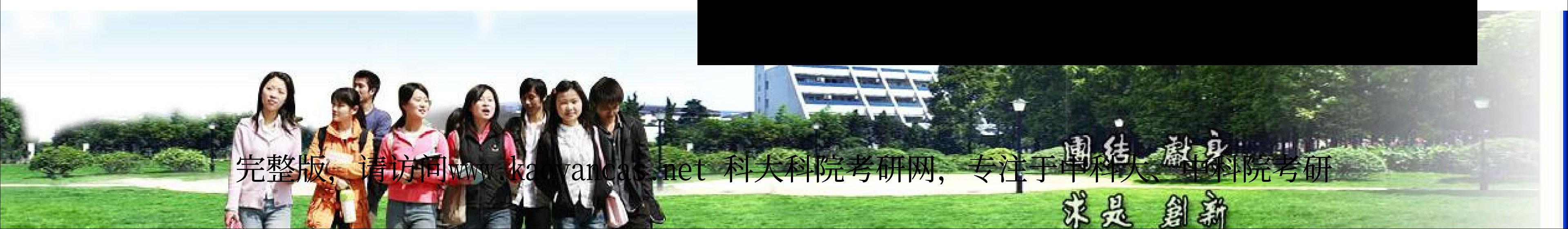
②运动突然停止，卡死



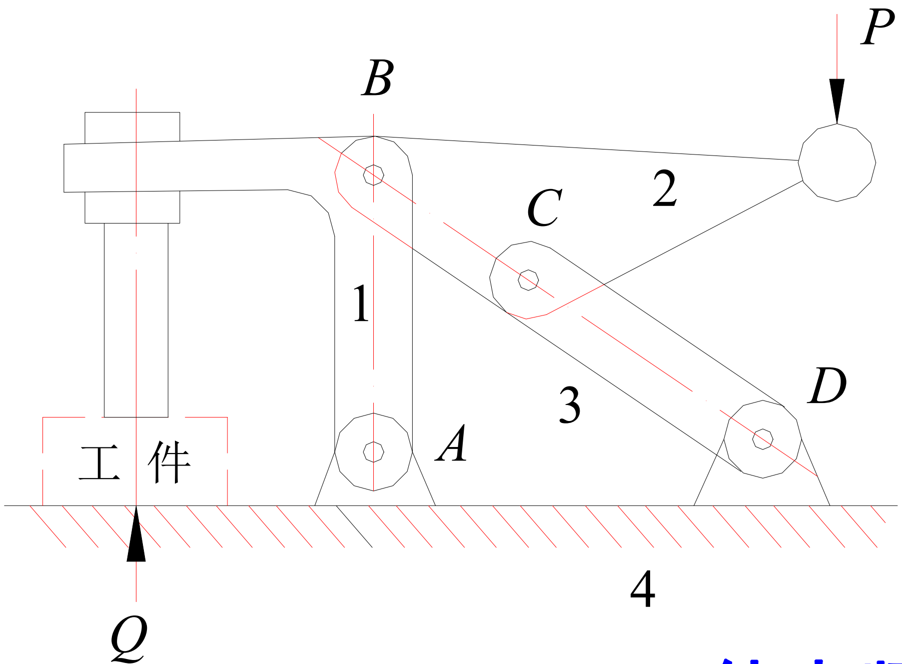
Example: sewing machine

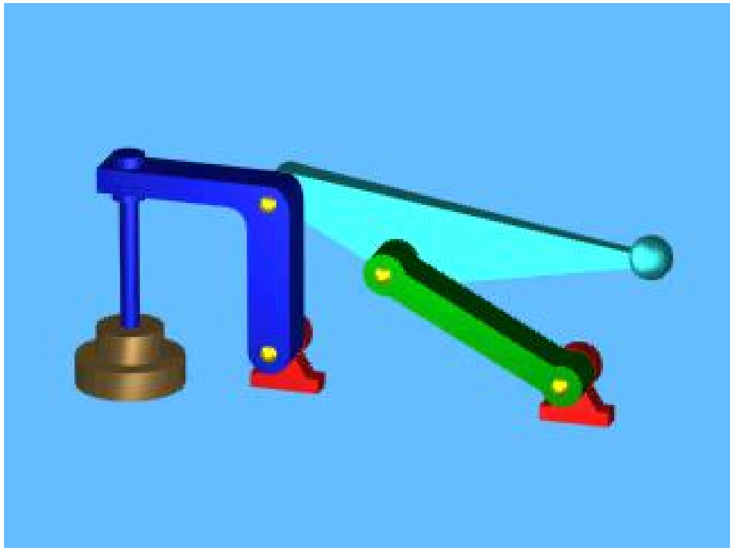


- 避免由死点处启动
- 运转时利用惯性通过死点

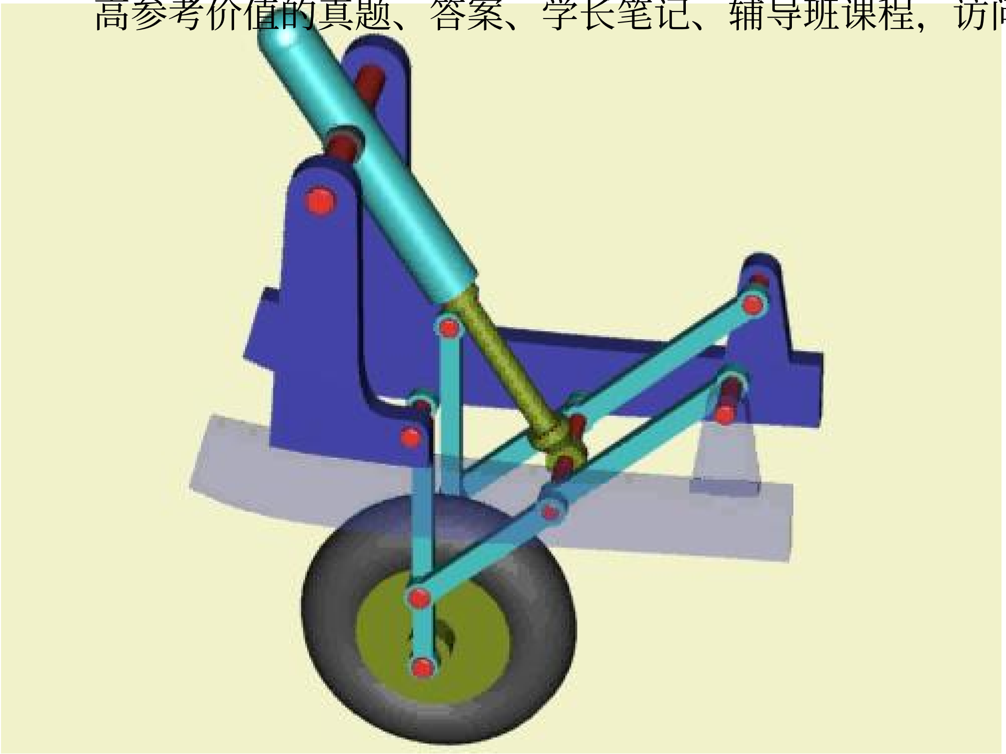


3.死点位置的应用--- In some circumstances(情况), the dead point is very useful. It can provide a self-locking(自锁) feature(性能).





工件夹紧机构



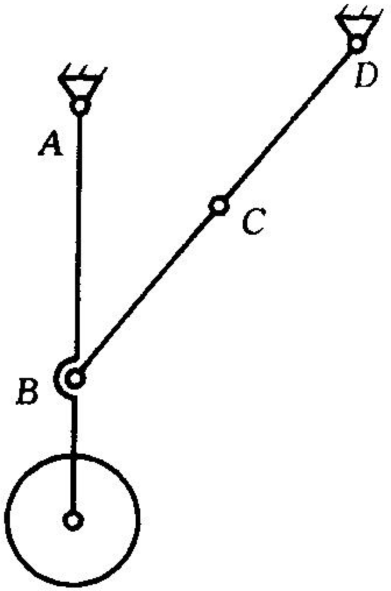
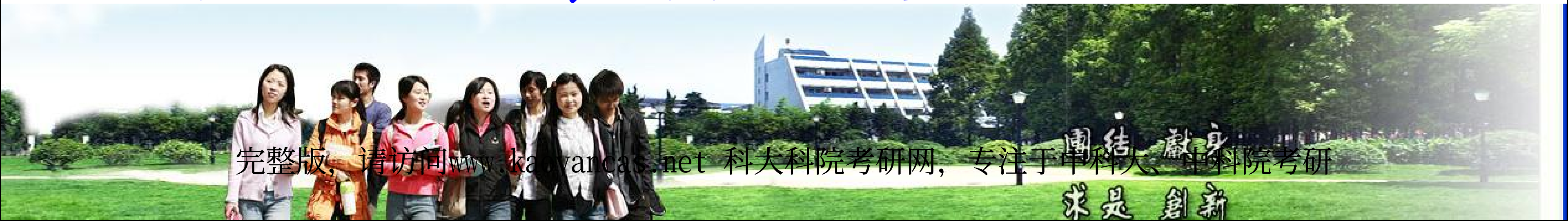


Fig. 4-30

Landing mechanism in airplane飞机起落架

轮子上的力将不能引起机构运动，力通过转动中心D-----dead position;

需要收起落架时，转动CD即可。



4.3.4 Quick Return Characteristics ---急回运动特性

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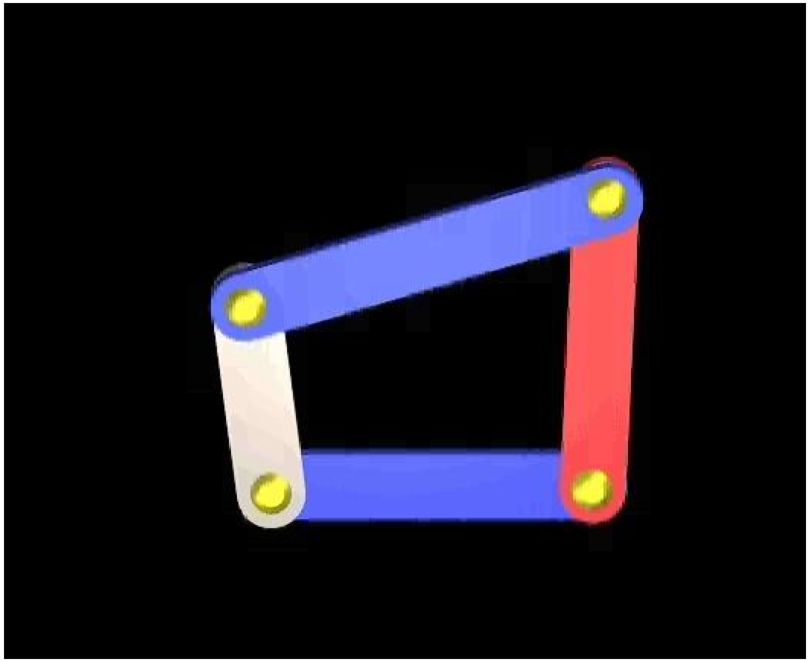
crank→rotate in a constant angle velocity

driven links→ the working stroke→slower speed

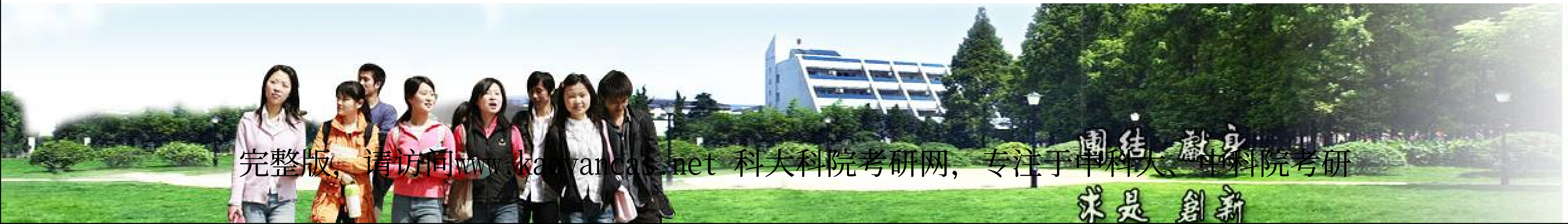
(rocker,slider) the return stroke→faster speed

↓

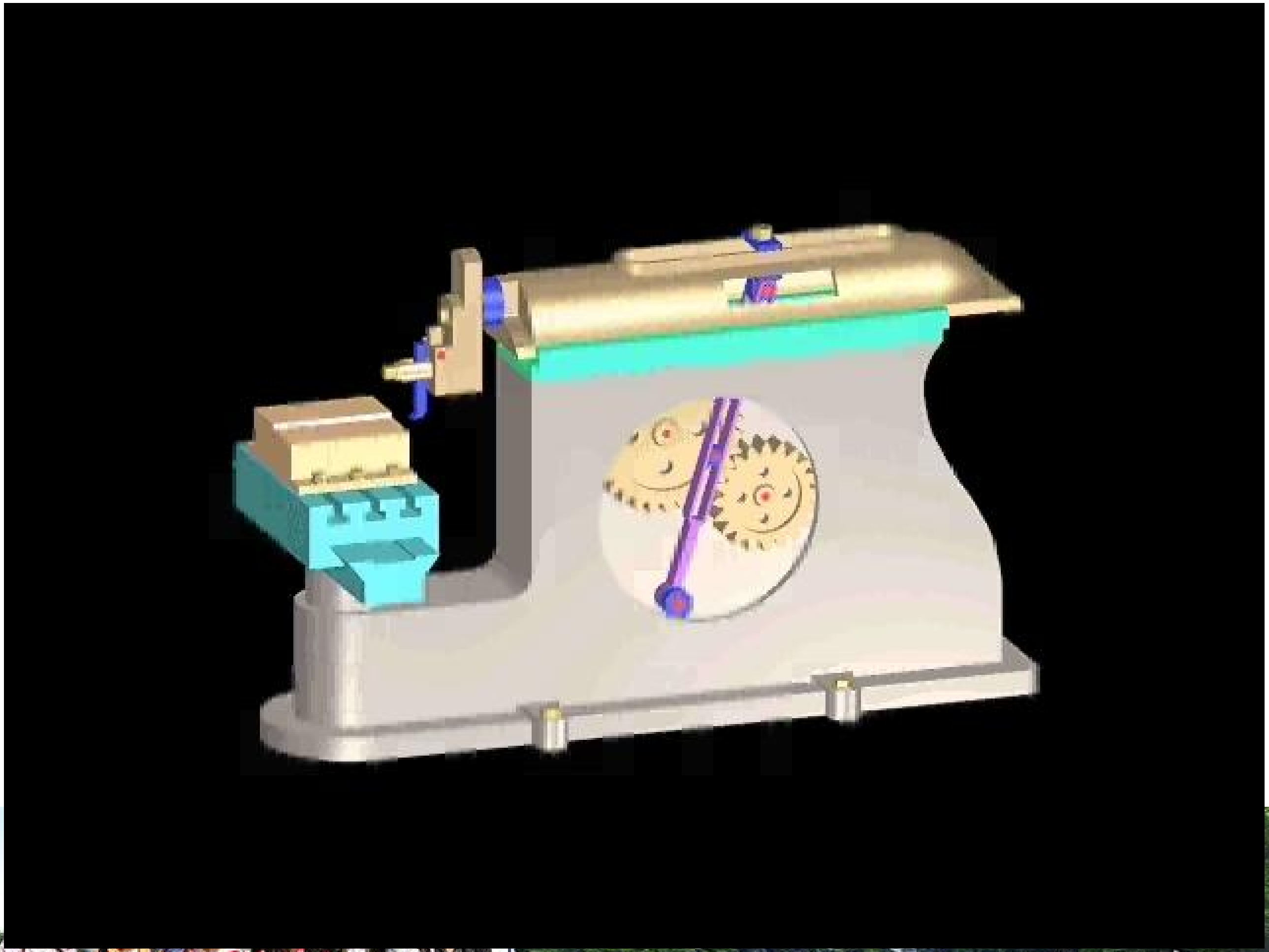
Quick-return mechanism

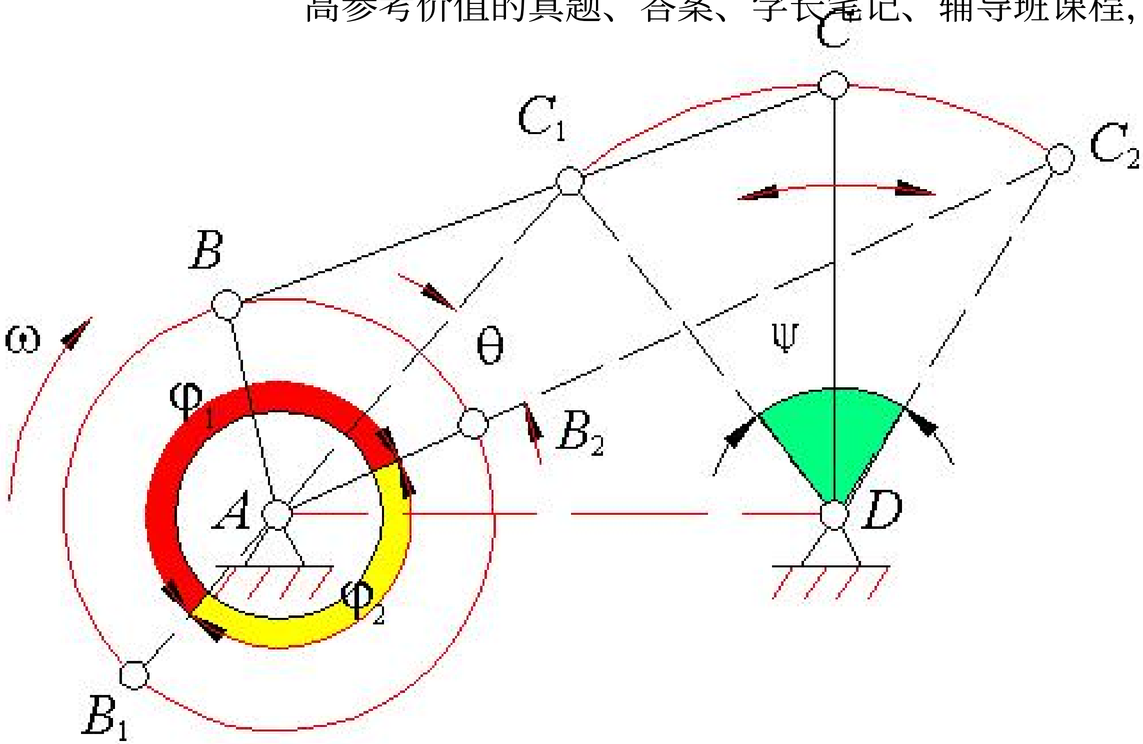


原动件作匀速转动，从动件相对机架作往复运动的机构，从动件正行程和反行程的平均速度不相等。这种特性称急回运动特性。



$V_{工作}<V_{回程}$，所以急回运动特性可缩短非生产时间，提高劳动生产率。例：牛头刨床机构



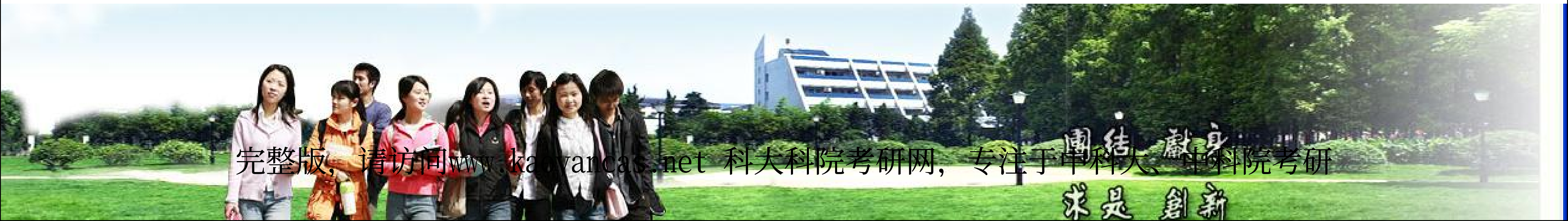


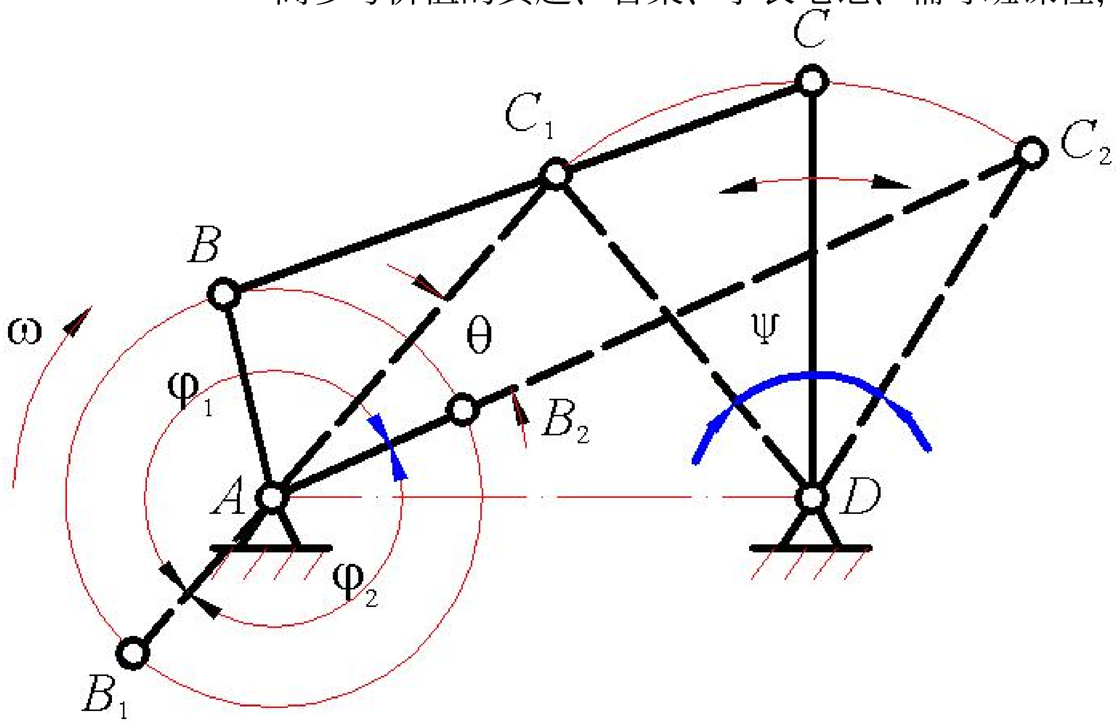
正行程：曲柄$AB_1—AB_2$，$φ_1$，$t_1=φ_1/ω_1$

摇杆$C_1D—C_2D$，ψ，$ω'_3=ψ/t_1$ ——慢

反行程：曲柄$AB_2—AB_1$，$φ_2(φ_2< φ_1)$，$t_2=φ_2/ω_1$（$<t_1$）

摇杆$C_2D—C_1D$，ψ，$ω''_3=ψ/t_2$——快

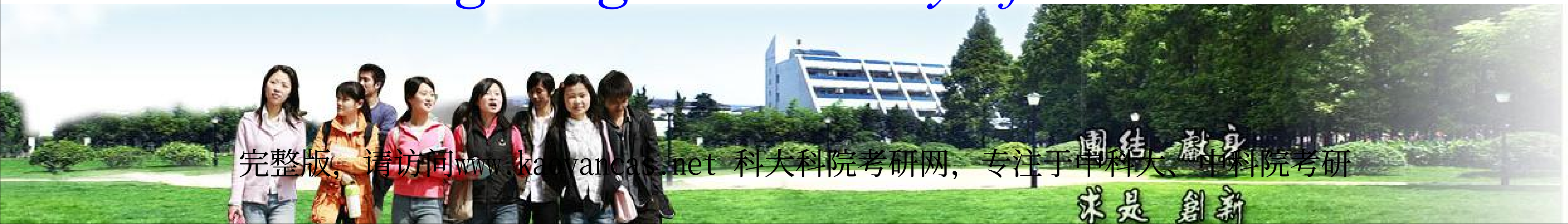


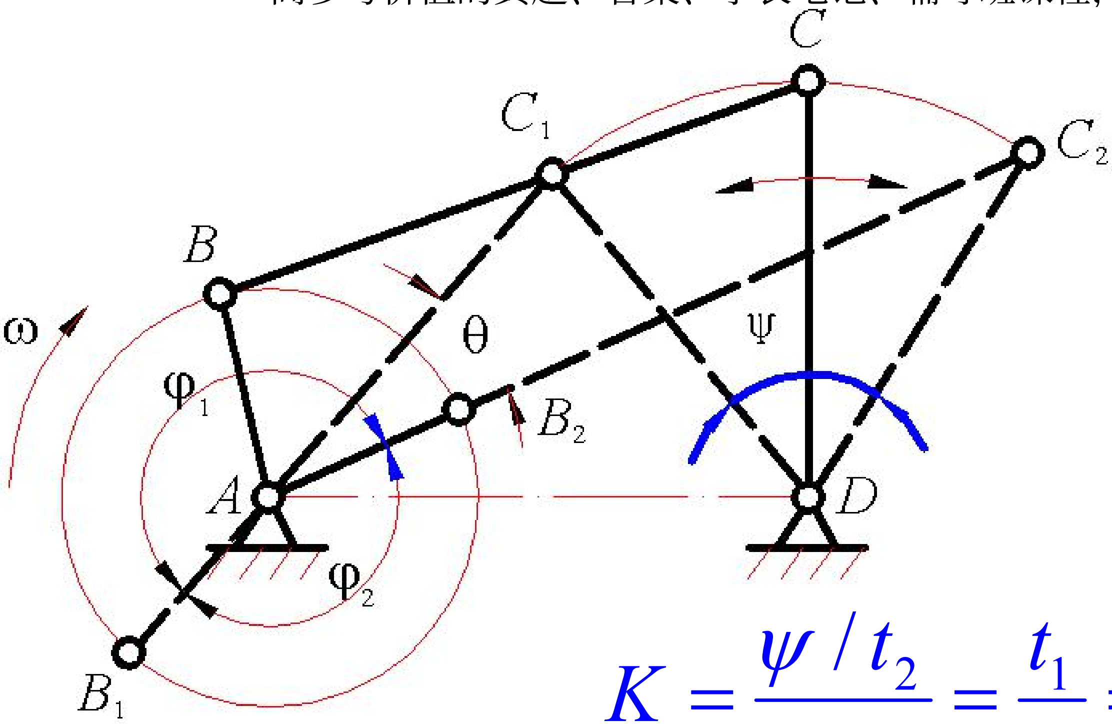


K—coefficient of travel speed variation. K≥1

从动件行程速度变化系数。

$$K = \frac{\text{the average angular velocity of faster stroke}}{\text{the average angular velocity of slower stroke}} \geq 1$$





$$K=\frac{\psi/t_2}{\psi/t_1}=\frac{t_1}{t_2}=\frac{\varphi_1/\omega}{\varphi_2/\omega}=\frac{\pi+\theta}{\pi-\theta}$$

θ→crank acute angle between the two limiting positions [0，180⁰]

θ 为极位夹角： $\theta=180^\circ\frac{K-1}{K+1}$ **θ 越大，急回特性越显著**

3. 其他具有急回特性的机构

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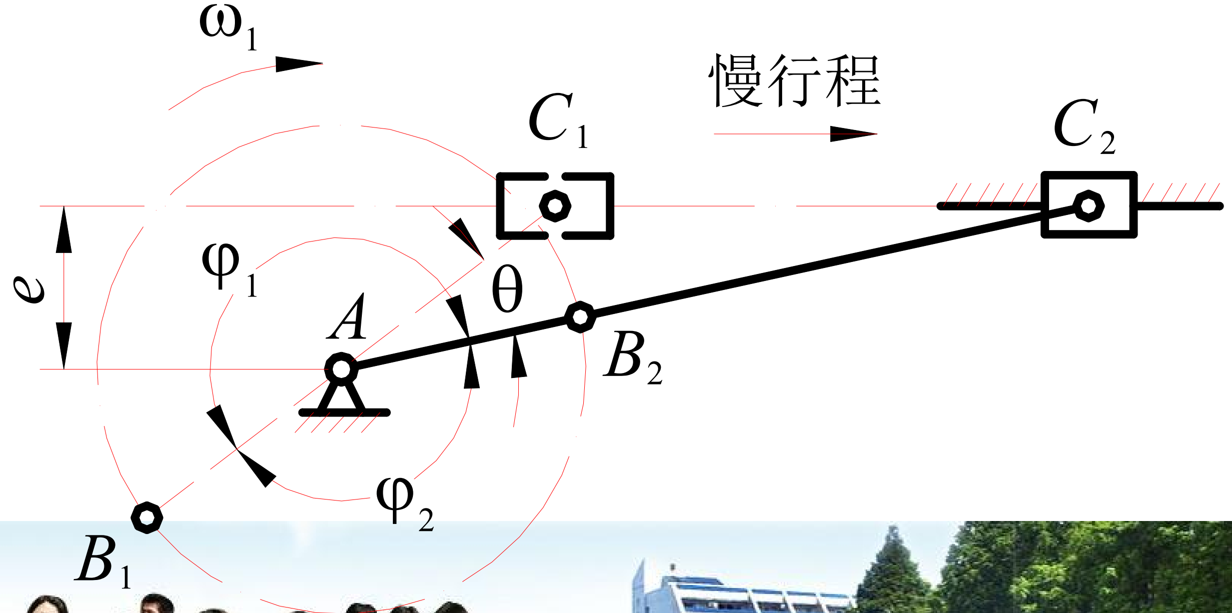
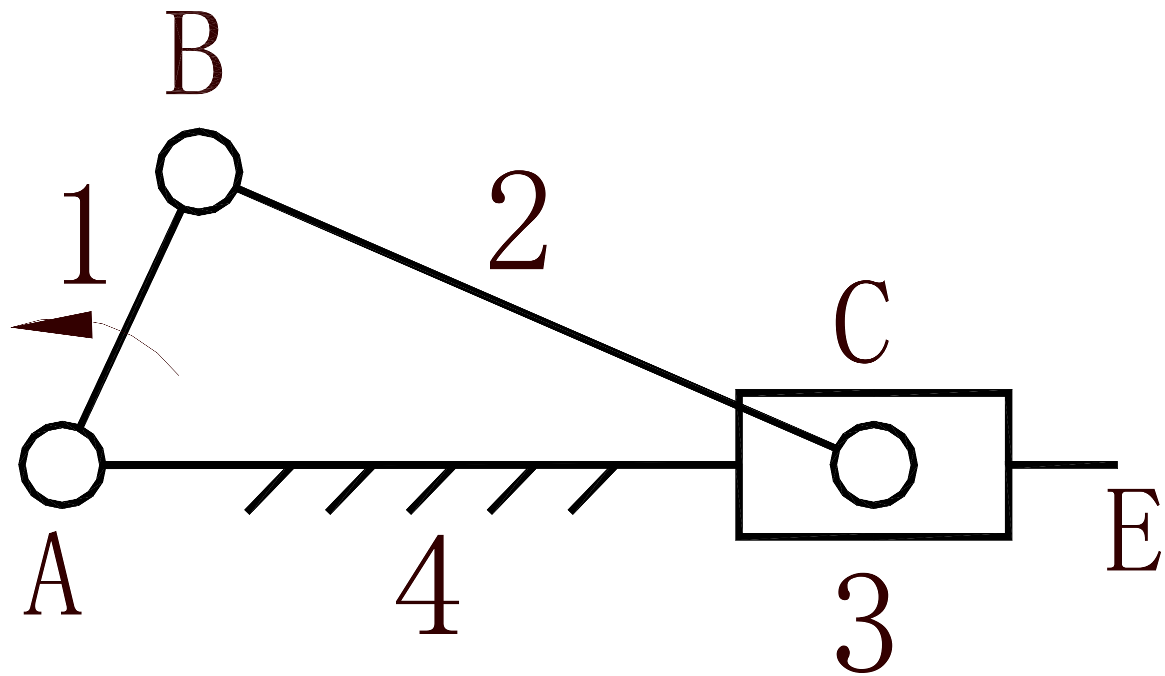
offset slider-crank mechanism偏置曲柄滑块机构：

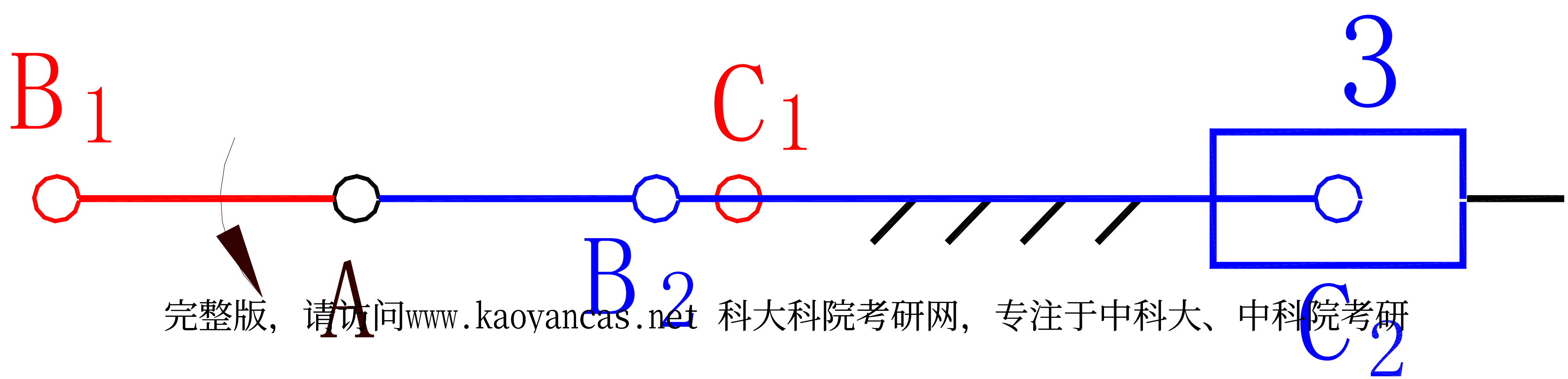
If the driving crank AB rotates clockwise with constant angular velocity, the slider will take a longer time in its rightward(向右) stroke than in its leftward(向左) stroke.



团结 献身 求是 创新

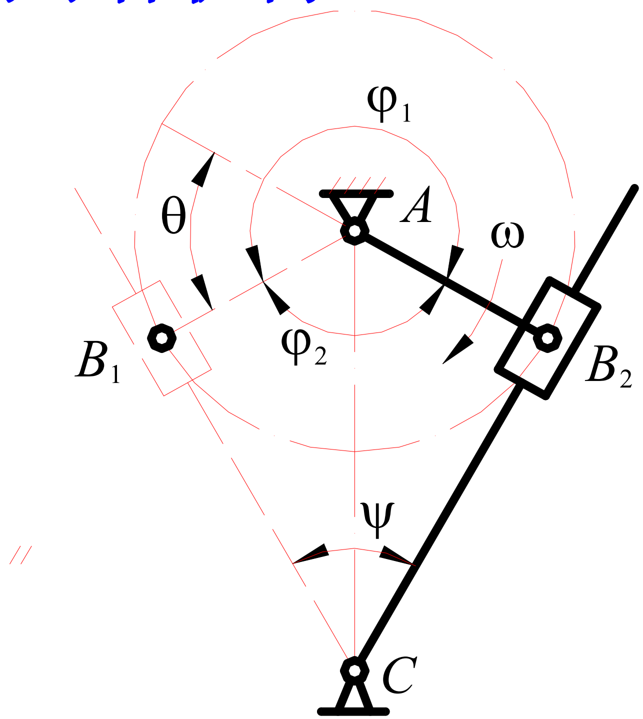
Since θ=0º, an in-line(对心) slider-crank mechanism has no quick-return characteristics.

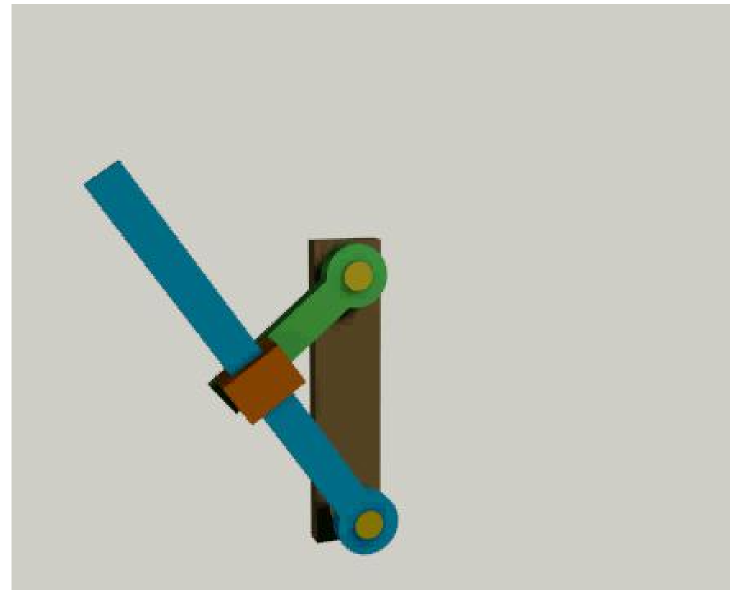




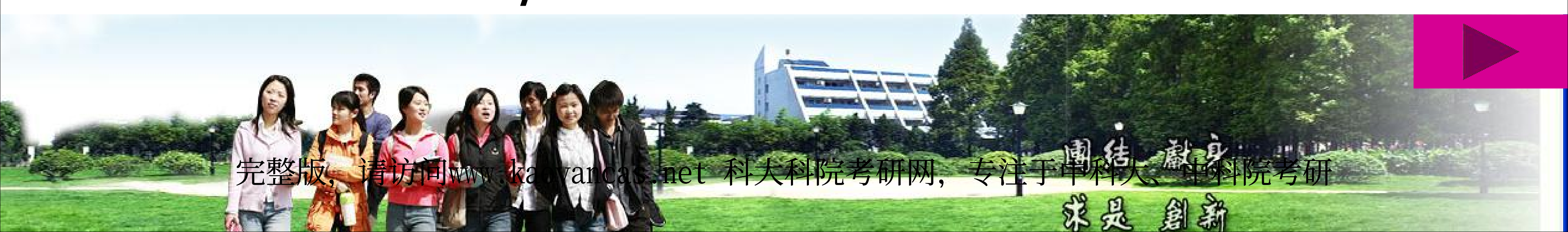
oscillating guide-bar mechanism

摆动导杆机构：





$$\theta = \psi$$



4.4 Dimensional Synthesis of Four-bar Linkages

Dimensional synthesis(综合) of a mechanism is the determination of the kinematic dimensions necessary to achieve(获得) the required motion.

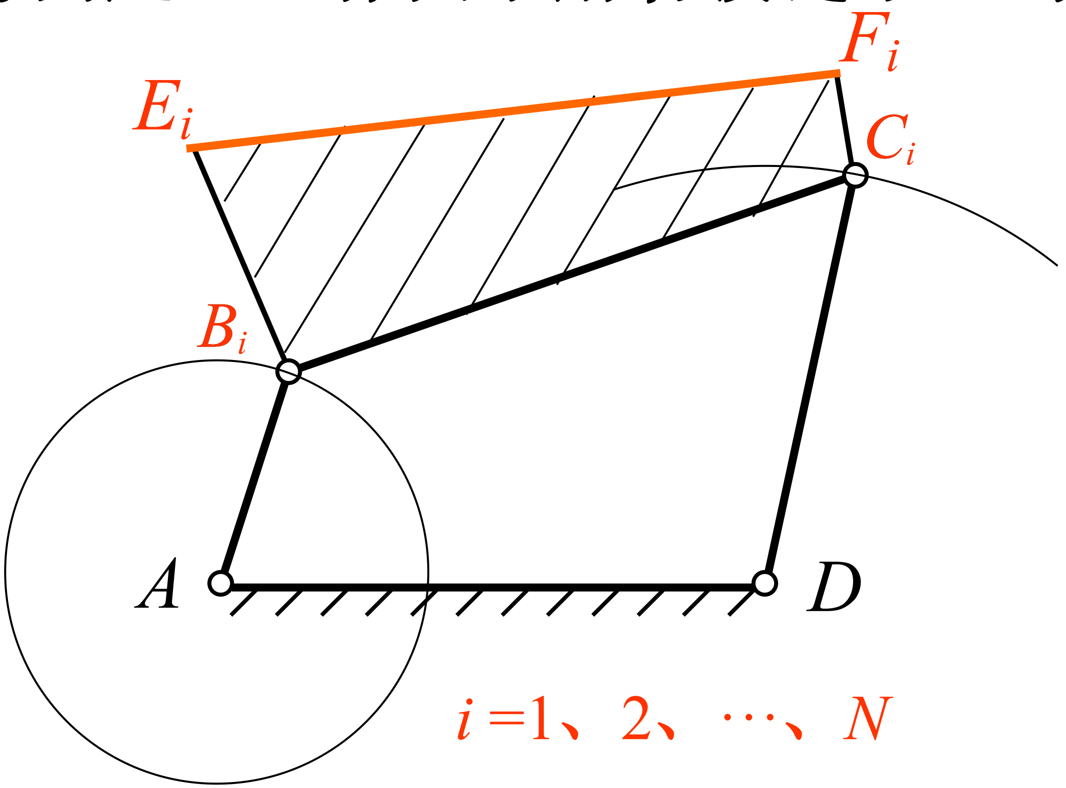
连杆机构的设计有二个任务：机构选型（称为型综合）和确定机构的尺寸（称为尺度综合）。

Usually, different problems will use different methods.

- **Graphical method图解法**
- **Analytical method解析法**
- **Experimental method实验法**

图解设计的基本原理

➤**图解设计问题——作图求解各铰链中心的位置问题。**

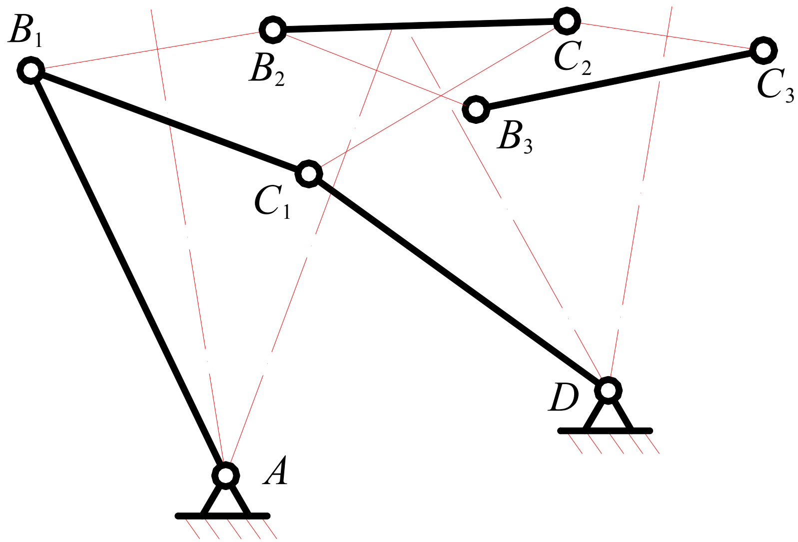


➤**各铰链间的运动关系：**

固定铰链 A、D： 圆心

活动铰链 B、C： 圆或圆弧

1、已知B，C及连杆的三个位置，设计该铰链四杆机构。



∵ *B*点绕*A*点、*C*点绕*D*点定轴转动

① 连接B1B2、B2B3；

② 作B1B2、B2B3垂直平分线交于A点；

③ 连接C1C2、C2C3；

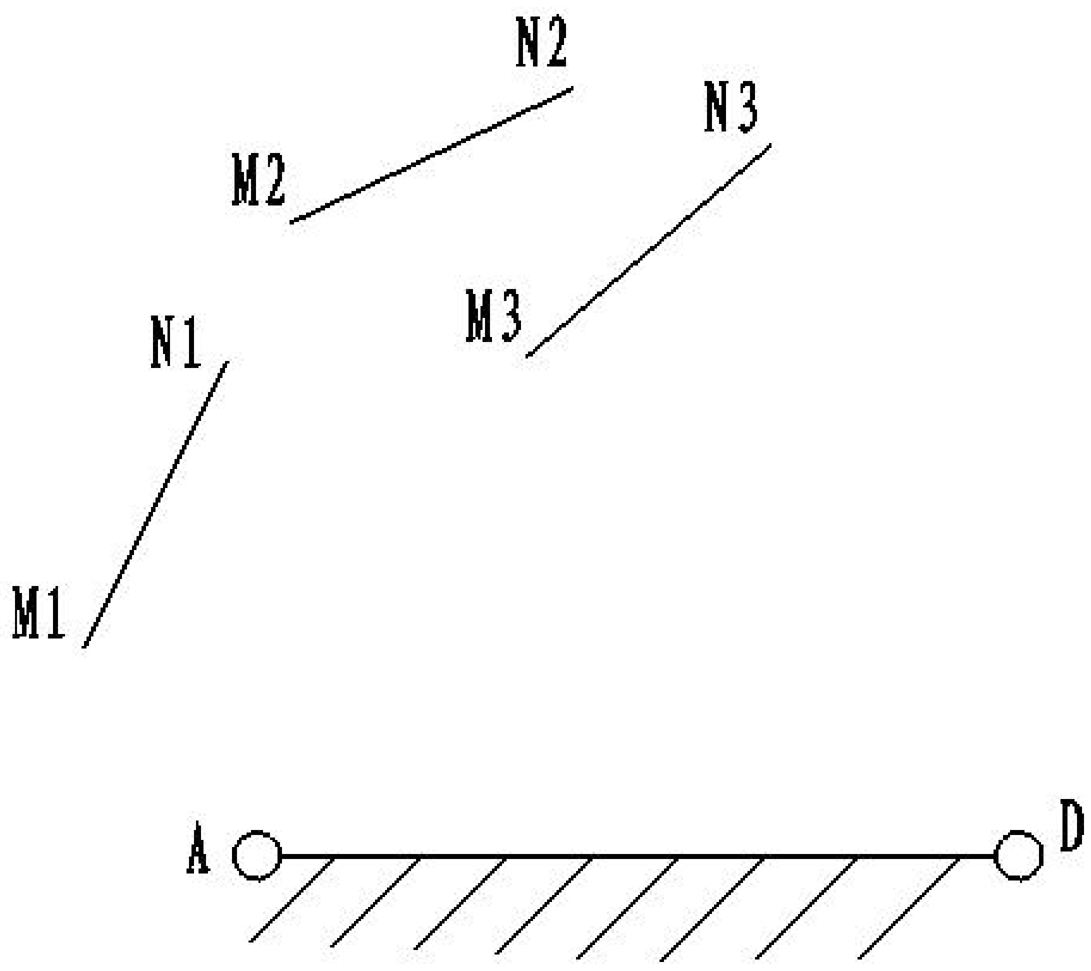
④ 作C1C2、C2C3垂直平分线交于D点。

给出B、C三个位置，A、D位置唯一

给出B、C二个位置，A、D位置无穷

（需加其他条件方可获得唯一解）

2、已知A，D及连杆MN的三个位置，设计该铰链四杆机构。

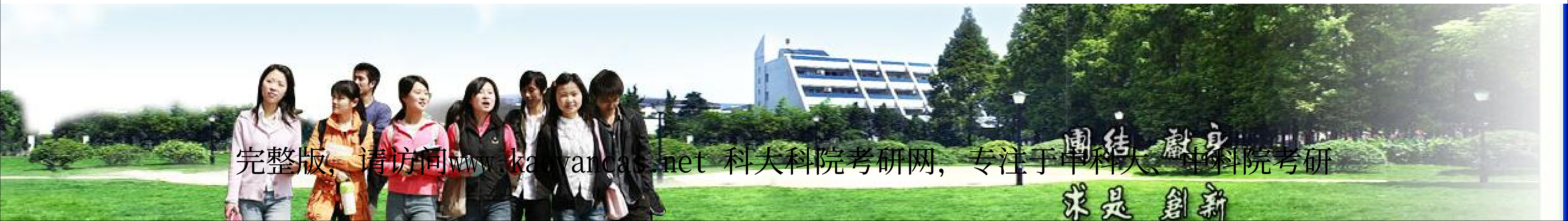


➢机构的倒置原理

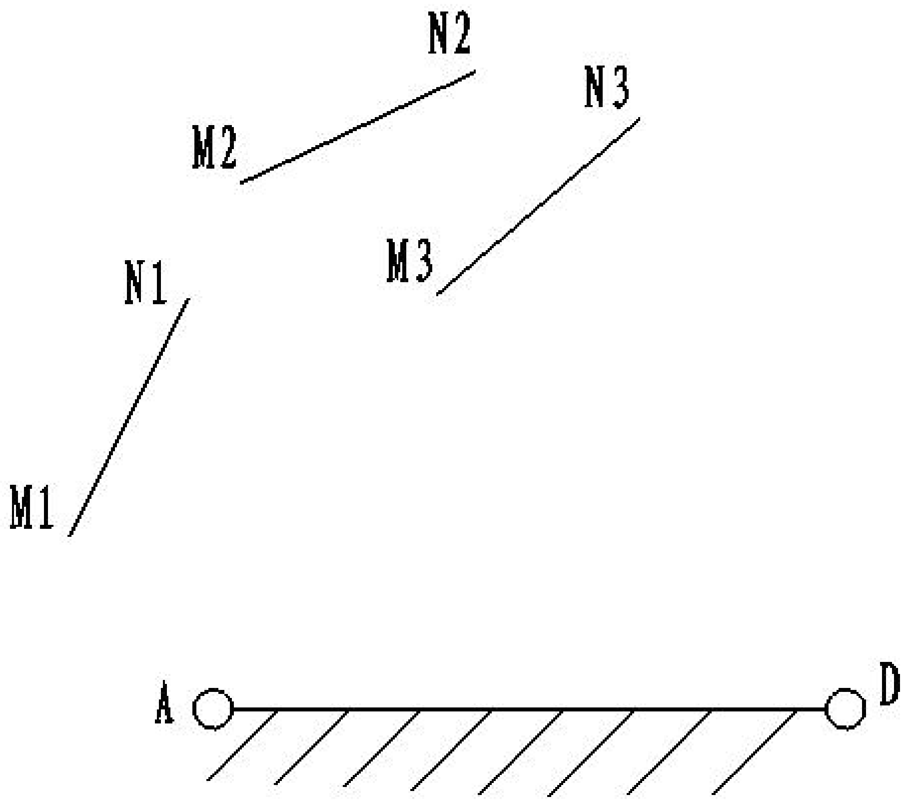
为了求活动铰链的位置，可将待求活动铰链所在的杆视作**新机架**，而将其相对的杆视为**新连杆**。

接下来，将原机构的各位置的构型均视为刚体，并向某一选定位置相对移动，使新机架的各杆位置重合，便可得新连杆相对于新机架的各个位置，即实现了**机构的倒置**。

这样，就将求活动铰链的位置问题转化为求固定铰链的位置问题了。这种方法又称为反转法。



求解步骤动画



以M_1N_1为机架，M_1N_1为原位

1、刚化AM_2N_2D，使得M_2N_2与M_1N_1重合，求得A_2'、D_2'

2、刚化AM_3N_3D，使得M_3N_3与M_1N_1重合，求得A_3'、D_3'

3、作$A_1'A_2'$、$A_2'A_3'$的公垂线交于B_1

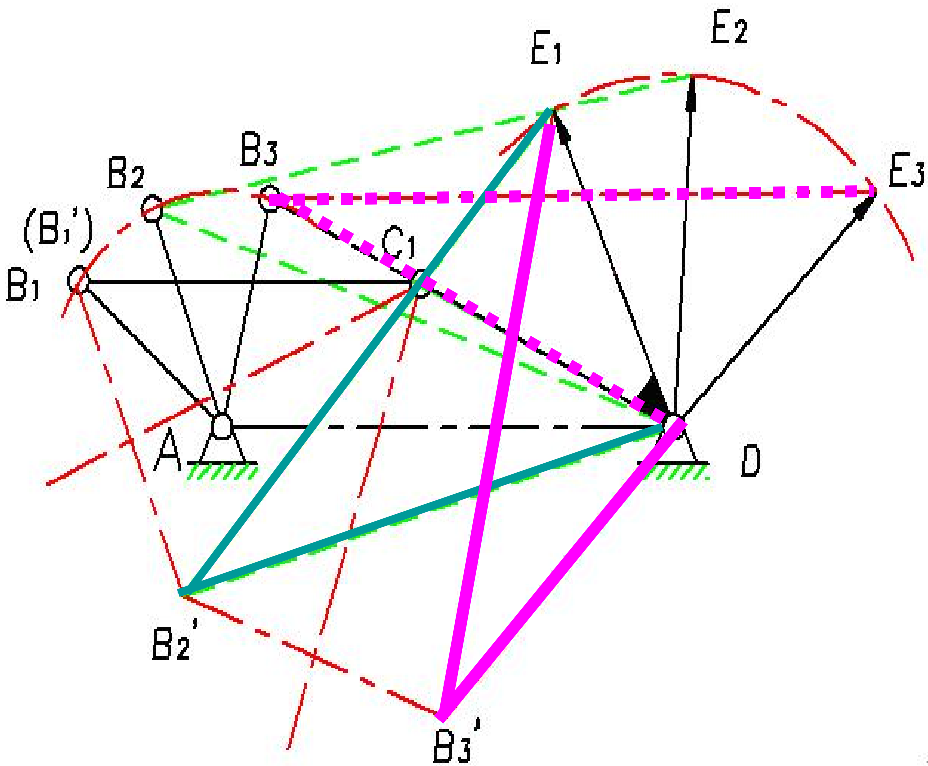
4、作$D_1'D_2'$、$D_2'D_3'$的公垂线交于C_1

AB_1C_1D便是所求

3、按给定两连架杆的位置设计四杆机构

目的：求解出铰链*C*。

引入转换机架的思想，采用反转法求得。



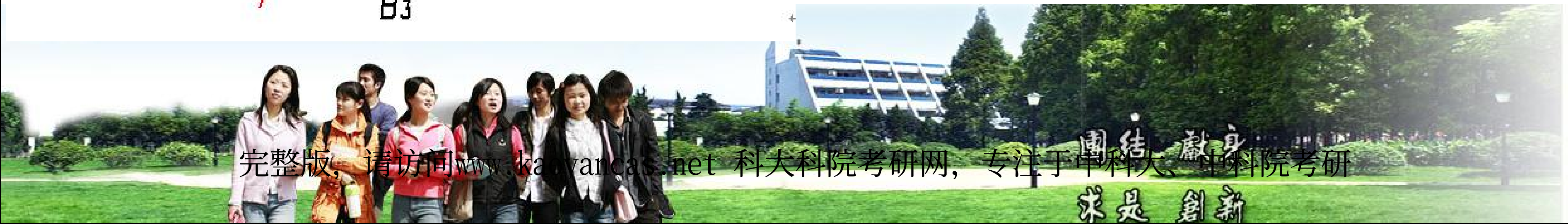
① 作△*DE*1*B*2'≌ △*DE*2*B*2，得*B*2'；

② 作△*DE*1*B*3'≌ △*DE*3*B*3，得*B*3'；

③ 作*B*1'*B*2'、B2'B3'的垂直平分线，交点就是所求*C*1。

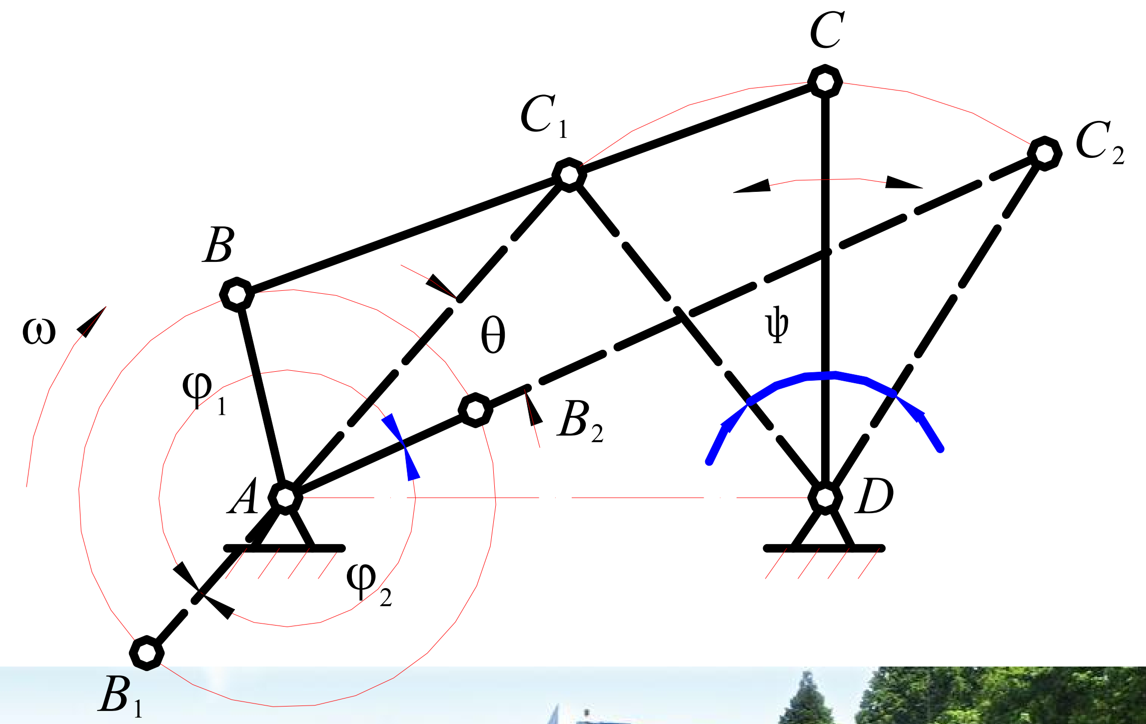
连杆长度： $b=u_l \times B1C1$

摇杆长度： $c=u_l \times D1C1$



4、按K设计四杆机构

已知：曲柄摇杆机构，摇杆CD长度，摆角，K 设计此机构（确定A,曲柄和连杆长）



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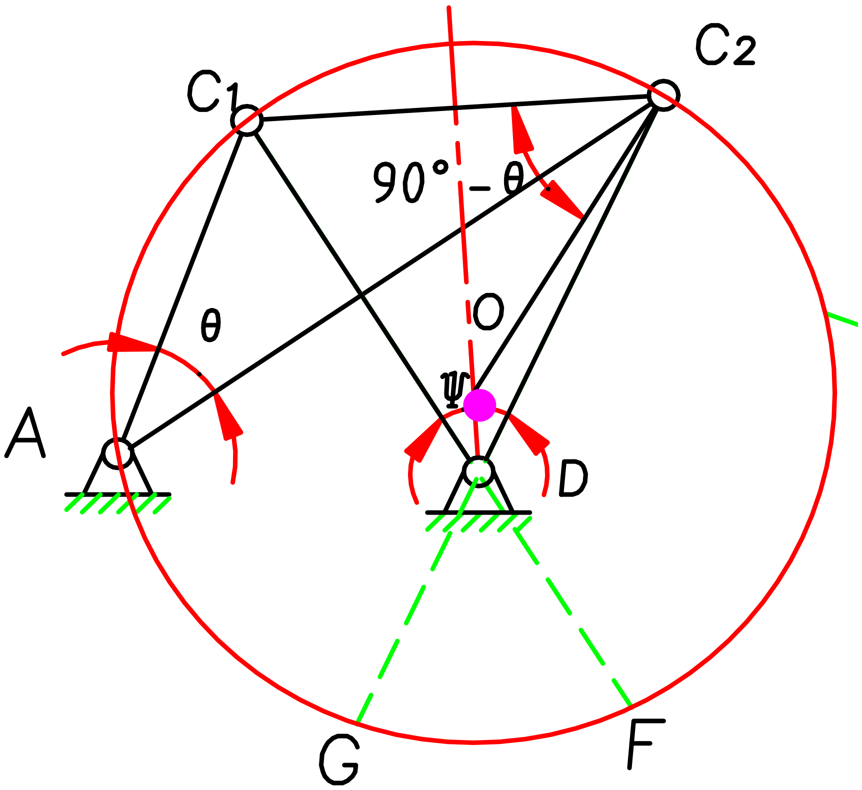
$$\theta = 180^\circ \frac{K-1}{K+1}$$



① 由(1)式算出极位夹角θ;

② 任选D的位置，按已知条件作出摇杆极限位置$DC1$和$DC2$;

③ 作∠$C2C1O$=∠$C1C2O$=90°－θ得$C1O$与$C2O$交点O;

④ 以O为圆心，$OC1$为半径作辅助圆，A点在圆弧上任选。

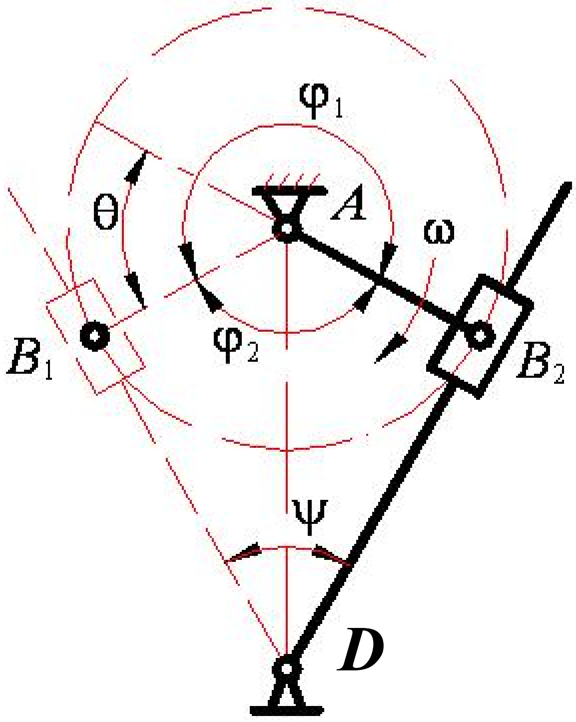
$$\left.\begin{aligned} l_{AC_1} &= b-a \\ l_{AC_2} &= b+a \end{aligned}\right\} \Rightarrow a,b$$

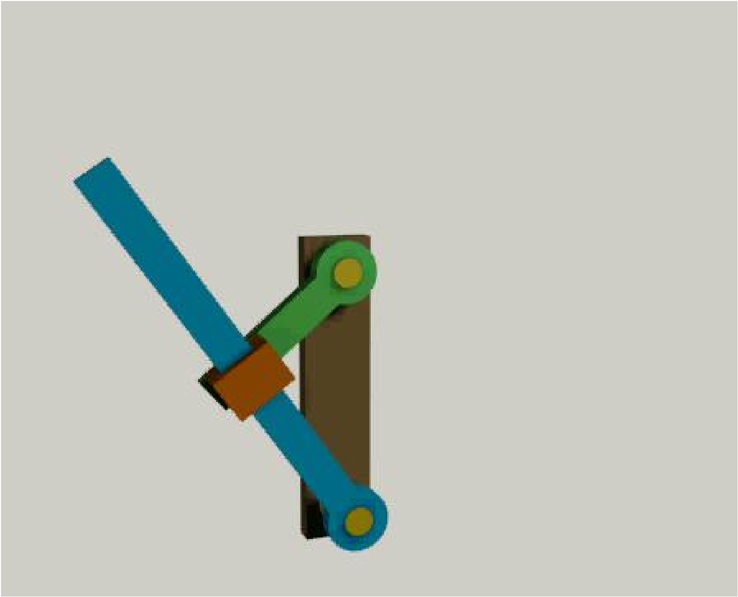
for example： Oscillating guide-bar mechanism

Known: K (time ratio)

l_{AD}(the frame)

Require: l_{AB}





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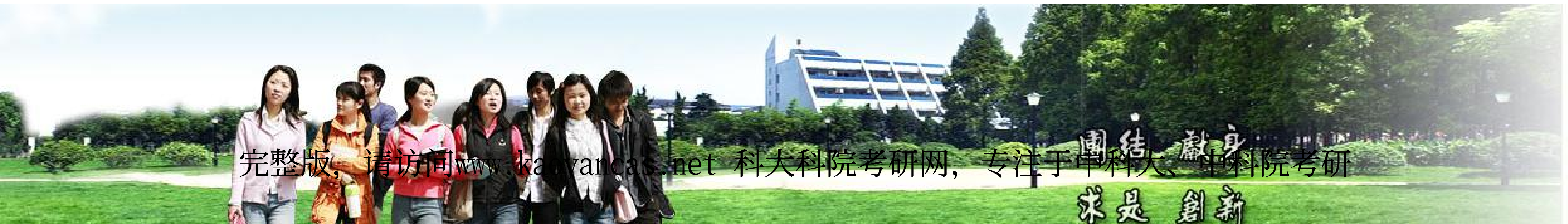
Attentions (this chapter):

- **The types of four-bar linkages**
- **Conditions for having a crank**
- **Pressure angle and transmission angle**
- **Dead point and quick return characteristic**
- **Dimentional synthesis of fourbar linkages**



Question ？



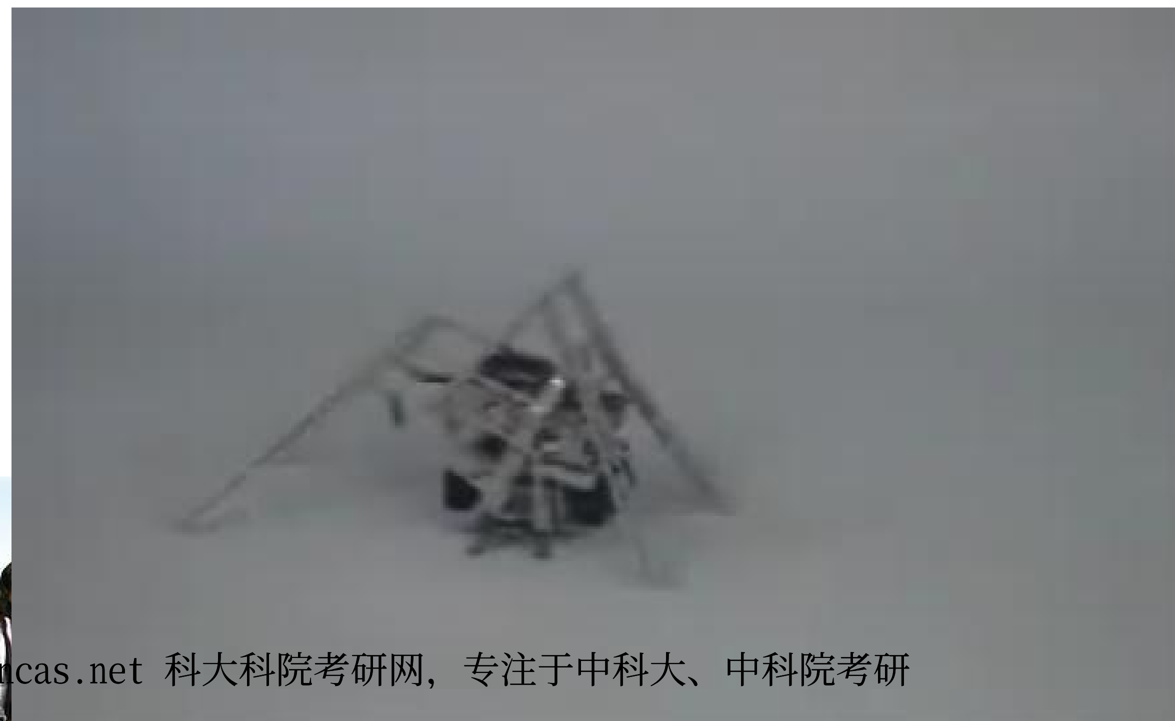

杆件数目？

运动副类型？

连杆机构类型？

课外实践作品

——仿生尺蠖机构



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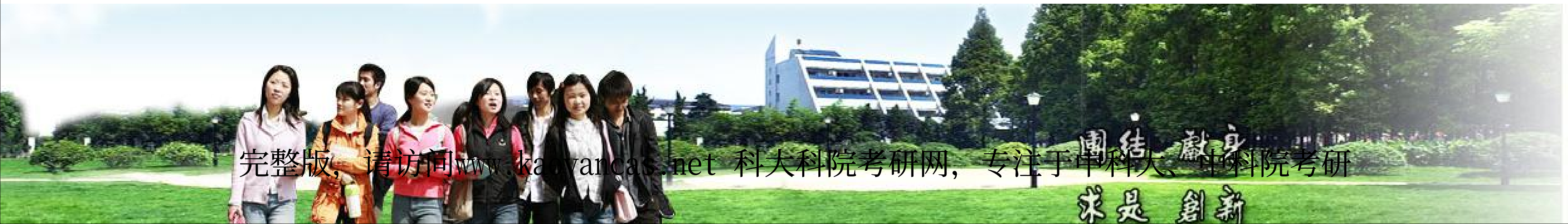
Homework

1. Read book p43-57.
2. Exercise p66:4-3,4-4(1),(2):a,b,c,d
   4-5,4-6

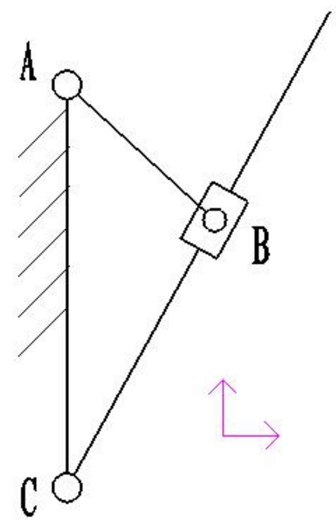


复习思考题

1、如何依照各杆长度判别铰链四杆机构的型式？

2、平面四连杆机构最基本形态是什么？由它演化为其它平面四杆机构，有哪些具体途径？

3、图示摆动导杆机构中，**AB**杆匀角速转动。该机构存在的几何条件是什么？给定其摆杆的行程速度变化系数**K**后，怎么用**K**值表达**AB**和**AC**杆的长度关系？



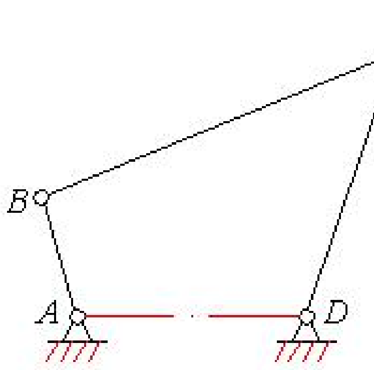
习题

1、图示铰链四杆机构，已知：l_{BC}=50mm，l_{CD}=35mm，l_{AB}=30mm，AD为机架，

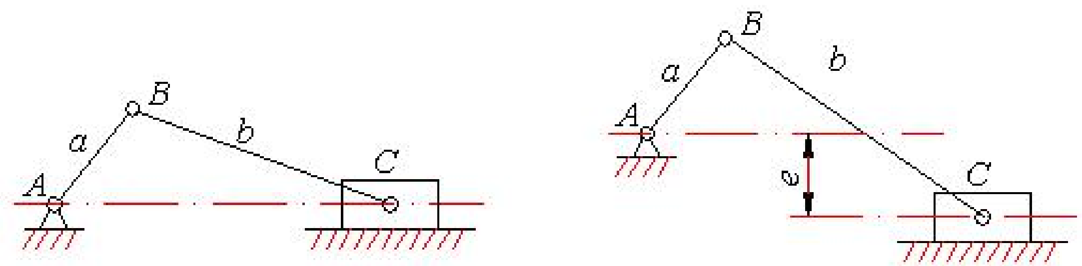
（1）若此机构为曲柄摇杆机械，且AB为曲柄，求l_{AB}的最大值：

（2）若此机构为双曲柄机构，求l_{AB}的范围；

（3）若此机构为双摇杆机构，求l_{AB}的范围。



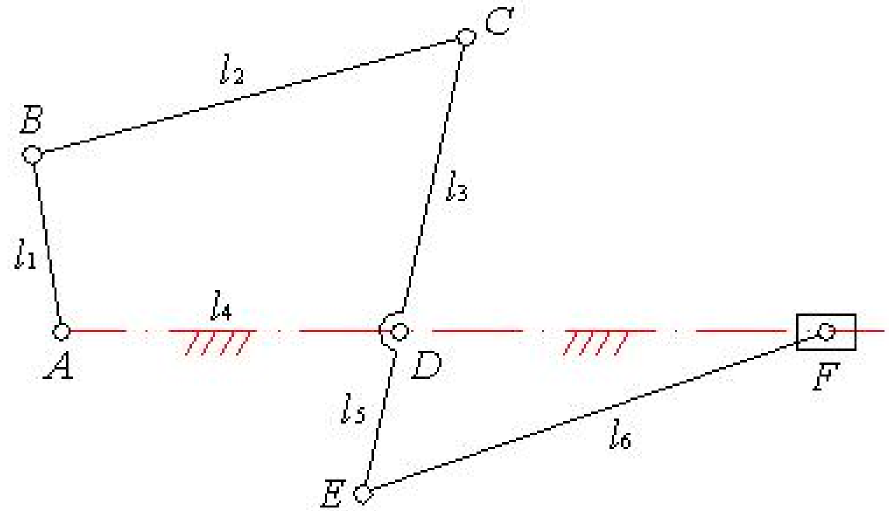
题1图



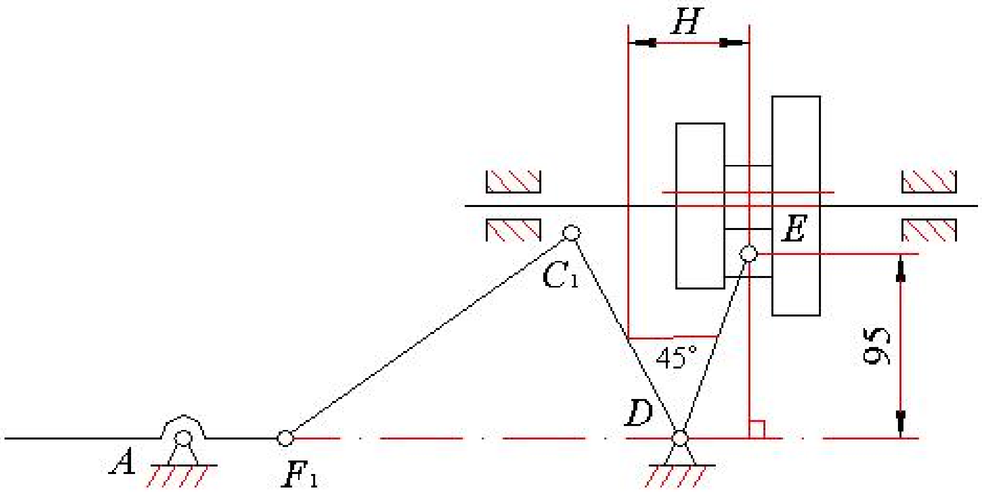
题2图

2、图示两种曲柄滑块机构，若已知a=120mm，b=600mm，对心时e=0及偏置时e=120mm，求此两机械的极位夹角θ及行程速比系数K。又在对心曲柄滑块机构中，若连杆BC为二力杆件，则滑块的压力角将在什么范围内变化？

3、图示六杆机构，已知（单位mm）：l_1=20，l_2=53，l_3=35，l_4=40，l_5=20，l_6=60，试确定：1）构件AB能否整周回转？2）滑块行程h；3）滑块的行程速度变化系数K；4）机构DEF中的最大压力角α_{max}。



4、图示机床变速箱中操纵滑动齿轮的操纵机构，已知滑动齿轮行程H=60mm，l_{DE}=100mm，l_{CD}=120mm，l_{AD}=250mm，其相互位置如图所示。当滑动齿轮在行程的另一端时，操纵手柄朝垂直方向，试设计此机构。



5、设计一偏置曲柄滑块机构，已知滑块的行程速度变化系数K=1.5，滑块的冲程l_{C1C2}=50mm，导路的偏距e=20mm，求曲柄长度l_{AB}和连杆长度l_{BC}。