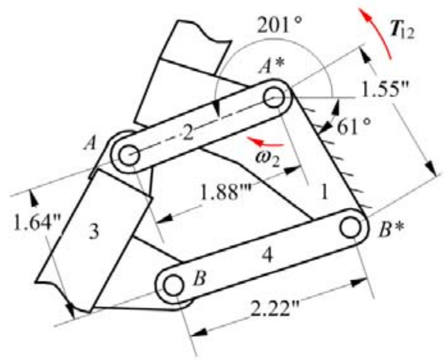
Solutions to Chapter 1 Exercise Problems

Problem 1.1

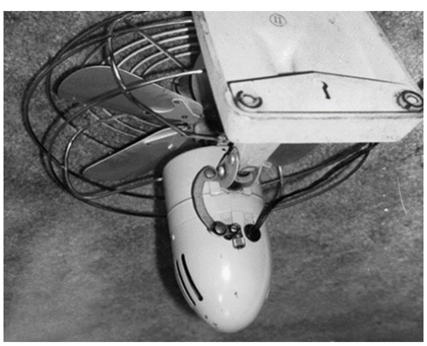
Find a mechanism as an isolated device or in a machine and make a realistic sketch of the mechanism. Then make a freehand sketch of the kinematic schematics for the mechanism chosen.

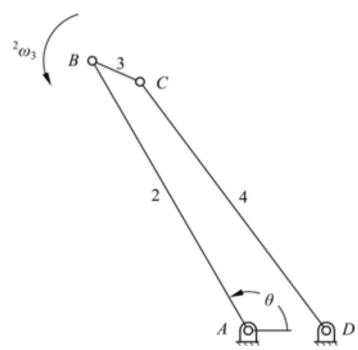
Solution:

Typical examples of solutions for this problem are given in the problem definitions of Chapter 1. Some examples are:

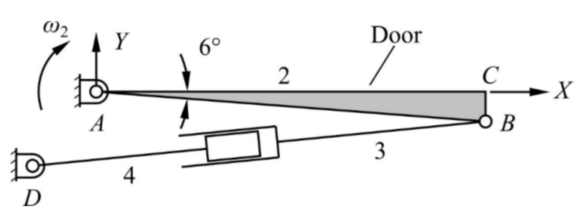


Bicycle suspension





Oscillating fan



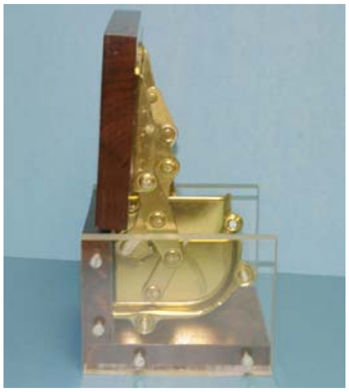
Door closing linkage

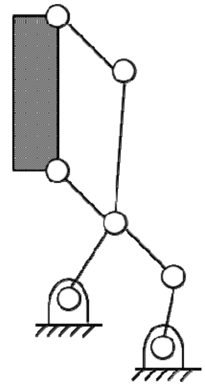
Problem 1.2

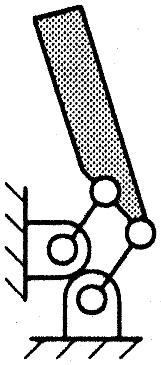
Cabinet hinges use various types of linkages for the folding mechanism. Identify three types of cabinet hinges and make a freehand sketch of the kinematic mechanism used.

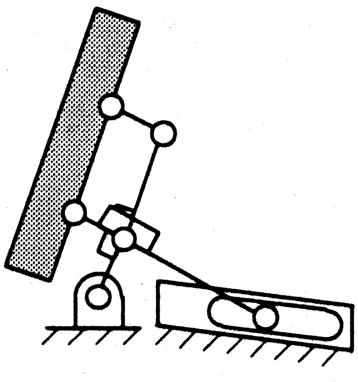
Solution:

There are a large number of mechanisms that are used to obtain various types of hinge motions. Below are three of them. The first is a 6-bar Watt's linkage used for chest lids. The hinge guides the chest lid such that no part of the lid crosses the plane of the back of the chest. The second example is a four bar linkage that guides the door from the open to closed position. The hinge is basically hidden when the door is closed. The third uses a 6-bar Watt's linkage with a slider. The lid glides about the back corner of the box.



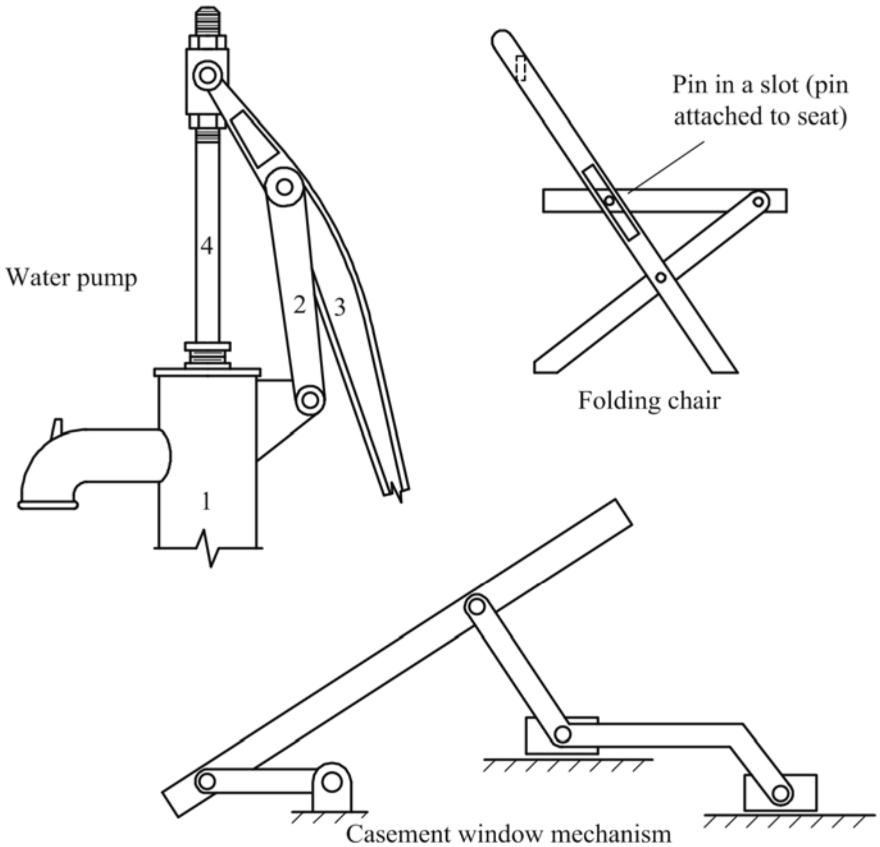




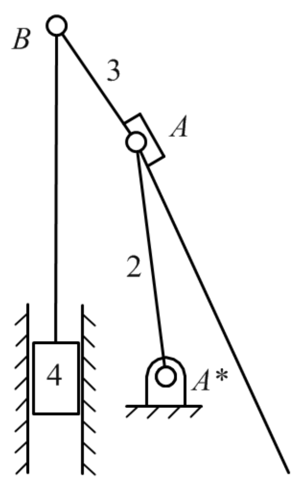


Problem 1.3

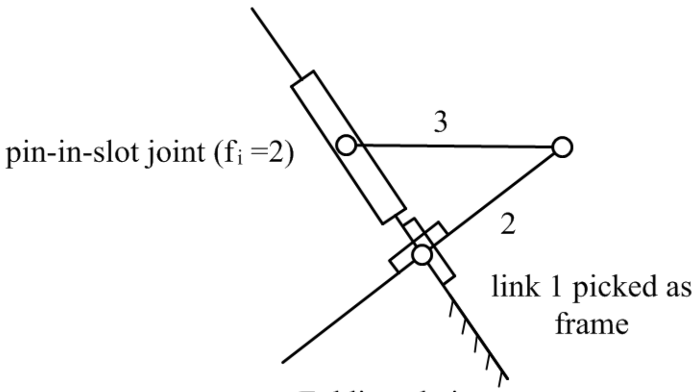
The drawings shown below are pictorial representations of real mechanisms that are commonly encountered. Make a freehand sketch of the kinematic schematic representation of each mechanism.



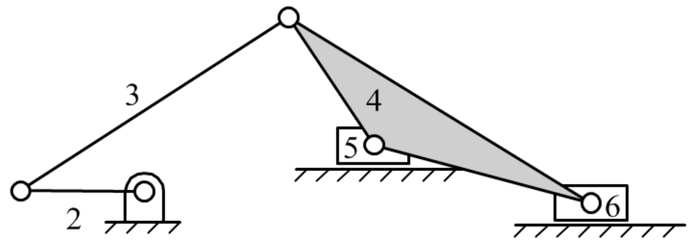
Solution



Water pump



Folding chair



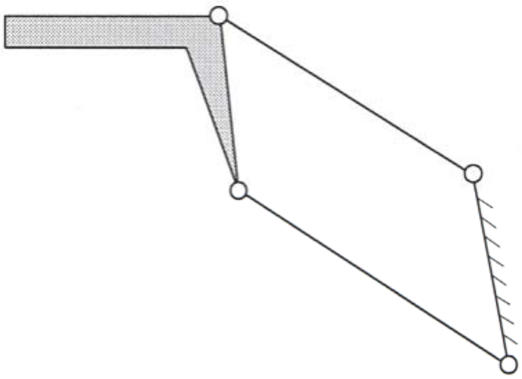
Casement window mechanism

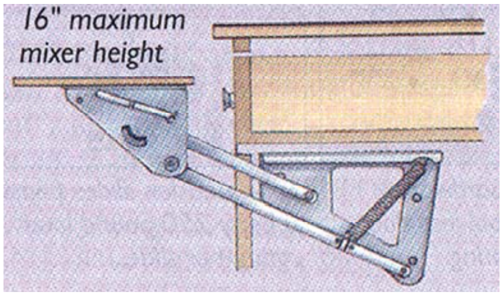
Problem 1.4

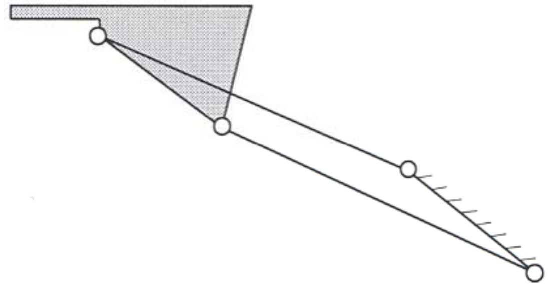
Linkages are often used to guide devices such as computer keyboards in and out of cabinets. Find three such devices, and make a freehand sketch of the kinematic mechanisms used for the devices.

Solution:

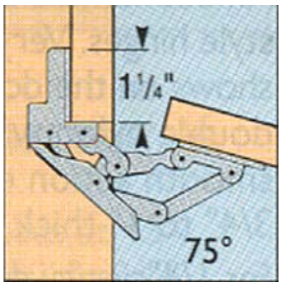

Typewriter desk linkage

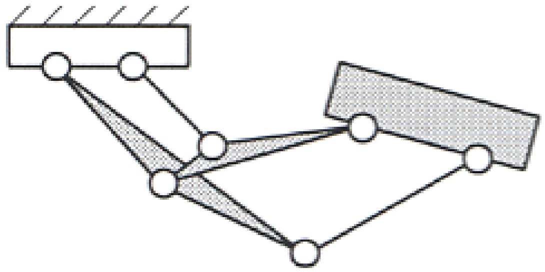






Under drawer swing up mechanism





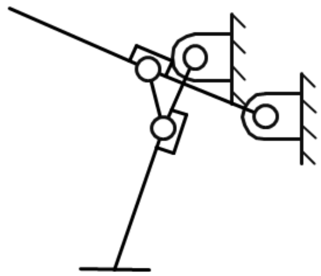
Overhead bin hinge

Problem 1.5

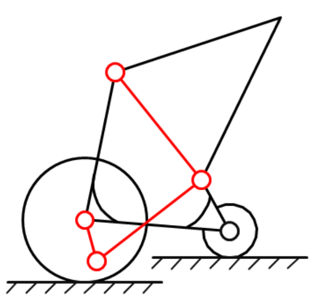
Four bar linkages are used in common devices around the home and businesses. Locate six such devices and make a freehand sketch of each device and describe its function.

Solution:

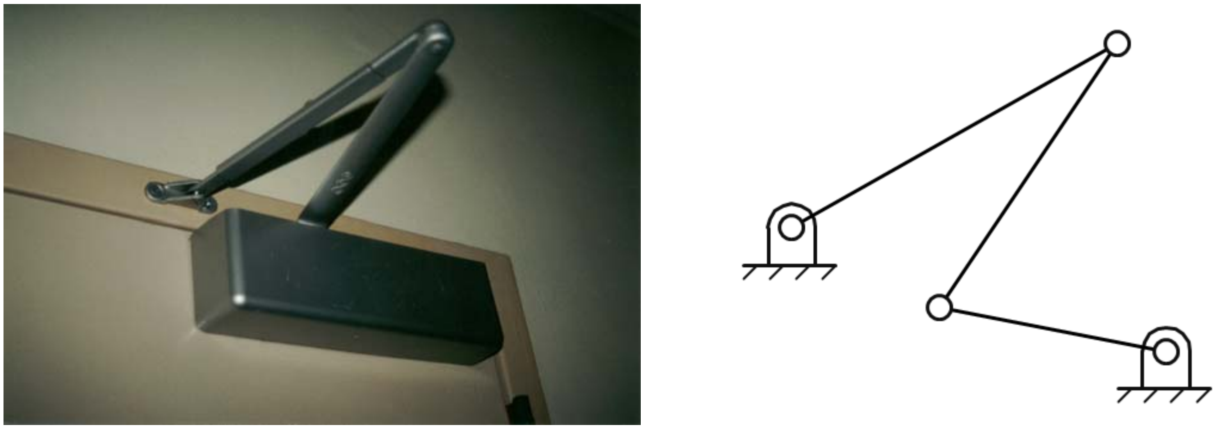
Sample examples are given in the following:



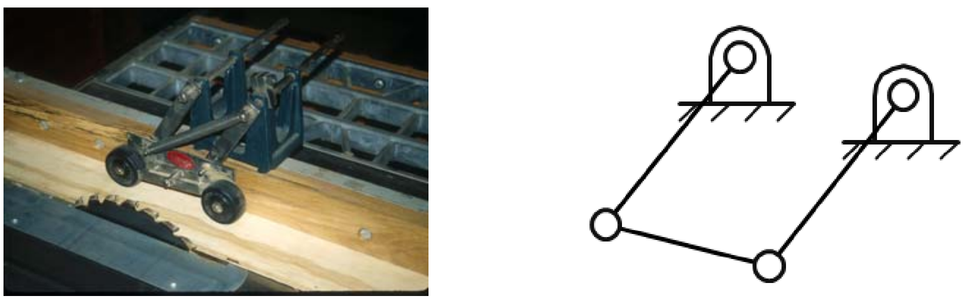
Brake for wheelchair. The mechanism exhibits a toggle motion



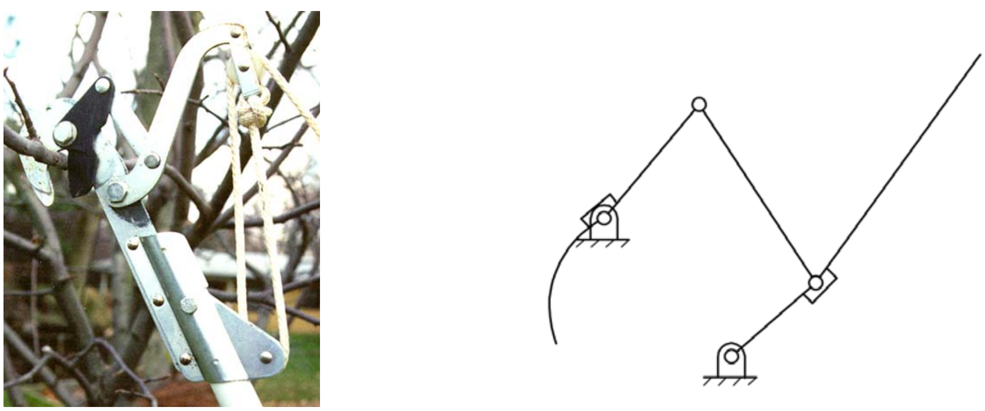
Walking toy. The four bar linkage moves the leg and wing.



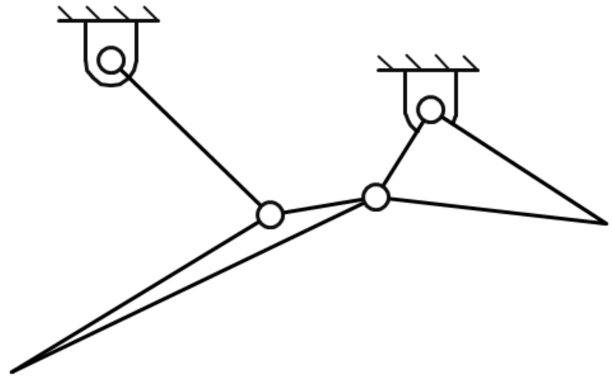
Door closer.   The four bar linkage is connected to a damper mechanism



Kickback protector on table saw.   The four bar linkage is a parallelogram linkage.



Tree trimmer. The four bar linkage is a double lever mechanism used to increase the mechanical advantage

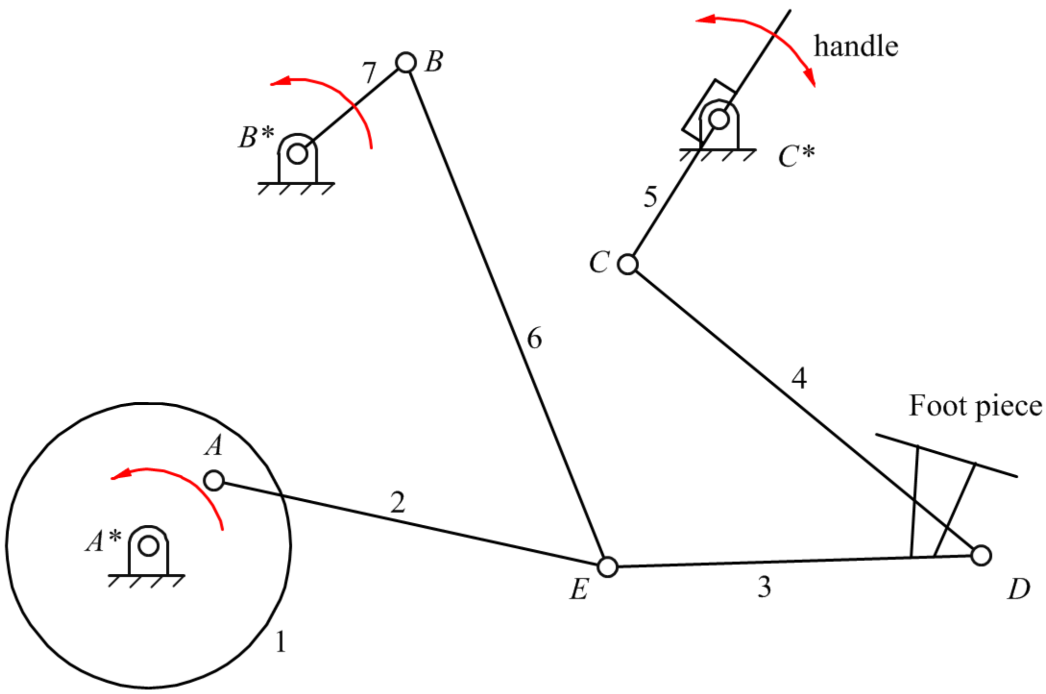
Vice grips. The four bar linkage is a toggle mechanism

Problem 1.6

The figure shows an elliptical trainer machine. The mechanism is a planar linkage. There are linkages on both sides of the machine. The linkage on the right is a mirror image of the one on the left and the linkages are connected together so that they are always 180° out of phase with each other. For the left side linkage identify the moving joints and links. There is a handle that rotates about a fixed pivot. There is also a foot pedal that floats in that it is not connected to the frame of the machine. Sketch the topology of the linkage. How many links and joints are there? How many binary links? How many ternary links? How many four-bar loops can you identify? Which linkage topology in Figure 1.23 or 1.24 does the topology match? Identify any joints that perform complete rotations as the mechanism is cycled? Identify the joints in a four-bar loop and determine the Grashof type of that loop.

Solution:

Elliptic trainers come with different designs. A user manipulates a foot piece rigidly attached to a moving body. This moves a hand crank and the wheel. The model below shows a schematic with n=8, j=9. The mobility of this mechanism is $M = 3(n - j - 1) + \sum f_i = 3(8 - 9 - 1) + 9 = 3$. One can intuitively understand it as follows: Once the position/orientation of foot piece (link 4) is prescribed by the user, all other joint angles are determined. It has 7 binary links and 1 ternary link (the frame).

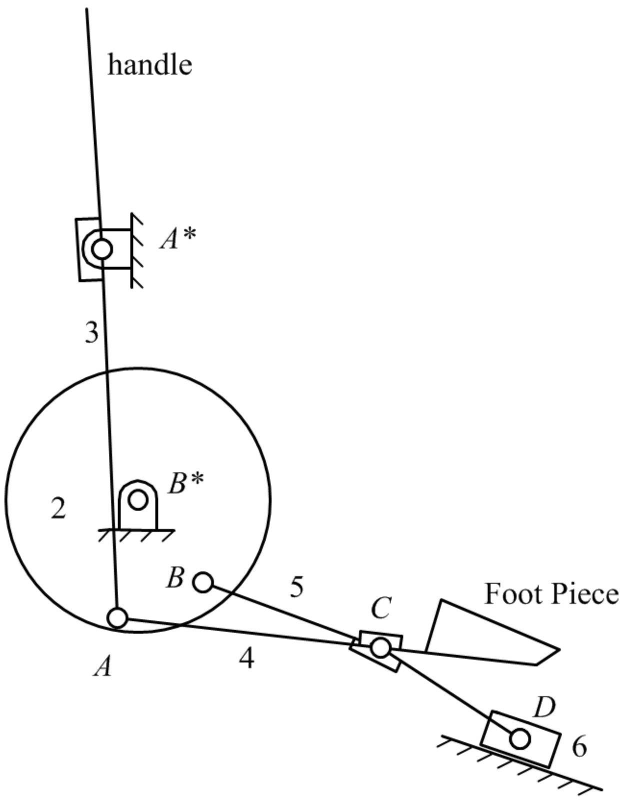


Problem 1.7

The figure shows another type of elliptical trainer machine. The mechanism is a planar linkage which includes a slider joint. There are linkages on both sides of the machine. The linkage on the right is a mirror image of the one on the left and the linkages are connected together so that they are always 180º out of phase with each other. For the left side linkage identify the moving joints and links. There is a handle that rotates about a fixed pivot. There is also a foot pedal that floats in that it is not connected to the frame of the machine. Sketch the topology of the linkage. How many links and joints are there? How many binary links? How many ternary links? Identify any joints that perform complete rotations as the mechanism is cycled? Identify the joints in a four-bar loop and determine the Grashof type of that loop.

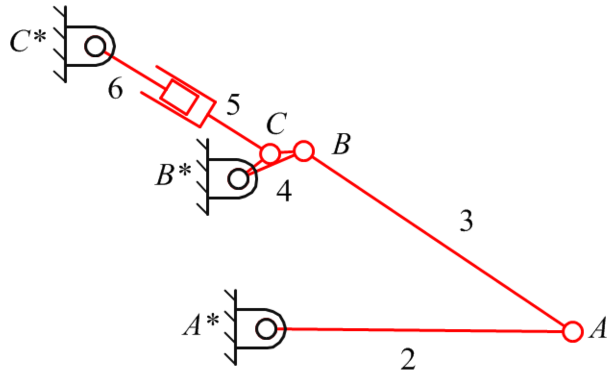
Solution:

Elliptic trainers come with different designs. A user manipulates a foot piece rigidly attached to a moving body. This moves a hand crank and the wheel. The model below shows a schematic with n=6, j=7. The mobility of this mechanism is $M = 3(n - j - 1) + \sum f_i = 3(6 - 7 - 1) + 7 = 1$. One can intuitively understand it as follows: Once the position/orientation of foot piece (link 4) is prescribed by the user, all other joint angles are determined. It has 4 binary links and 2 ternary link (links 1 and 5). There is no Grashof fourbar linkage in the configuration given because there is no four-bar loop involving the frame.



Problem 1.8

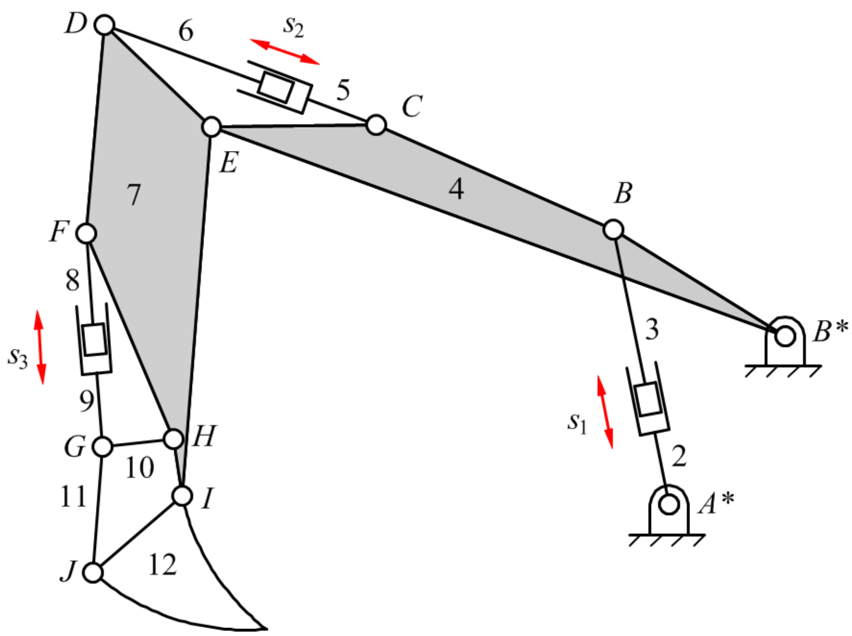
The figure shows a bicycle suspension linkage. If the shock absorber is considered, the linkage can be represented as a six bar mechanism. Draw the back suspension linkage and identify the chain in Fig. 1.23 to which the topography corresponds.



This mechanism can be considered as a 4-bar mechanism and an inverted slider-crank mechanism in series where the output of the 4-bar (A*ABB*) is the input to the inverted crank-slider (B*CC*). It will be characterized as a Watt's mechanism.

Problem 1.9

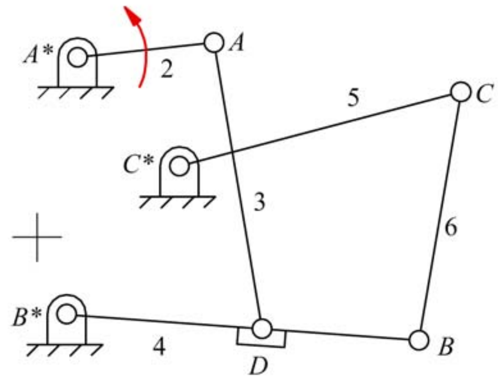
A small excavator is shown in the photograph. The machine has a swing linkage but the main mechanism is planar. Draw the planar excavation linkage. Treat each hydraulic cylinders as a slider in a tube.



This excavator has three degrees-of-freedom s_1, s_2, s_3 in the plane which are controlled by the three linear actuators.

Problem 1.10

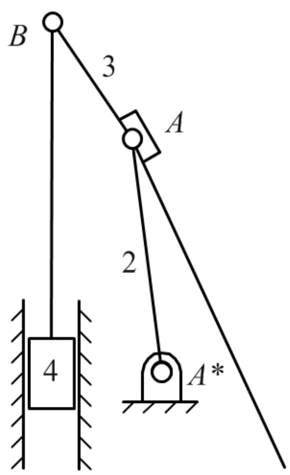
1.10 Since the mid 1940's, modern tractors used for farming, construction, and landscape work have used a 3-point hitch to attach implements to the rear of the tractor. This allows the operator to control the height and orientation of the implement using the tractor hydraulic system. A 3-point hitch is shown in the figure below along with a schematic of the linkage. The kinematics of the system can be studied using a planar schematic as shown. In the schematic, link 2 is rotated using a hydraulic motor, and the implement being controlled is link 6.   Characterize the linkage as a Watt's or Stephenson's six bar linkage.



Watt's chain: As 2 rotates, member 4 is the output link of a 4-bar chain A*ADB*. This output then uniquely moves the members BC and CC*.

Problem 1.11

Calculate the mobility, or number of degrees of freedom, of each of the mechanisms in Problem 1.3.

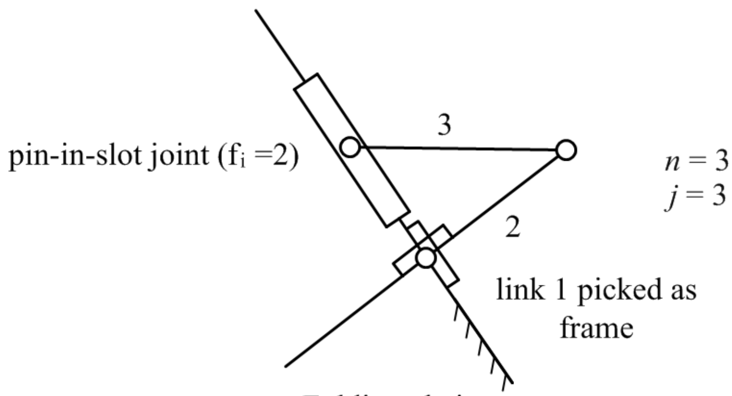


$n = 4$
$j = 4$

Water pump

$$M = 3(n - j - 1) + \sum f_i = 3(4 - 4 - -1) + 4 = -3 + 4 = 1$$

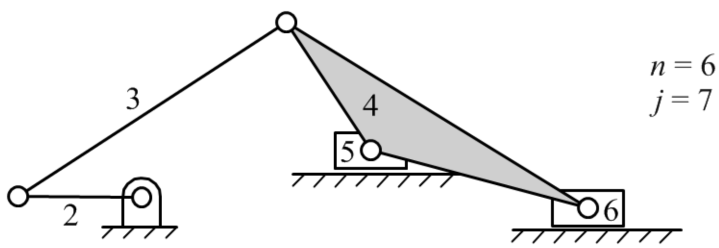
Mobility = 1.



Folding chair

$$M = 3(n - j - 1) + \sum f_i = 3(3 - 3 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1.



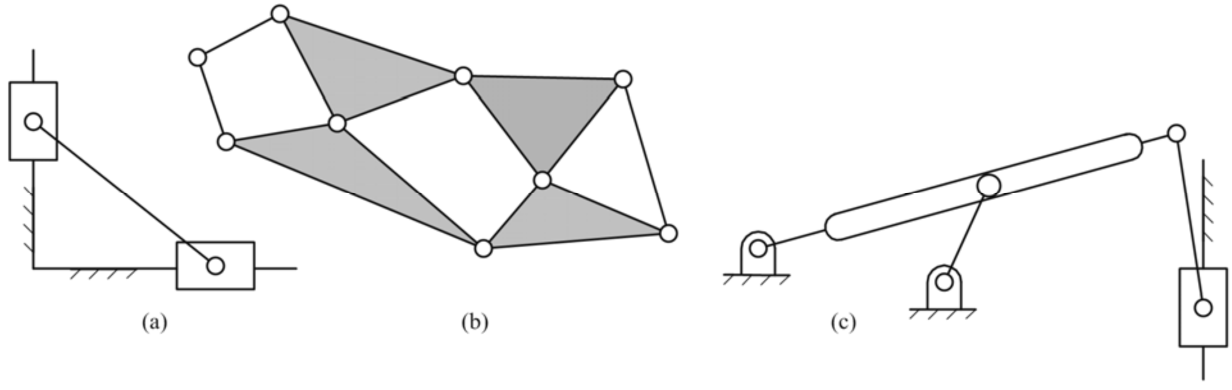
Casement window mechanism

$$M = 3(n - j - 1) + \sum f_i = 3(6 - 7 - 1) + 7 = -6 + 7 = 1$$

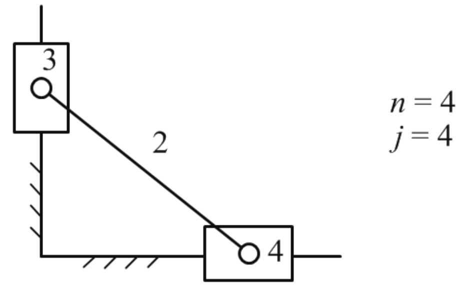
Mobility = 1.

Problem 1.12

What is the number of members, number of joints, and mobility of each of the planar linkages shown below?



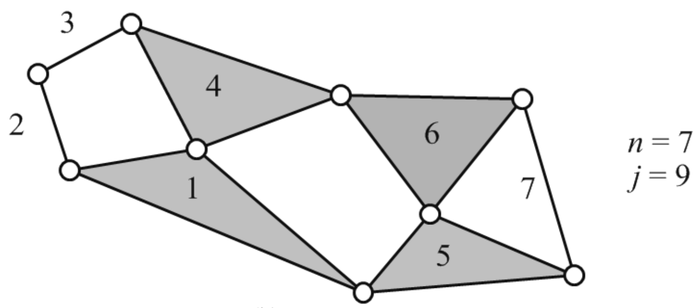
Solution:



(a)

$$M = 3(n - j - 1) + \sum f_i = 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

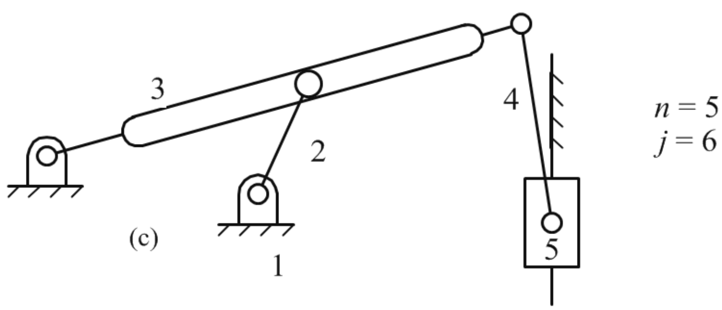
Mobility = 1.



(b)

$$M = 3(n - j - 1) + \sum f_i = 3(7 - 9 - 1) + 9 = -9 + 9 = 0$$

Mobility = 0.



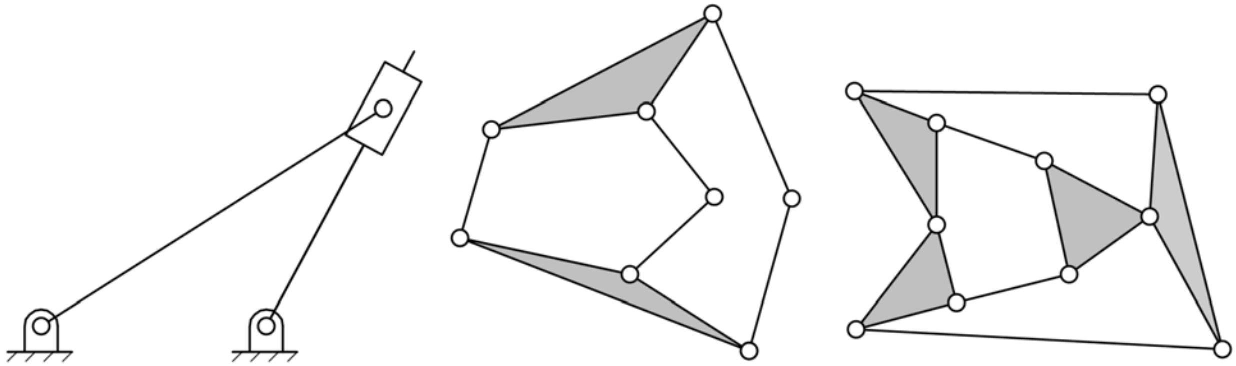
(c)

$$\sum f_i = 5 \times 1 + 1 \times 2 = 7$$
$$M = 3(n - j - 1) + \sum f_i = 3(5 - 6 - 1) + 7 = -6 + 7 = 1$$

Mobility = 1.

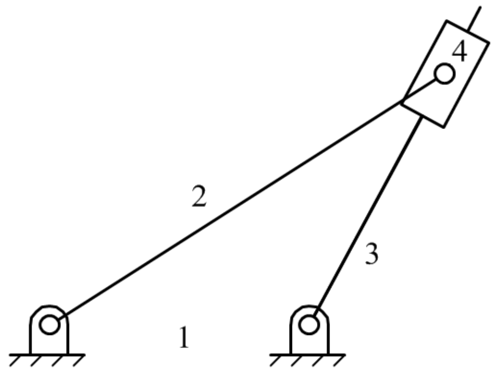
Problem 1.13

What are the number of members, number of joints, and mobility of each of the planar linkages shown below?



(a) (b) (c)

Solution:

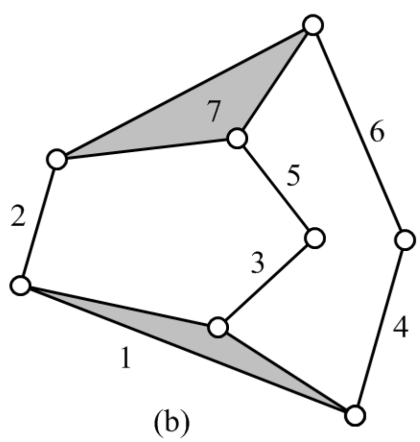


(a)

$n = 4$
$j = 4$

$M = 3(n - j - 1) + \sum f_i = 3(4 - 4 - 1) + 4 = -3 + 4 = 1$

Mobility = 1.

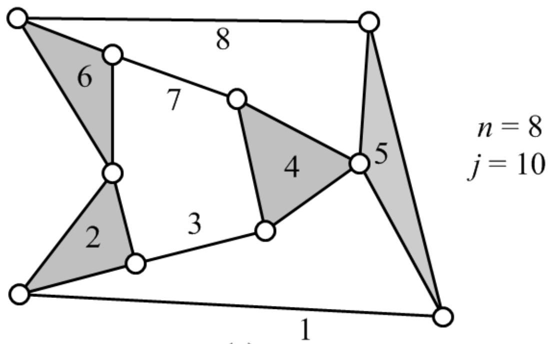


(b)

$n = 7$
$j = 8$

$M = 3(n - j - 1) + \sum f_i = 3(7 - 8 - 1) + 8 = -6 + 8 = 2$

Mobility = 2.



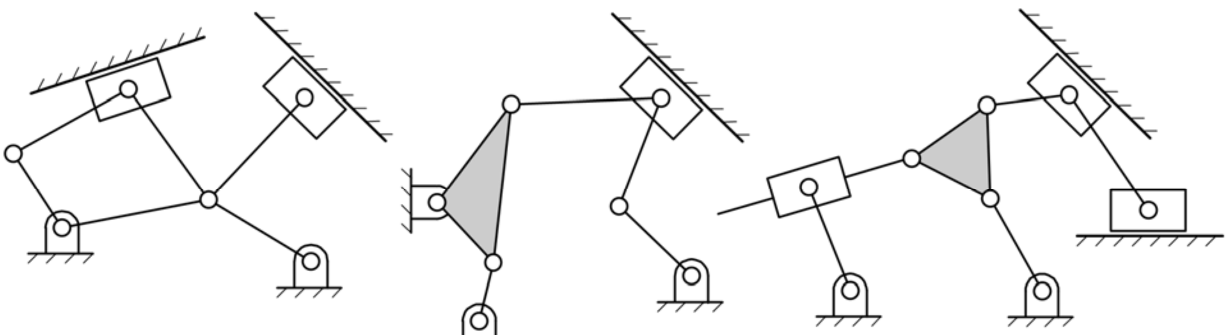
(c)

$$M = 3(n - j - 1) + \sum f_i = 3(8 - 10 - 1) + 10 = -9 + 10 = 1$$

Mobility = 1.

Problem 1.14

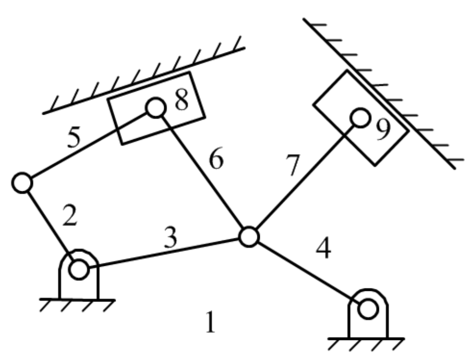
Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used and identify the input and output links assumed when determining your answers.



(a) (b) (c)

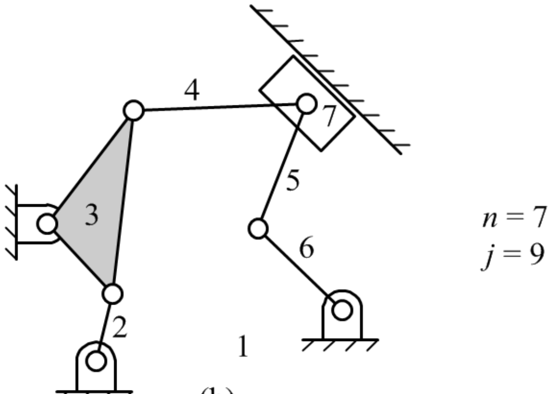
Solution:

(a)



$$M = 3(n - j - 1) + \sum f_i = 3(9 - 12 - 1) + 12 = -12 + 12 = 0$$

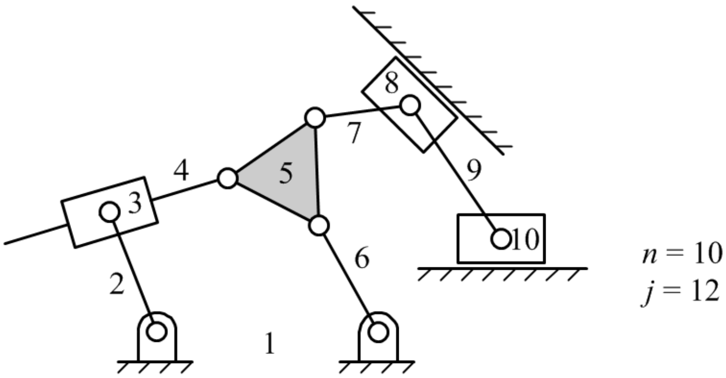
Mobility = 0.
Idle DOF = 0



(b)

$$M = 3(n - j - 1) + \sum f_i = 3(7 - 9 - 1) + 9 = -9 + 9 = 0$$

Mobility = 0.
Idle DOF = 0



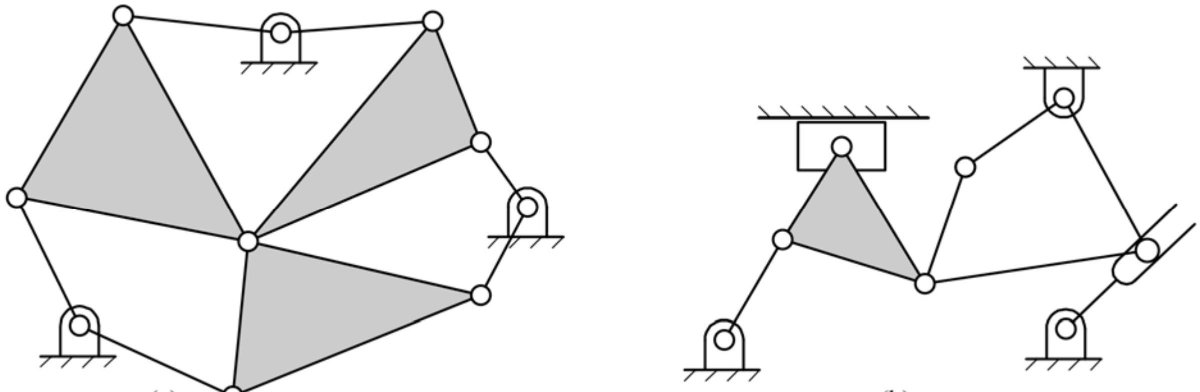
(c)

$$M = 3(n - j - 1) + \sum f_i = 3(10 - 12 - 1) + 12 = -9 + 12 = 3$$

Mobility = 3.
Idle DOF = 0

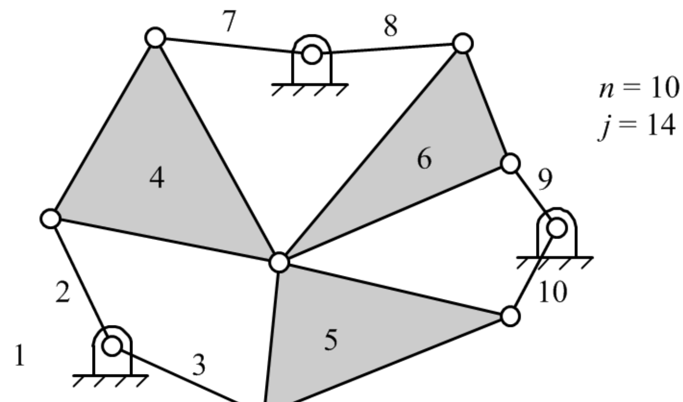
Problem 1.15

Determine the mobility and the number of idle degrees of freedom of the linkages shown below. Show the equations used and identify any assumptions made when determining your answers.



(a) (b)

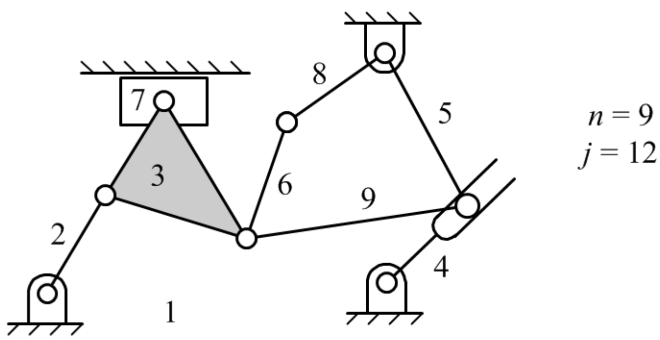
Solution:



(a)

$$M = 3(n - j - 1) + \sum f_i = 3(10 - 14 - 1) + 14 = -15 + 14 = -1$$

Mobility = -1.
Idle DOF = 0



(b)

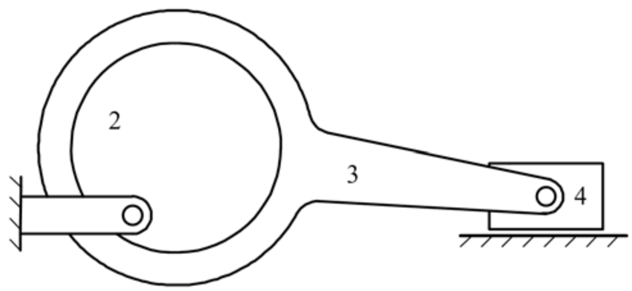
$$\sum f_i = 10 \times 1 + 2 \times 2 = 14$$

$$M = 3(n - j - 1) + \sum f_i = 3(9 - 12 - 1) + 14 = -12 + 14 = 2$$

Mobility = 2.
Idle DOF = 0

Problem 1.16

Determine the mobility and the number of idle degrees of freedom associated with the mechanism. Show the equations used and identify any assumptions made when determining your answers.



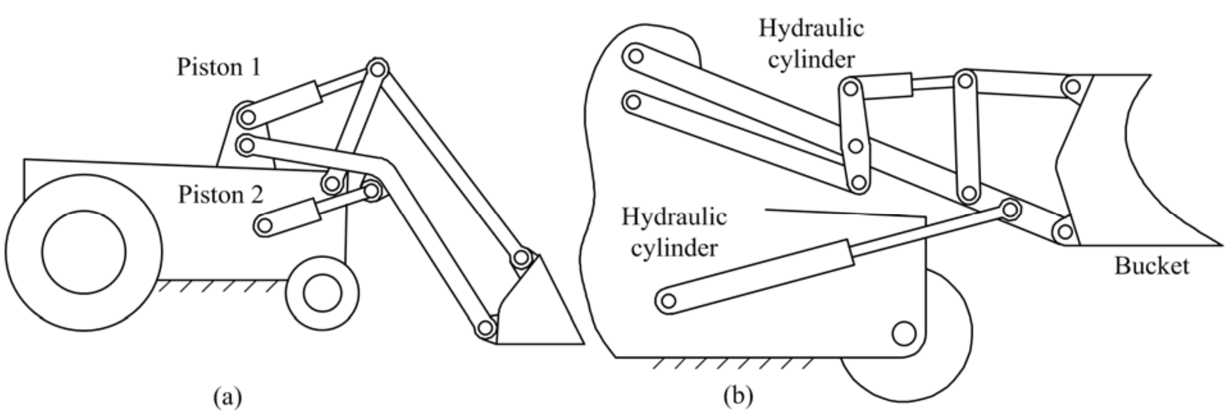
Solution:

$$n = 4$$
$$j = 4$$
$$M = 3(n - j - 1) + \sum f_i = 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1.
Idle DOF = 0
Assume that link 2 has a circular motion around link 3.

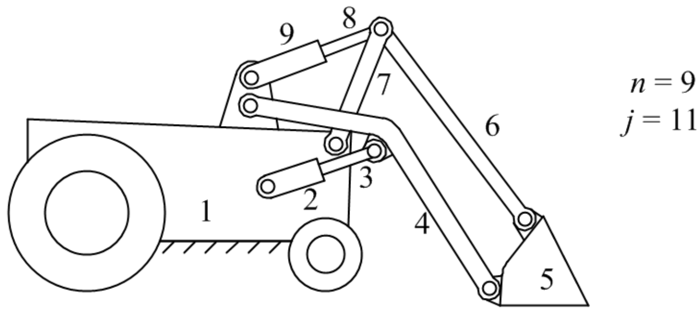
Problem 1.17

Determine the mobility of each of the planar linkages shown below. Show the equations used to determine your answers.



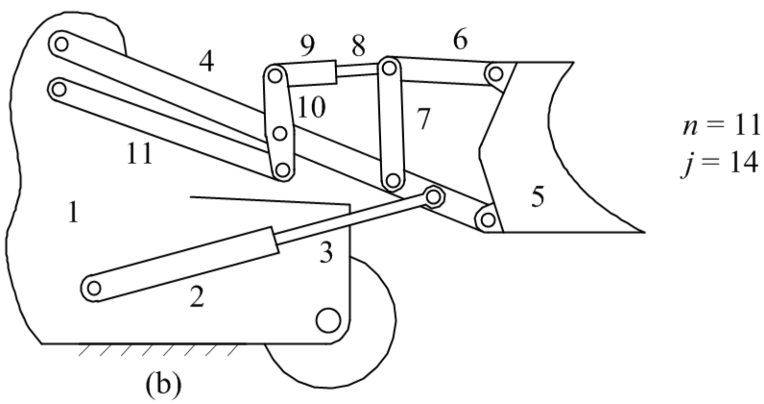
Solution:

(a)



$$M = 3(n - j - 1) + \sum f_i = 3(9 - 11 - 1) + 11 = -9 + 11 = 2$$

Mobility = 2.
Idle DOF = 0



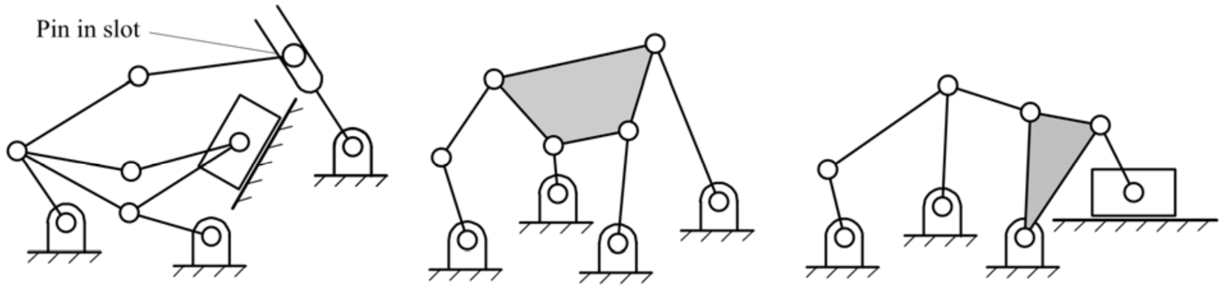
(b)

$$M = 3(n - j - 1) + \sum f_i = 3(11 - 14 - 1) + 14 = -12 + 14 = 2$$

Mobility = 2.
Idle DOF = 0

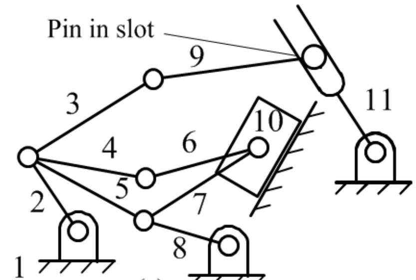
Problem 1.18

Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used to determine your answers.



(a) (b) (c)

Solution:



(a)

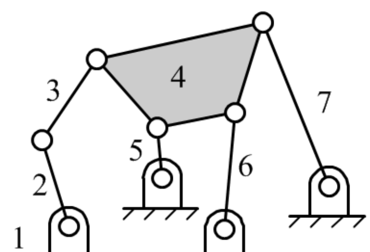
$n = 11$
$j = 14$

$\sum f_i = 13\times 1 + 1\times 2 = 15$

$M = 3(n - j - 1) + \sum f_i = 3(11 - 14 - 1) + 15 = -12 + 15 = 3$

Mobility = 3.

Idle DOF = 0



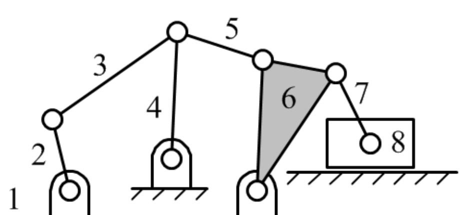
(b)

$n = 7$
$j = 9$

$M = 3(n - j - 1) + \sum f_i = 3(7 - 9 - 1) + 9 = -9 + 9 = 0$

Mobility = 0.

Idle DOF = 0



(c)

$n = 8$
$j = 10$

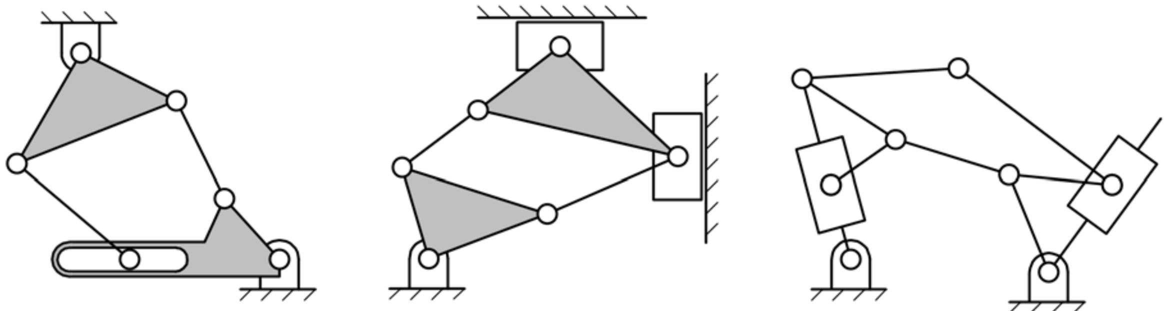
$M = 3(n - j - 1) + \sum f_i = 3(8 - 10 - 1) + 10 = -9 + 10 = 1$

Mobility = 1.

Idle DOF = 0

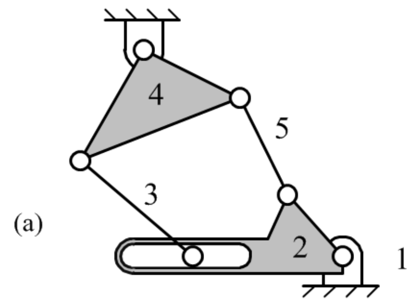
Problem 1.19

Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used to determine your answers.



(a) (b) (c)

<u>Solution:</u>

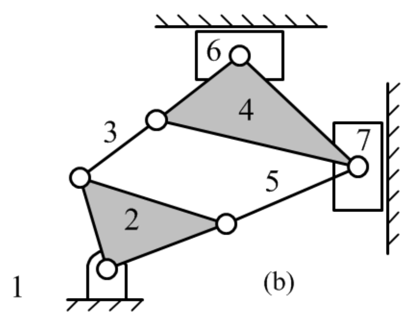


$n = 5$
$j = 6$

$\sum f_i = 5 \times 1 + 1 \times 2 = 7$

$M = 3(n - j - 1) + \sum f_i = 3(5 - 6 - 1) + 7 = -6 + 7 = 1$

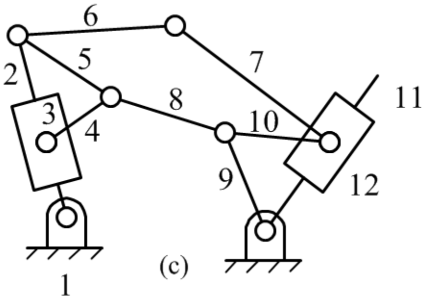
Mobility = 1.
Idle DOF = 0



$n = 7$
$j = 9$

$M = 3(n - j - 1) + \sum f_i = 3(7 - 9 - 1) + 9 = -9 + 9 = 0$

Mobility = 0.
Idle DOF = 0



$n = 12$
$j = 15$

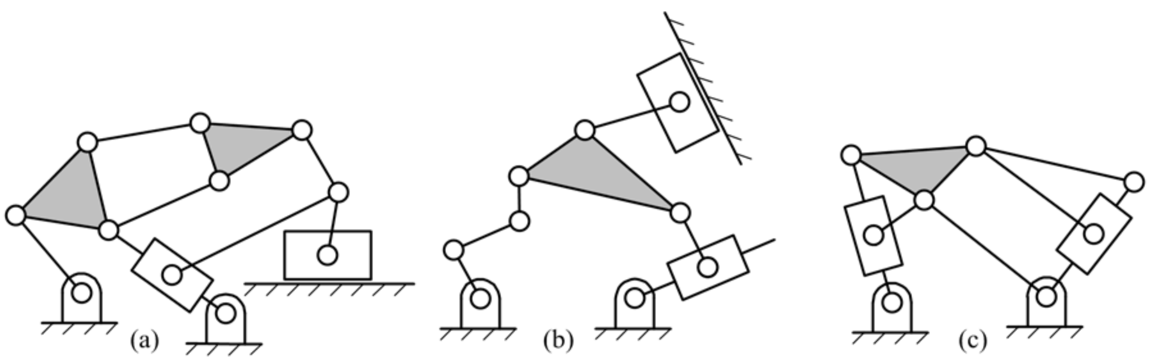
$$M = 3(n - j - 1) + \sum f_i = 3(12 - 15 - 1) + 15 = -12 + 15 = 3$$

Mobility = 3.
Idle DOF = 0

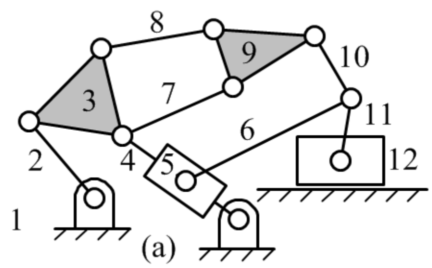
Problem 1.20

Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used to determine your answers.

Solution:



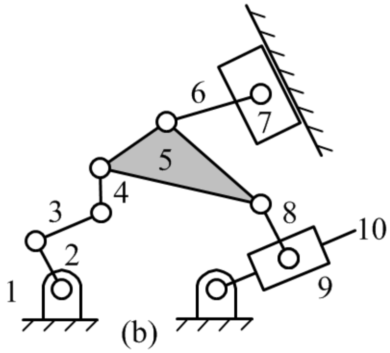
Solution:



$n = 12$
$j = 15$

$$M = 3(n - j - 1) + \sum f_i = 3(12 - 15 - 1) + 15 = -12 + 15 = 3$$

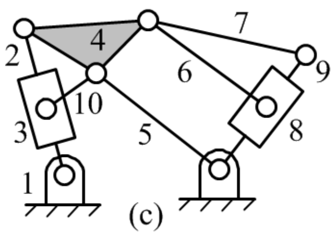
Mobility = 3.
Idle DOF = 0



$n = 10$
$j = 11$

$$M = 3(n - j - 1) + \sum f_i = 3(10 - 11 - 1) + 11 = -6 + 11 = 5$$

Mobility = 5.
Idle DOF = 0



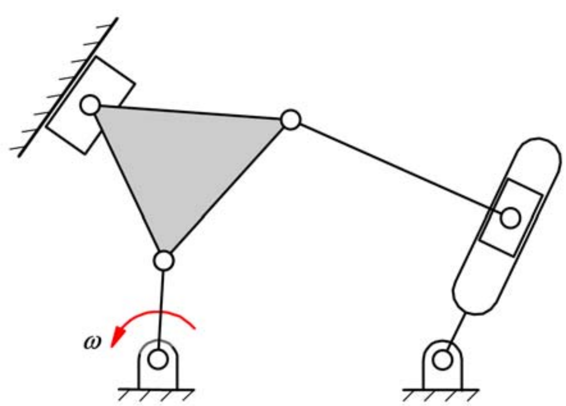
$n = 10$
$j = 13$

$$M = 3(n - j - 1) + \sum f_i = 3(10 - 13 - 1) + 13 = -12 + 13 = 1$$

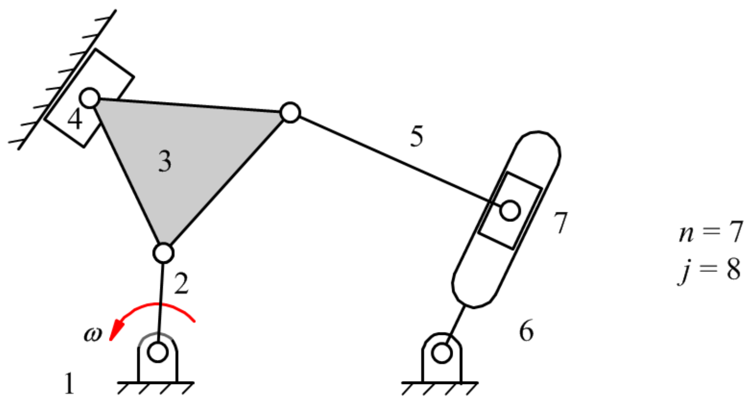
Mobility = 1.
Idle DOF = 0

Problem 1.21

If position information is available for all points in the planar linkage shown below, can all of the velocities be determined uniquely if the magnitude of ω is given?   Explain your answer.



Solution:



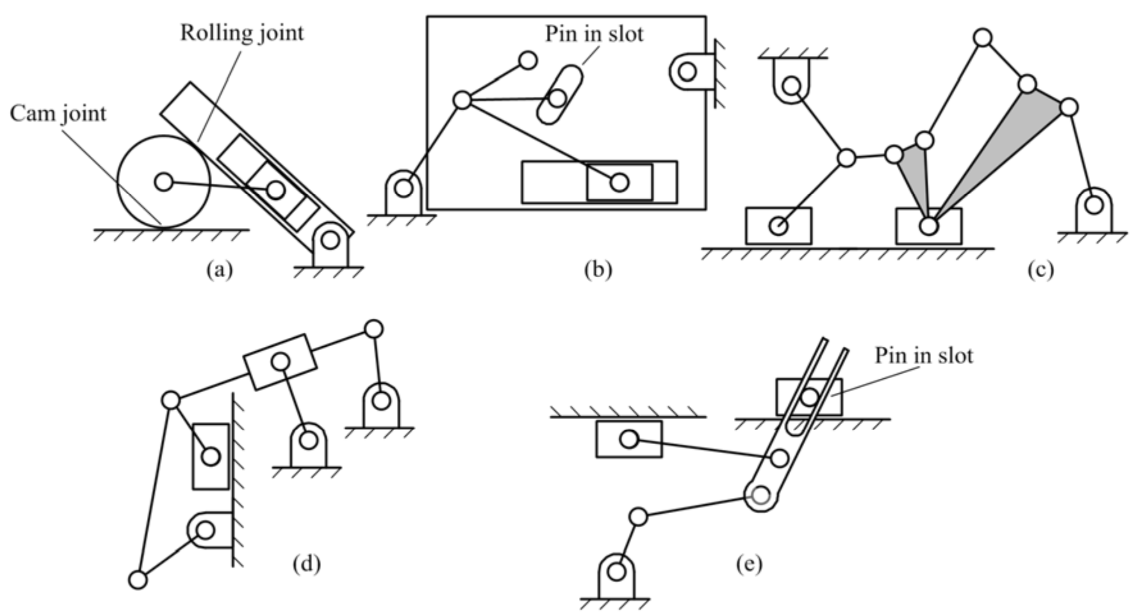
$$M = 3(n - j - 1) + \sum f_i = 3(7 - 8 - 1) + 8 = -6 + 8 = 2$$

Mobility = 2.

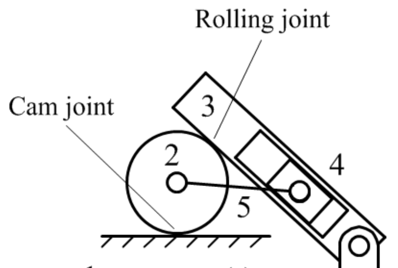
Therefore, the answer to the problem is no. The mechanism has two degrees of freedom, and two independent input variables must be specified before all of the velocities can be determined.

Problem 1.22

Determine the mobility and the number of idle degrees of freedom associated with each mechanism. Show the equations used and identify any assumptions made when determining your answers.



Solution:

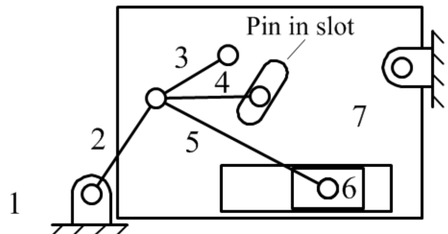


(a)

$n = 5$
$j = 6$

$$\sum f_i = 5\times1+1\times2=7$$
$$M = 3(n-j-1)+\sum f_i = 3(5-6-1)+7=-6+7=1$$

Mobility = 1.
Idle DOF = 0

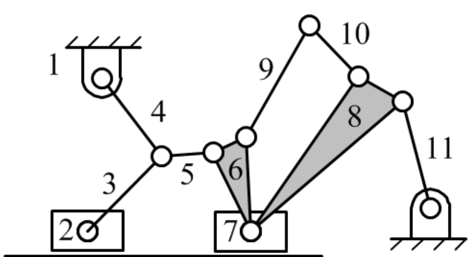


(b)

$n = 7$
$j = 9$

$$\sum f_i = 8\times1+1\times2=10$$
$$M = 3(n-j-1)+\sum f_i = 3(7-9-1)+10=-9+10=1$$

Mobility = 1.
Idle DOF = 0

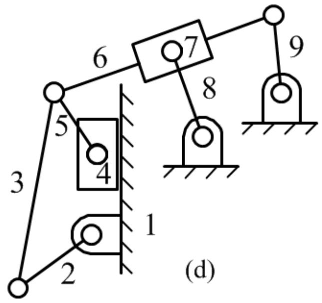


(c)

$n = 11$
$j = 14$

$$M = 3(n-j-1)+\sum f_i = 3(11-14-1)+14=-12+14=2$$

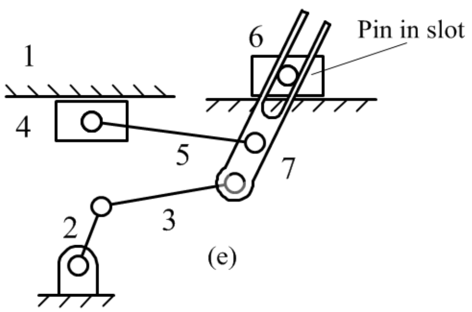
Mobility = 2.
Idle DOF = 0



$n = 9$
$j = 11$

$$M = 3(n - j - 1) + \sum f_i = 3(9 - 11 - 1) + 11 = -9 + 11 = 2$$

Mobility = 2.
Idle DOF = 0



$n = 7$
$j = 8$

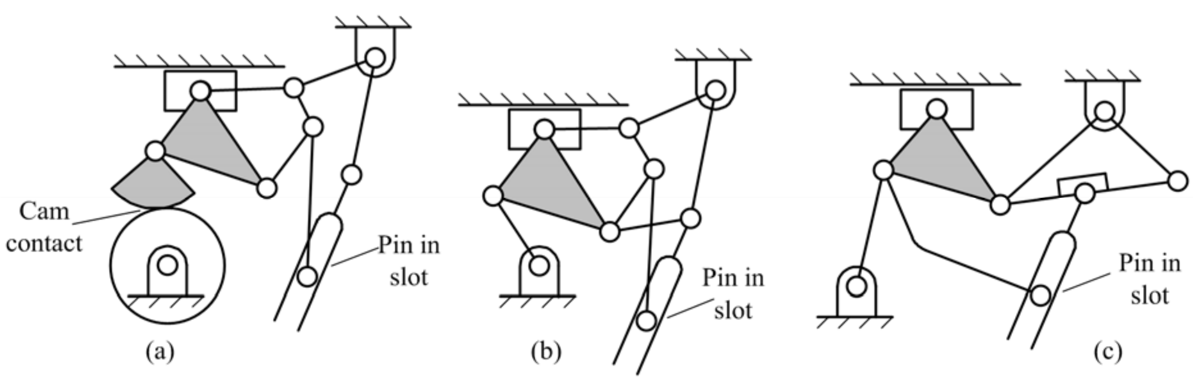
$$\sum f_i = 7 \times 1 + 1 \times 2 = 9$$

$$M = 3(n - j - 1) + \sum f_i = 3(7 - 8 - 1) + 9 = -6 + 9 = 3$$

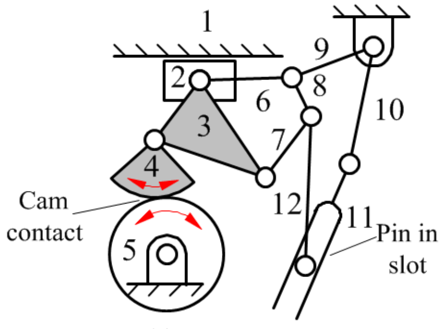
Mobility = 1.
Idle DOF = 0

Problem 1.23

Determine the mobility and the number of idle degrees of freedom for each of the mechanisms shown. Show the equations used and identify any assumptions made when determining your answers.



Solution:



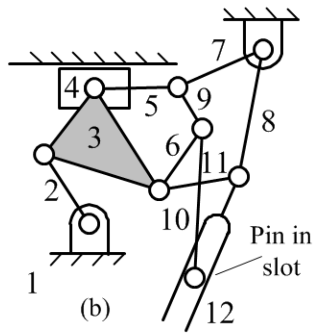
(a)

$n = 12$
$j = 15$

$$\sum f_i = 13 \times 1 + 2 \times 2 = 17$$

$$M = 3(n - j - 1) + \sum f_i = 3(12 - 15 - 1) + 17 = -12 + 17 = 5$$

Mobility = 5.
Idle DOF = 2



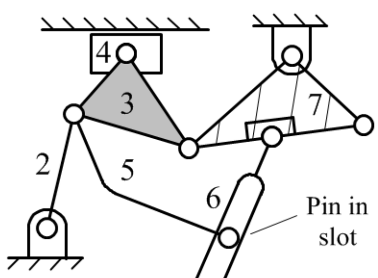
(b)

$n = 12$
$j = 16$

$$\sum f_i = 15 \times 1 + 1 \times 2 = 17$$

$$M = 3(n - j - 1) + \sum f_i = 3(12 - 16 - 1) + 17 = -15 + 17 = 2$$

Mobility = 2.
Idle DOF = 0



(c)

$n = 7$ Note: 3 links form a triangle which acts as 1 rigid body
$j = 9$

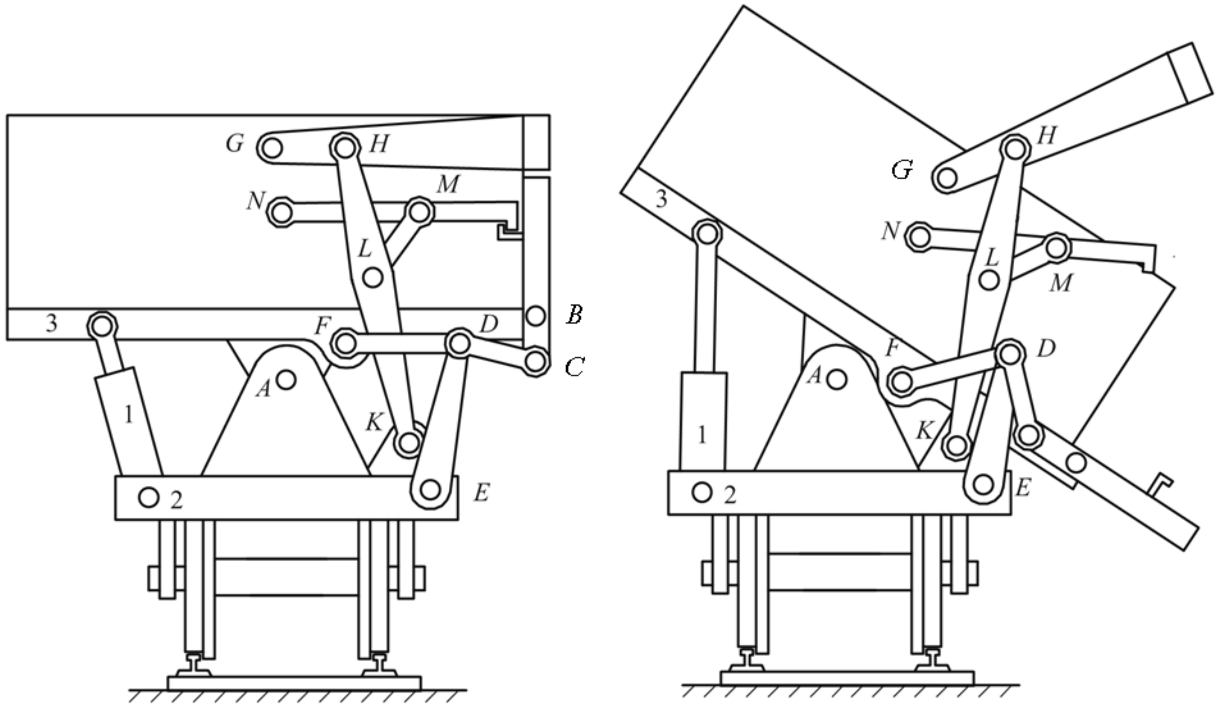
$$\sum f_i = 8 \times 1 + 1 \times 2 = 10$$

$$M = 3(n - j - 1) + \sum f_i = 3(7 - 9 - 1) + 10 = -9 + 10 = 1$$

Mobility = 1.
Idle DOF = 0

Problem 1.24

Determine the mobility and the number of idle degrees of freedom associated with the mechanism shown below. The mechanism is a side-dumping car that consists of body 2 and truck 3 connected together by two six-bar linkages, *ABCDEF* and *AGHKLMN*. Link *NM* is designed as a latch on its free end (see left drawing). When jack 1 is operated, body 3 is lifted to the dumping position shown in the right-hand drawing. Simultaneously, the six-bar linkage *AGHKLMN* opens the latch on link *NM* and raises link *GH*. Linkage *ABCDEF* swings open side *BC* and the load can be dumped at some distance from the car (see right-hand drawing). Show the equations used to determine your answers.

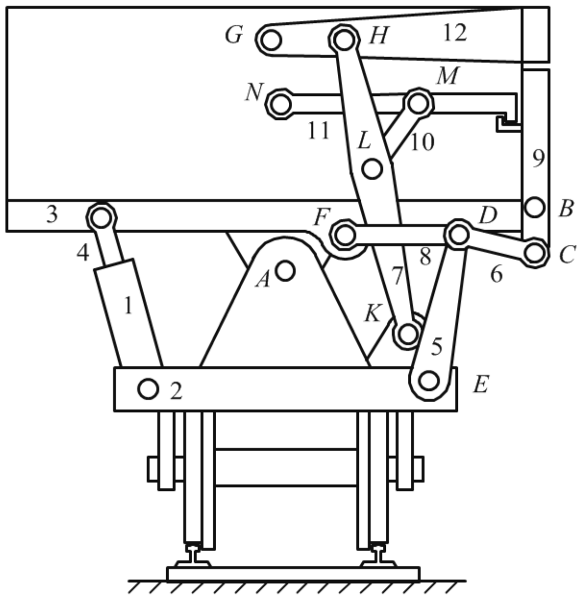


Solution:

The link numbers are shown in the figure below.

$$M = 3(n - j - 1) + \sum f_i = 3(12 - 16 - 1) + 16 = -15 + 16 = 1$$

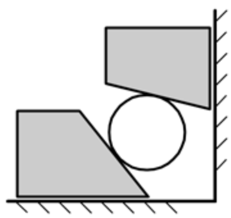
Mobility = 1.
Idle DOF = 0



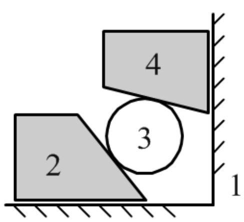
$n = 12$
$j = 16$

Problem 1.25

Determine the mobility and the number of idle degrees of freedom associated with the mechanism below. The round part rolls without slipping on the pieces in contact with it.



Solution:



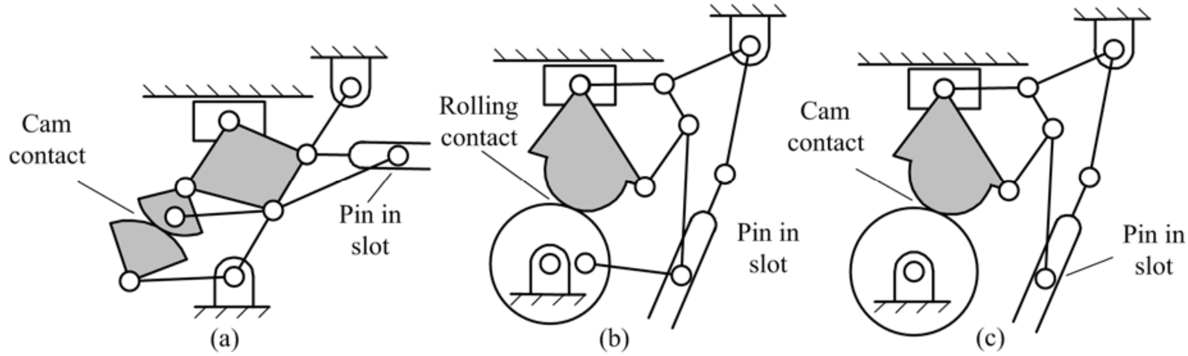
$n = 4$
$j = 4$

$$M = 3(n - j - 1) + \sum f_i = 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

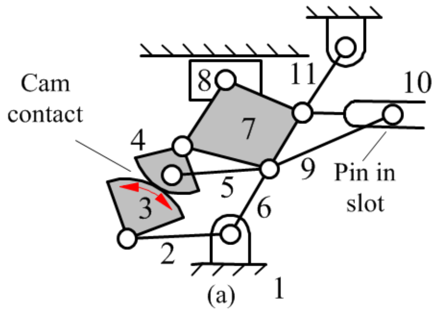
Mobility = 1.
Idle DOF = 0

Problem 1.26

Determine the mobility and the number of idle degrees of freedom for each of the mechanisms shown. Show the equations used to determine your answers.



Solution:

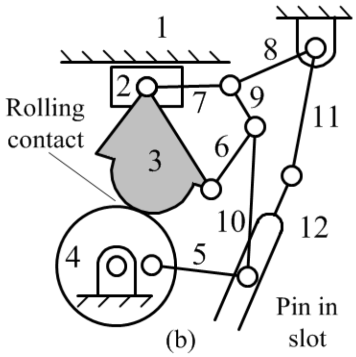


$n = 11$
$j = 15$

$$\sum f_i = 13 \times 1 + 2 \times 2 = 17$$

$$M = 3(n - j - 1) + \sum f_i = 3(11 - 15 - 1) + 17 = -15 + 17 = 2$$

Mobility = 2.
Idle DOF = 1

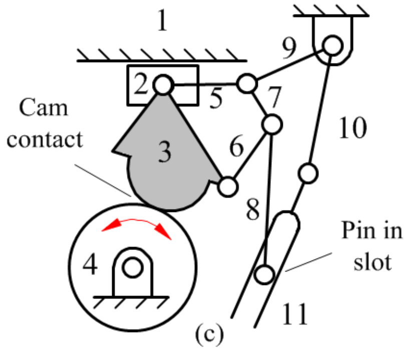


$n = 12$
$j = 16$

$$\sum f_i = 14 \times 1 + 2 \times 2 = 18$$

$$M = 3(n - j - 1) + \sum f_i = 3(12 - 16 - 1) + 18 = -15 + 18 = 3$$

Mobility = 3.
Idle DOF = 0



$n = 11$
$j = 14$

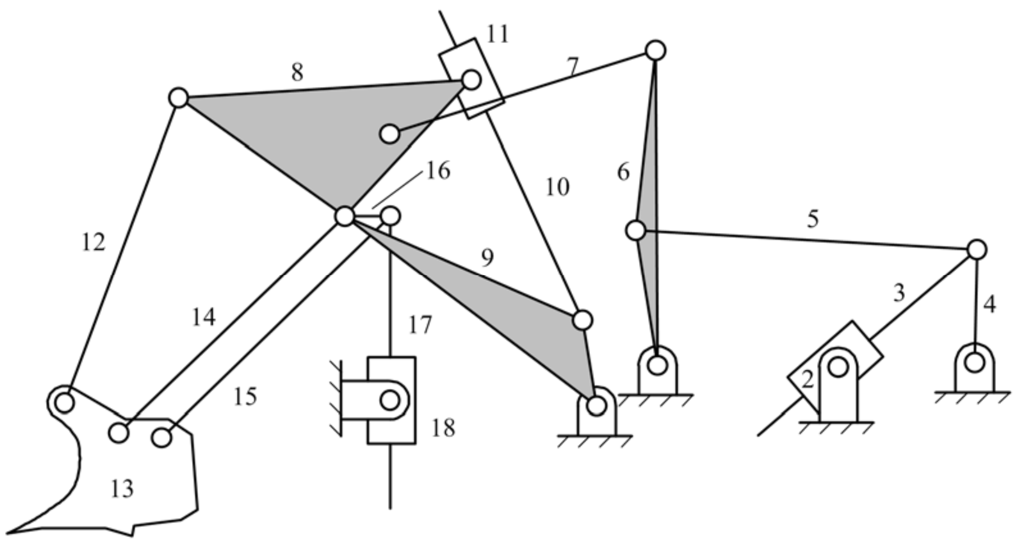
$$\sum f_i = 12 \times 1 + 2 \times 2 = 16$$

$$M = 3(n - j - 1) + \sum f_i = 3(11 - 14 - 1) + 16 = -12 + 16 = 4$$

Mobility = 4.
Idle DOF = 1

Problem 1.27

Determine the mobility and the number of idle degrees of freedom associated with the mechanism below. The figure is a schematic of the entire linkage for a large power shovel used in strip mining. It can cut into a bank 20 m high and can dump to a height of 14.5 m. Link 7 is connected to link 8 with a revolute joint.



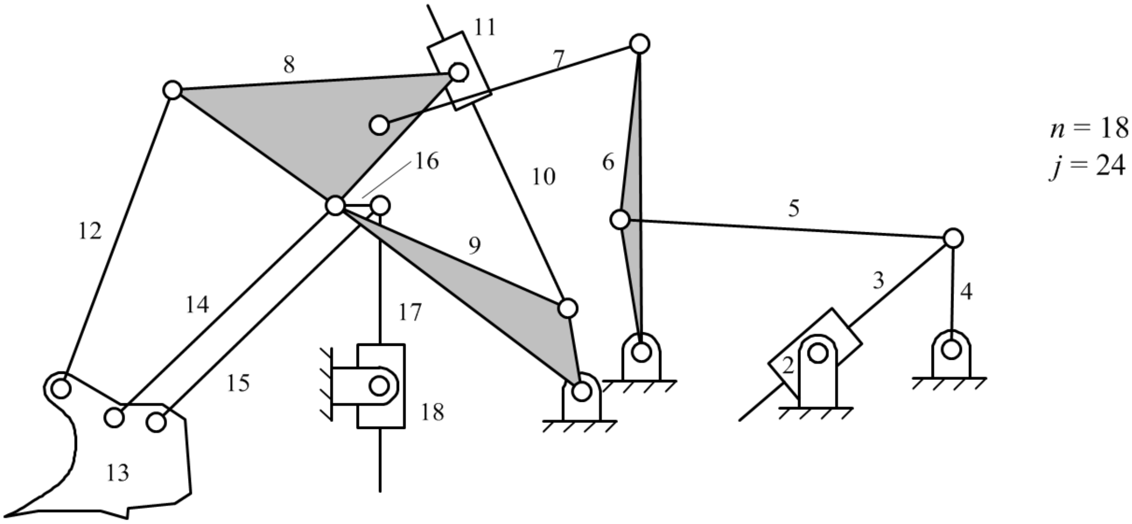
Solution:

The figure is redrawn on the following page with the link and joint numbers identified.

$$\sum f_i = 24 \times 1 = 24$$

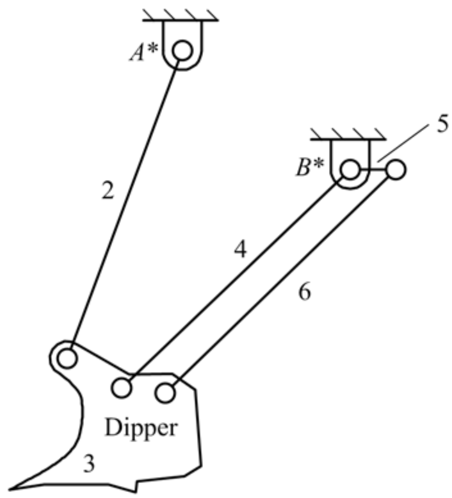
$$M = 3(n - j - 1) + \sum f_i = 3(18 - 24 - 1) + 24 = -21 + 24 = 3$$

Mobility = 3.
Idle DOF = 0



Problem 1.28

In the figure is a portion of the support mechanism for the dipper on a large earth-moving machine used in removing overburden in strip mining operations. The fixed centers for the portion of the mechanism really move, but useful information can be obtained by observing the dipper motion relative to the "frame" as shown in the sketch. Both links 4 and 5 are mounted at O_4. Links 4 and 6 are parallel and of equal length. The dipper is moved by a hydraulic cylinder driving crank 5 about its fixed cylinder. Determine the number of degrees of freedom of the mechanism.



Solution:

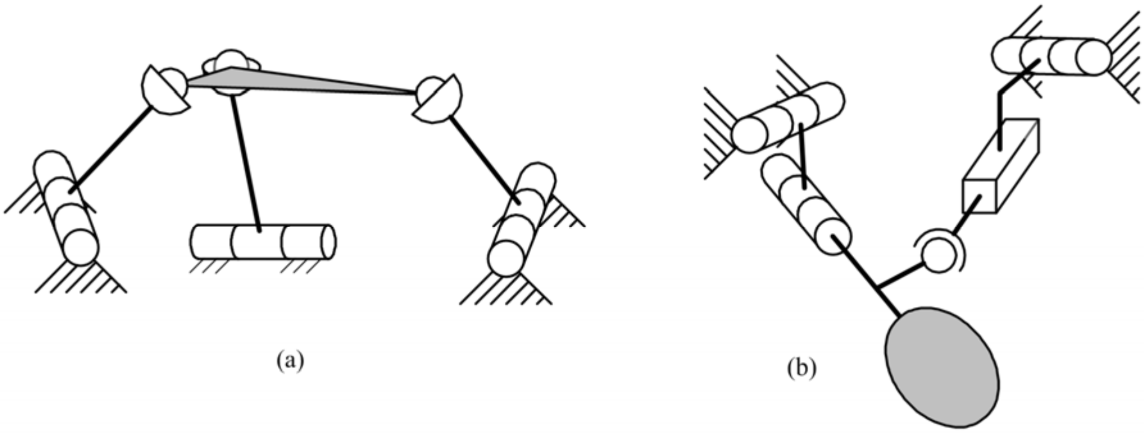
The figure is redrawn on the following page with the link and joint numbers identified.

$$M = 3(n - j - 1) + \sum f_i = 3(6 - 7 - 1) + 6 = -6 + 7 = 1$$

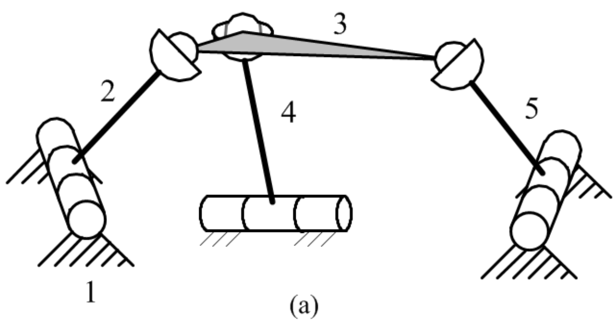
Mobility = 1.

Problem 1.29

What is the number of members, number of joints, mobility, and the number of idle degrees of freedom of each of the spatial linkages shown below?



<u>Solution:</u>

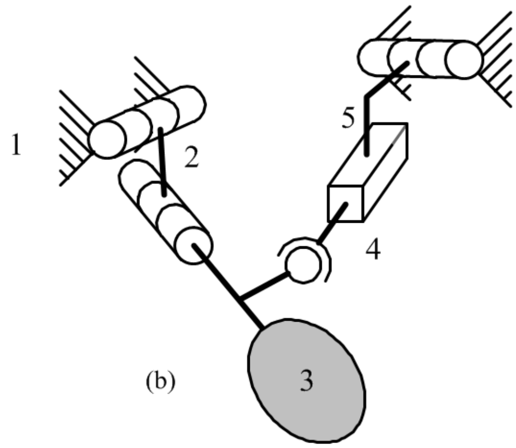


$n = 5$
$j = 6$

$$\sum f_i = 3\times3 + 3\times1 = 12$$

$$M = 6(n - j - 1) + \sum f_i = 6(5-6-1) + 12 = -12 + 12 = 0$$

Mobility = 0.
Idle DOF = 0



$n = 5$
$j = 5$

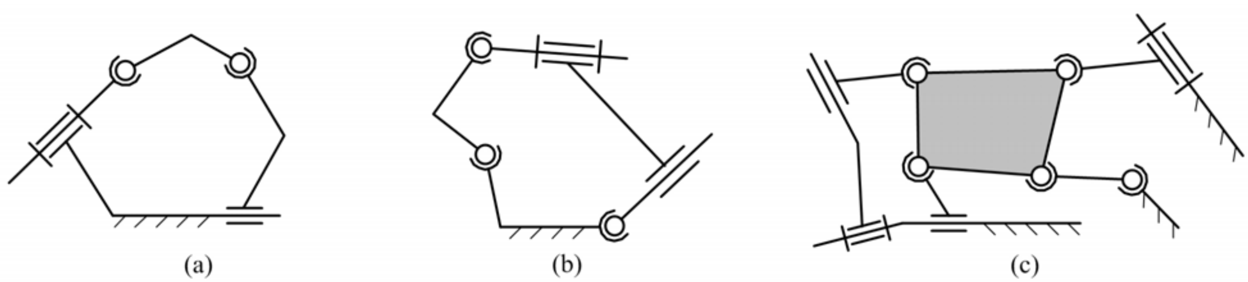
$$\sum f_i = 1\times 3 + 1\times 1 + 3\times 1 = 7$$

$$M = 6(n - j - 1) + \sum f_i = 6(5 - 5 - 1) + 7 = -6 + 7 = 1$$

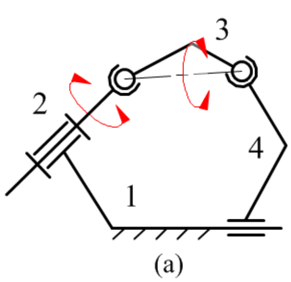
Mobility = 1.
Idle DOF = 0

Problem 1.30

Determine the mobility and the number of idle degrees of freedom of the spatial linkages shown below. Show the equations used to determine your answers.



Solution:

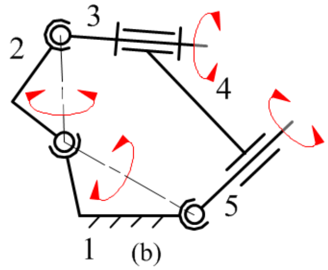


$n = 4$
$j = 4$

$$\sum f_i = 2\times 3 + 1\times 1 + 1\times 2 = 9$$

$$M = 6(n - j - 1) + \sum f_i = 6(4 - 4 - 1) + 9 = -6 + 9 = 3$$

Mobility = 3.
Idle DOF = 2

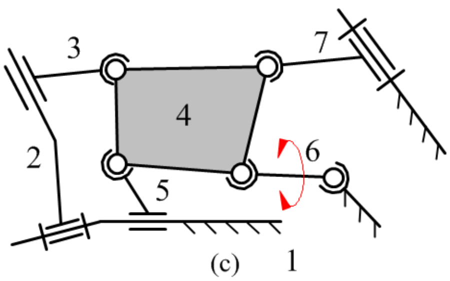


$n = 5$
$j = 5$

$$\sum f_i = 3\times3+1\times1+1\times2=12$$

$$M = 6(n-j-1)+\sum f_i = 6(5-5-1)+12=-6+12=6$$

Mobility = 6.
Idle DOF = 4



$n = 7$
$j = 9$

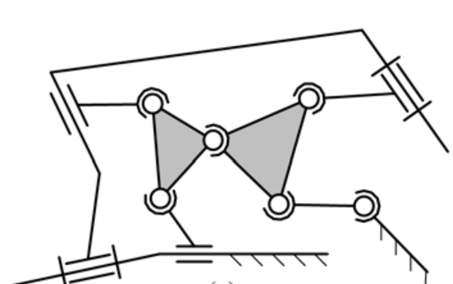
$$\sum f_i = 5\times3+2\times1+2\times2=21$$

$$M = 6(n-j-1)+\sum f_i = 6(7-9-1)+21=-18+21=3$$

Mobility = 3.
Idle DOF = 1

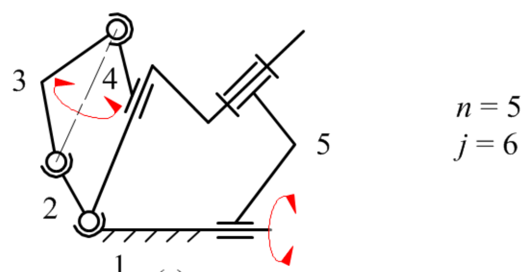
Problem 1.31

Determine the mobility and the number of idle degrees of freedom of the spatial linkages shown below. Show the equations used to determine your answers.



(a) (b) (c)

<u>Solution:</u>



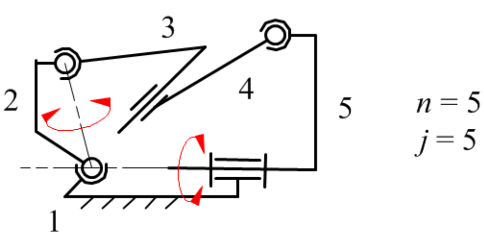
(a)

$$\sum f_i = 3\times3 + 2\times2 + 1\times1 = 14$$

$$M = 6(n - j - 1) + \sum f_i = 6(5-6-1) + 14 = -12 + 14 = 2$$

Mobility = 2.

Idle DOF = 2



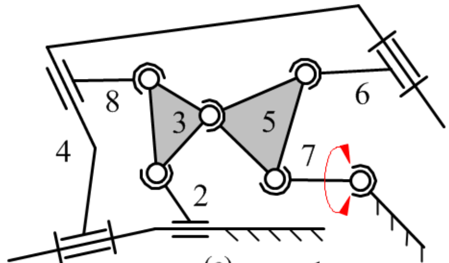
(b)

$$\sum f_i = 3\times3 + 1\times2 + 1\times1 = 12$$

$$M = 6(n - j - 1) + \sum f_i = 6(5-5-1) + 12 = -6 + 12 = 6$$

Mobility = 6.

Idle DOF = 2



(c)

$n = 8$
$j = 10$

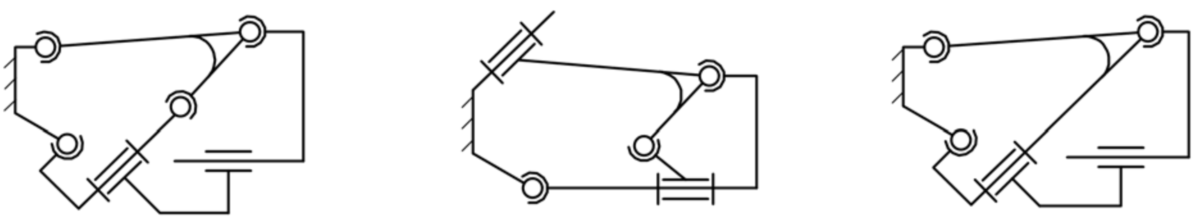
$$\sum f_i = 6\times3 + 2\times2 + 2\times1 = 24$$

$$M = 6(n - j - 1) + \sum f_i = 6(8 - 10 - 1) + 24 = -18 + 24 = 6$$

Mobility = 6.
Idle DOF = 1

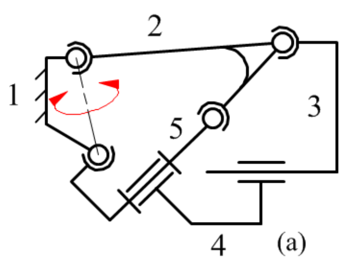
Problem 1.32

Determine the mobility and the number of idle degrees of freedom for each of the mechanisms shown. Show the equations used to determine your answers.



(a) (b) (c)

Solution:



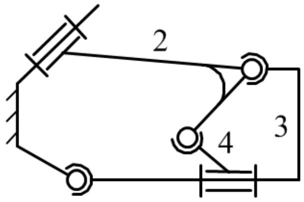
(a)

$n = 5$
$j = 6$

$$\sum f_i = 4\times3 + 1\times2 + 1\times1 = 15$$

$$M = 6(n - j - 1) + \sum f_i = 6(5 - 6 - 1) + 15 = -12 + 15 = 3$$

Mobility = 3.
Idle DOF = 1



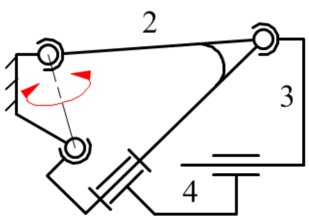
(b)

$n = 4$
$j = 5$

$$\sum f_i = 3\times 3 + 1\times 1 = 11$$

$$M = 6(n - j - 1) + \sum f_i = 6(4 - 5 - 1) + 11 = -12 + 11 = -1$$

Mobility = -1.
Idle DOF = 0



(c)

$n = 4$
$j = 5$

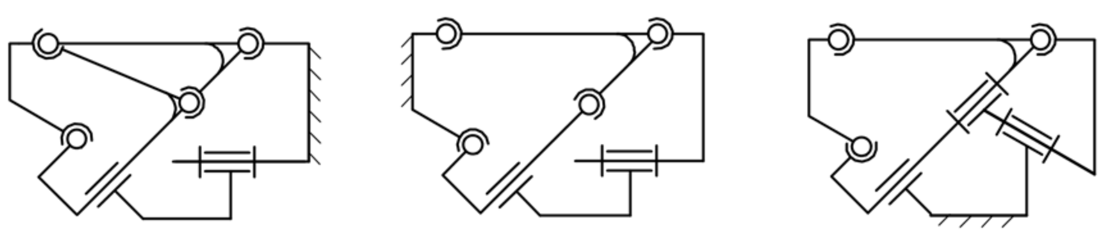
$$\sum f_i = 3\times 3 + 1\times 2 + 1\times 1 = 12$$

$$M = 6(n - j - 1) + \sum f_i = 6(4 - 5 - 1) + 12 = -12 + 12 = 0$$

Mobility = 0.
Idle DOF = 1

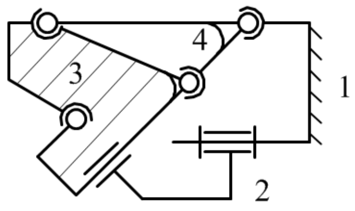
Problem 1.33

Determine the mobility and the number of idle degrees of freedom for each of the mechanisms shown. Show the equations used to determine your answers. For the idle degrees of freedom, identify the input and output links assumed.



(a) (b) (c)

Solution:



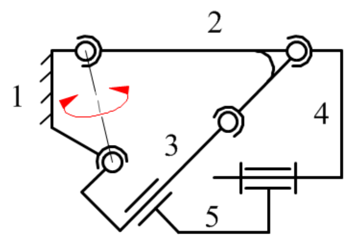
(a)

$n = 4$
$j = 5$

$\sum f_i = 3\times3+1\times2+1\times1=12$

$M = 6(n-j-1)+\sum f_i = 6(4-5-1)+12=-12+12=0$

Mobility = 0.
Idle DOF = 0



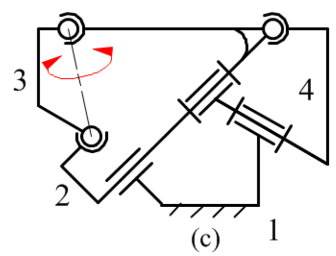
(b)

$n = 5$
$j = 6$

$\sum f_i = 4\times3+1\times2+1\times1=15$

$M = 6(n-j-1)+\sum f_i = 6(5-6-1)+15=-12+15=3$

Mobility = 3.
Idle DOF = 1



(c)

$n = 4$
$j = 6$

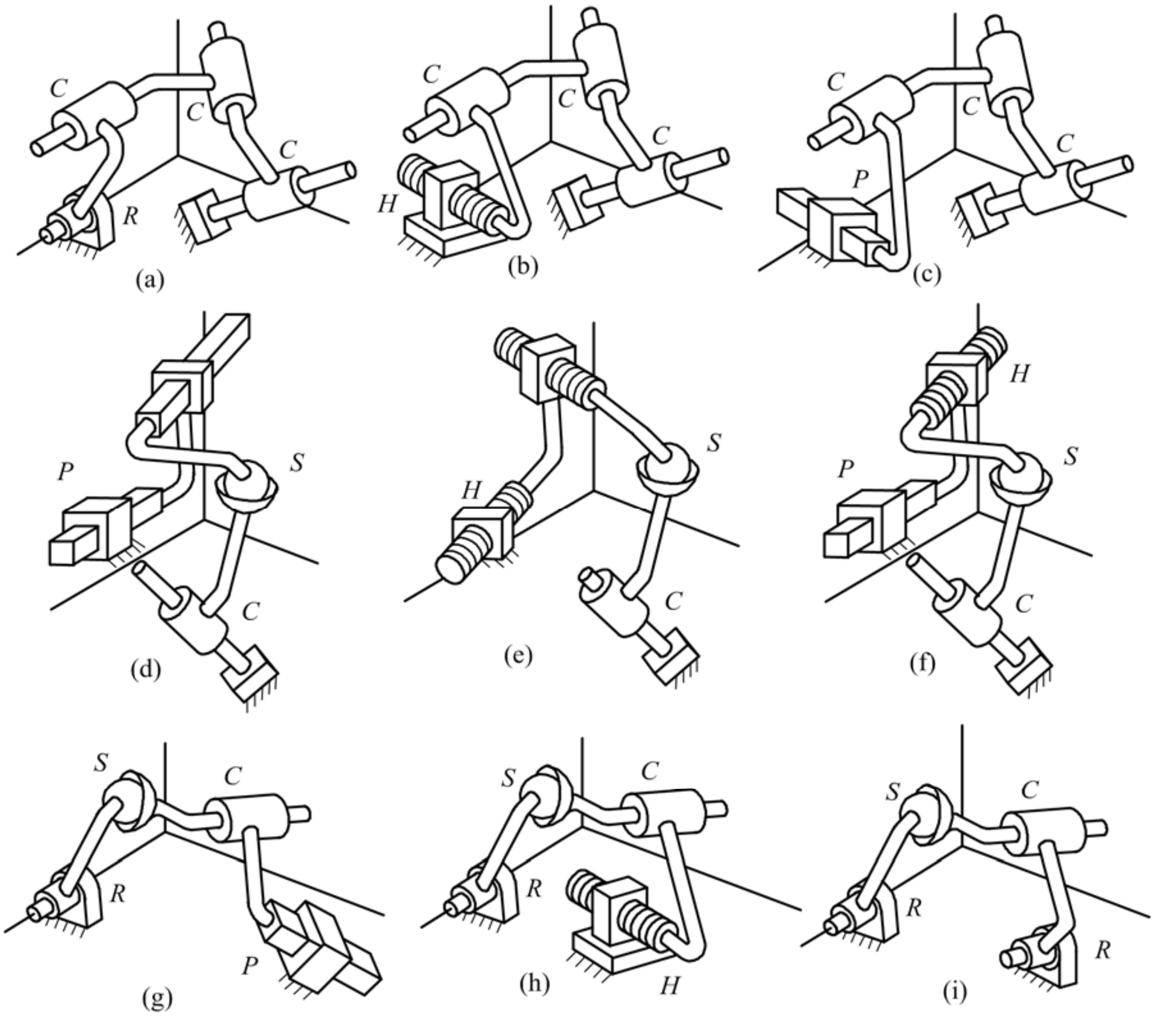
$\sum f_i = 3\times3+1\times2+2\times1=13$

$M = 6(n-j-1)+\sum f_i = 6(4-6-1)+13=-18+13=-5$

Mobility = -5.
Idle DOF = 1

Problem 1.34

Determine the mobility and the number of idle degrees of freedom associated with each mechanism[1]. Show the equations used to determine your answers.



[1] Problem based on paper entitled "A Number Synthesis Survey of Three-Dimensional Mechanisms" by L. Harrisberger, Trans. *ASME, J. of Eng. for Ind.*, May, 1965, pp. 213-220.

<u>Solution:</u>

Each of the mechanisms in this problem has 4 links and 4 joints. Therefore, the mobility is defined by the degrees of freedom of each joint. The individual cases are analyzed in the following:

a) $n = 4$

$j = 4$
$\sum f_i = 3\times 2 + 1\times 1 = 7$
$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$
Mobility = 1.
Idle DOF = 0

b) $n = 4$
$j = 4$
$\sum f_i = 3\times 2 + 1\times 1 = 7$
$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$
Mobility = 1.
Idle DOF = 0

c) $n = 4$
$j = 4$
$\sum f_i = 3\times 2 + 1\times 1 = 7$
$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$
Mobility = 1.
Idle DOF = 0

d) $n = 4$
$j = 4$
$\sum f_i = 1\times 3 + 1\times 2 + 2\times 1 = 7$
$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$
Mobility = 1.
Idle DOF = 0

e) $n = 4$
$j = 4$
$\sum f_i = 1\times 3 + 1\times 2 + 2\times 1 = 7$
$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$
Mobility = 1.
Idle DOF = 0

f) $n = 4$
$j = 4$
$\sum f_i = 1\times 3 + 1\times 2 + 2\times 1 = 7$
$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$
Mobility = 1.
Idle DOF = 0

g) $n = 4$
$j = 4$

$\sum f_i = 1\times3 + 1\times2 + 2\times1 = 7$

$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$

Mobility = 1.
Idle DOF = 0

h) $n = 4$

$j = 4$

$\sum f_i = 1\times3 + 1\times2 + 2\times1 = 7$

$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$

Mobility = 1.
Idle DOF = 0

i) $n = 4$

$j = 4$

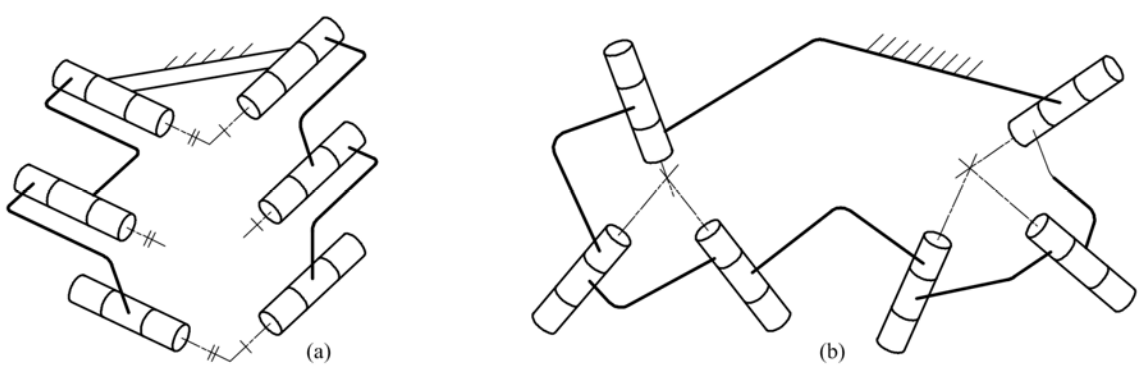
$\sum f_i = 1\times3 + 1\times2 + 2\times1 = 7$

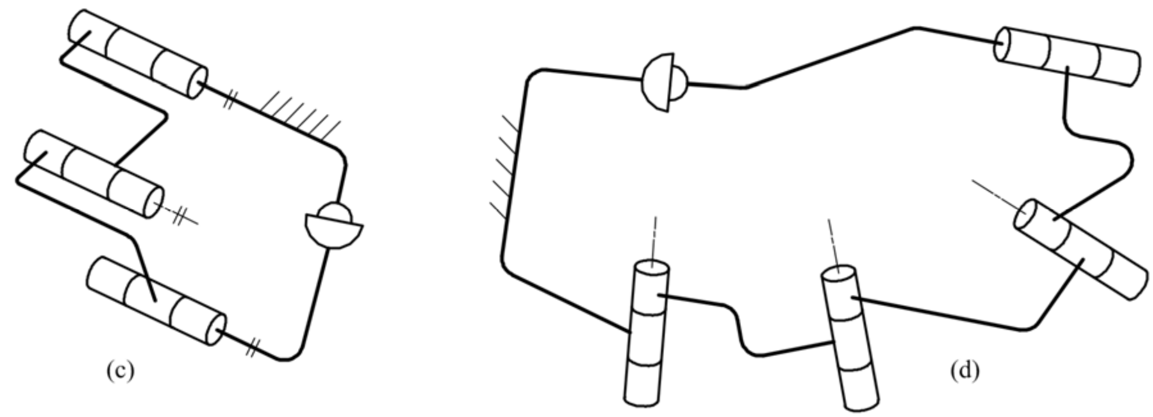
$M = 6(n - j - 1) + \sum f_i = 6(4-4-1) + 7 = -6 + 7 = 1$

Mobility = 1.
Idle DOF = 0

Problem 1.35

In the spatial linkages shown, (a) through (d) are all known to have mobility 1. The joints are revolute in all cases except for one spherical joint in each of (c) and (d). In each case determine if the linkage is properly constrained or overconstrained. Justify your answers. If the linkage is overconstrained, what geometrical specializations can you see that might result in mobility.





Solution:

(a) Note that 6R closed-chain linkages have mobility zero, since $n = j = 6$ and $\sum_{i=1}^{j} f_i = 6$. As a result, one would not expect mobility of the system. However, the mechanism shown has the following features: (i) first three joint axes are parallel, (ii) last three axes are parallel. These features provide the special mobility to this mechanism.

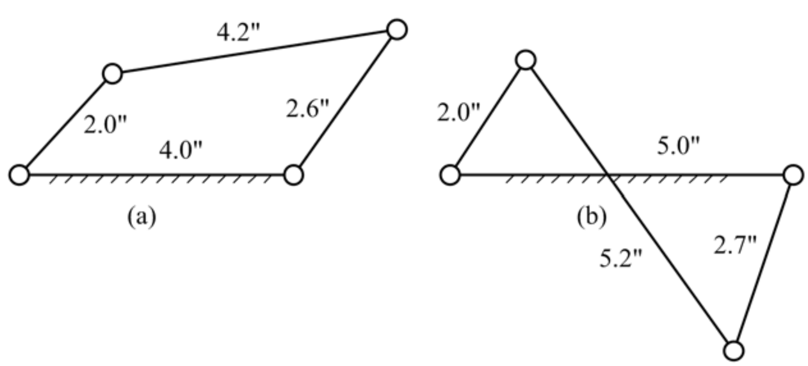
(b) Similar argument applies as (a). However, the first three joints intersect at a point and similarly the last three axes intersect at a point. This is similar to the wrist structure found in most industrial robots. The special mobility comes from this feature.

(c) Similar argument applies as (a). However, the first three axes are parallel to each other while the last three joints intersect at the center of the spherical joint. The special mobility comes from this feature making it behave similar to a planar 4 bar mechanism.

(d) This system can be thought of as a 7R closed-chain linkage with the spherical joint acting as the wrist. The mobility of such a system is 1. This can be verified by the formula, $M = 6(5-5-1)+(3+4\times 1)=1$, where n=j=5.

Problem 1.36

Determine which (if either) of the following linkages can be driven by a constant-velocity motor. For the linkage(s) that can be driven by the motor, indicate the driver link.



Solution:

a) Check the Grashof type

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

s=2.0; $\ell = 4.2$; $p = 2.6$; $q = 4.0$

$2.0+4.2 < 2.6+4.0 \Rightarrow 6.2 < 6.6 \Rightarrow \text{Grashof type 1}$

The mechanism is a crank rocker if the 2" crank is the driver.

b) Check the Grashof type

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

s=2.0; $\ell = 5.2$; $p = 2.7$; $q = 5.0$

$2.0+5.2 < 2.7+5.0 \Rightarrow 7.2 < 7.7 \Rightarrow \text{Grashof type 1}$

The mechanism is a crank rocker if the 2" crank is the driver.

Problem 1.37

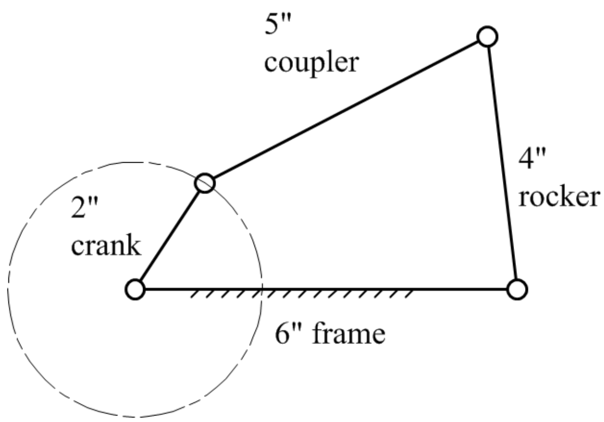
Assume that you have a set of links of the following lengths: 2 in, 4 in, 5 in, 6 in, 9 in. Design a 4-bar linkage that can be driven with a continuously rotating electric motor. Justify your answer with appropriate equations, and make a scaled drawing of the linkage. Label the crank, frame, coupler, and rocker (follower).

Solution:

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

s=2; $\ell = 6$; $p = 4$; $q = 5$

$2+6 < 4+5 \Rightarrow 8 < 9 \Rightarrow \text{Grashof type 1}$



Problem 1.38

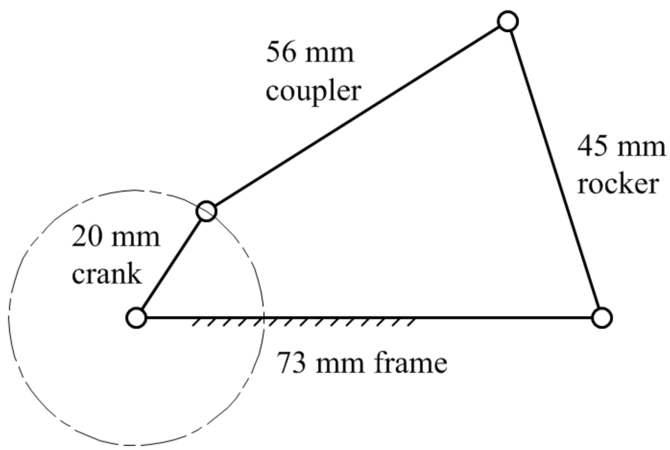
Assume that you have a set of links of the following lengths: 20 mm, 30 mm, 45 mm, 56 mm, 73 mm. Design a four-bar linkage that can be driven with a continuous-rotation electric motor. Justify your answer with appropriate equations, and make a freehand sketch (labeled) of the resulting linkage. Label the crank, frame, coupler, and rocker (follower).

<u>Solution:</u>

$s + \ell < p + q \Rightarrow$ Grashof type 1

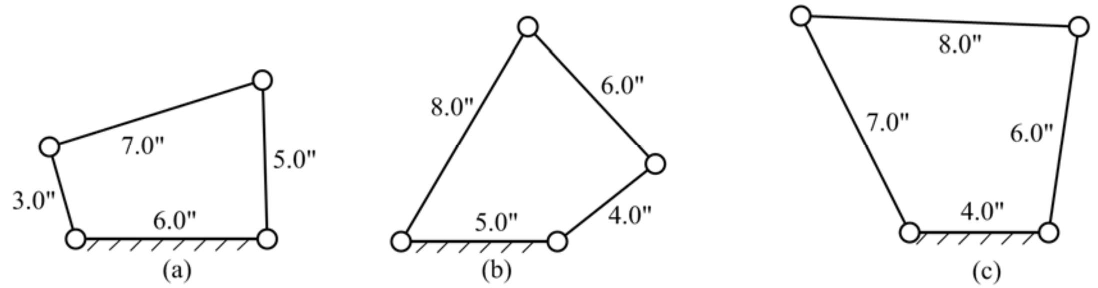
s=20; $\ell = 73$; $p = 45$; $q = 56$

$20 + 73 < 45 + 56 \Rightarrow 93 < 101 \Rightarrow$ Grashof type 1



Problem 1.39

For the four-bar linkages below, indicate whether they are Grashof type 1 or 2 and whether they are crank-rocker, double-crank, or double-rocker mechanisms.



Solution:

a)

$$s+\ell < p+q \Rightarrow \text{Grashof type 1}$$

$$s+\ell > p+q \Rightarrow \text{nonGrashof type 2}$$

$$s=3;\ \ \ell = 7;\ \ p = 6;\ \ q = 5$$

$$3+7 < 5+6 \Rightarrow 10 < 11 \Rightarrow \text{Grashof type 1}$$

Since the shortest member is connected to the frame, the linkage is a crank rocker

b)

$$s+\ell < p+q \Rightarrow \text{Grashof type 1}$$

$$s+\ell > p+q \Rightarrow \text{nonGrashof type 2}$$

$$s=4;\ \ \ell = 8;\ \ p = 5;\ \ q = 6$$

$$4+8 > 5+6 \Rightarrow 12 > 11 \Rightarrow \text{nonGrashof type 2}$$

All Grashof type 2 linkages are double rockers

c)

$$s+\ell < p+q \Rightarrow \text{Grashof type 1}$$

$$s+\ell > p+q \Rightarrow \text{nonGrashof type 2}$$

$$s=4;\ \ \ell = 8;\ \ p = 6;\ \ q = 7$$

$$4+8 < 6+7 \Rightarrow 12 < 13 \Rightarrow \text{Grashof type 1}$$

Since the shortest member is the frame, the linkage is a double crank or drag link mechanism

Problem 1.40

You are given a set of three links with lengths 2.4 in, 7.2 in, and 3.4 in. Select the length of a fourth link and assemble a linkage that can be driven by a continuously rotating motor. Is your linkage a Grashof type 1 or Grashof type 2 linkage? (Show your work.) Is it a crank-rocker, double-rocker, or double-crank linkage? Why?

Solution:

Let: ℓ = 7.2 in

s = 2.4 in

p = 3.4 in

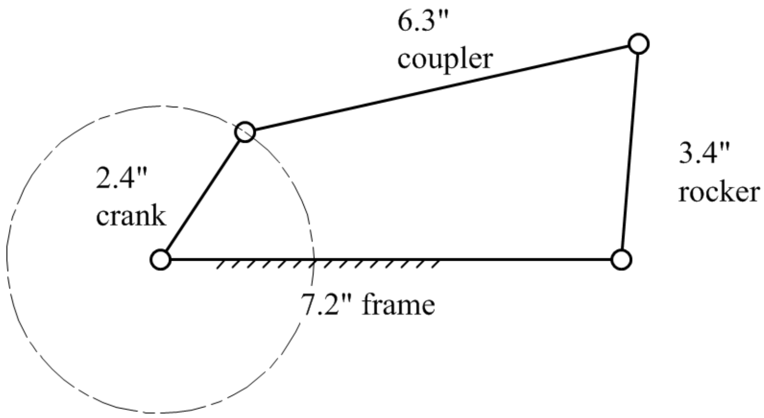
q = x in

$s + \ell < p + q \Rightarrow$ Grashof type 1

$2.4 + 7.2 < 3.4 + x$

$9.6 < 3.4 + x \Rightarrow x > 6.2$

Let $x = 6.3$



Problem 1.41

You have available a set of eight links from which you are to design a four-bar linkage. Choose the links such that the linkage can be driven by a continuous-rotation motor. Sketch the linkage and identify the type of four-bar mechanism resulting.

L_1 = 2”, L_2 = 3”, L_3 = 4”, L_4 = 6”, L_5 = 7”, L_6 = 9.5”, L_7 = 13”, and L_8 = 9”

Solution:

Let:

ℓ = 9.5 in

$s = 3.0$ in

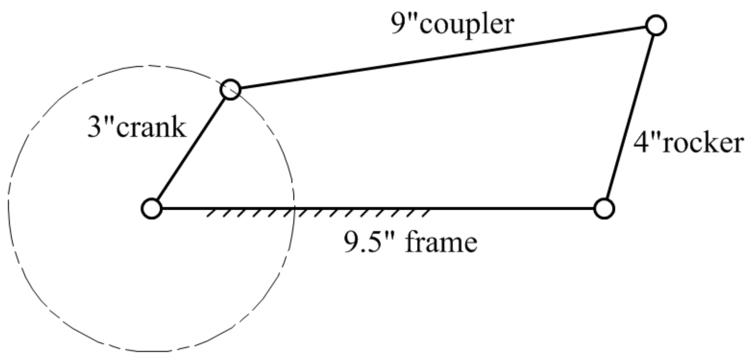
$p = 9.0$ in

$q = 4.0$ in

$s + \ell < p + q \Rightarrow$ Grashof type 1

$3 + 9.5 < 4 + 9$

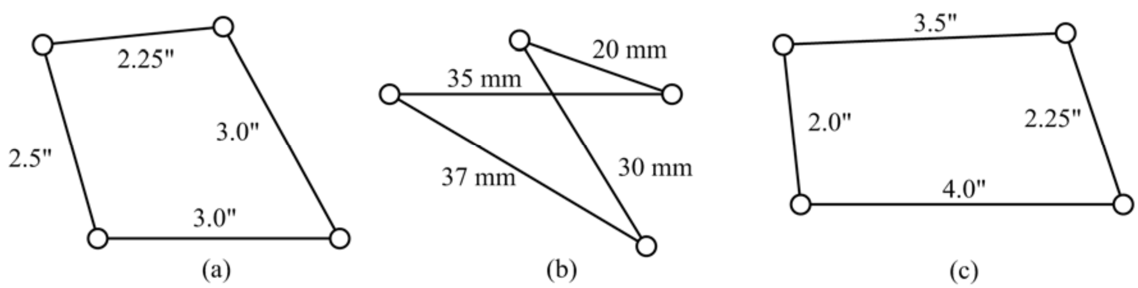
$12.5 < 13$



Since the shortest link is the driver, the mechanism is a crank-rocker.

Problem 1.42

Determine the number of fully rotating cranks in the planar mechanisms shown below. Show your calculations.



Solution:

(a) ℓ = 3.0 in

s = 2.25 in

p = 3.0 in

q = 2.5 in

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

$3+2.25 < 3+2.5$

$5.25 < 5.5$

Choosing s as the frame results in a double rocker with two fully rotating cranks.

Choosing ℓ, p or q as the frame results in a crank rocker or double rocker with one or zero rotating cranks, respectively.

(b) ℓ = 37.0 mm

s = 20.0 mm

p = 35.0 mm

q = 30.0 mm

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

$37+20 < 35+30$

$57 < 65$

Choosing s as the frame results in a double rocker with two fully rotating cranks.

Choosing ℓ, p or q as the frame results in a crank rocker or double rocker with one or zero rotating cranks, respectively.

(c) ℓ = 4.0 in

s = 2.0 in

p = 3.5 in

q = 2.25 in

$s+\ell > p+q \Rightarrow \text{nonGrashof type 2}$

$4+2 > 3.5+2.25$

$6 > 5.75$

No link can rotate fully. The mechanism is a type 2 double rocker.

Problem 1.43

If the link lengths of a four-bar linkage are L_1 = 1 mm, L_2 = 3 mm, L_3 = 4 mm, and L_4 = 5 mm and link 1 is fixed, what type of four-bar linkage is it? Also, is the linkage a Grashof type 1 or 2 linkage? Answer the same questions if L_1 = 2 mm.

Solution:

a)

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

$s+\ell > p+q \Rightarrow \text{nonGrashof type 2}$

$\text{s=1};\ \ell = 5;\ \ p=3;\ \ q=4$

$1+5<3+4 \Rightarrow 6<7 \Rightarrow \text{Grashof type 1}$

Since the shortest member is the frame, the linkage is a double crank

b)

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

$s+\ell > p+q \Rightarrow \text{nonGrashof type 2}$

$\text{s=2};\ \ell = 5;\ \ p=3;\ \ q=4$

$2+5=3+4 \Rightarrow 7=7 \Rightarrow \text{Transition Linkage}$

This is a transition linkage. The driver can rotate 360˚, but at the dead center position, the linkage must be "helped" to continue the rotation.

Problem 1.44

You are given two sets of links. Select four links from each set such that the coupler can rotate fully with respect to the others. Sketch the linkage and identify the type of four-bar mechanism.

a) L_1 = 5”, L_2 = 8”, L_3 = 15”, L_4 = 19”, and L_5 = 28”

b) L_1 = 5”, L_2 = 2”, L_3 = 4”, L_4 = 3.5”, and L_5 = 2.5”

Solution:

(a) Let: ℓ = 28.0 in

s = 5.0 in

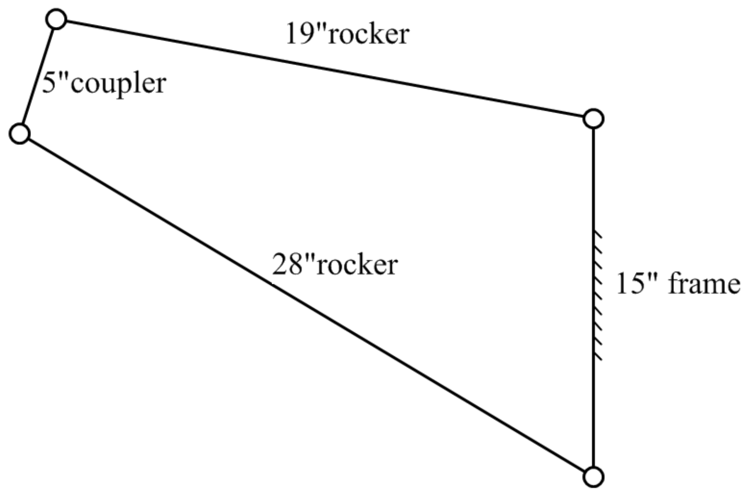
p = 19.0 in

q = 15.0 in

$s+\ell < p+q \Rightarrow \text{Grashof type 1}$

$5+28<15+19$

$33<34$



Since the shortest link is the coupler, the mechanism is a type 1 double-rocker.

(b) Let: ℓ = 5.0 in

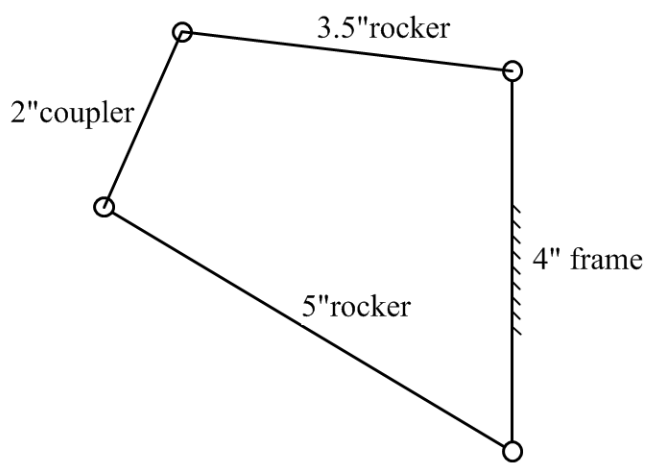
s = 2.0 in

p = 4.0 in

q = 3.5 in

$s + \ell < p + q \Rightarrow$ Grashof type 1

$2 + 5 < 3.5 + 4 \Rightarrow 7 < 7.5$



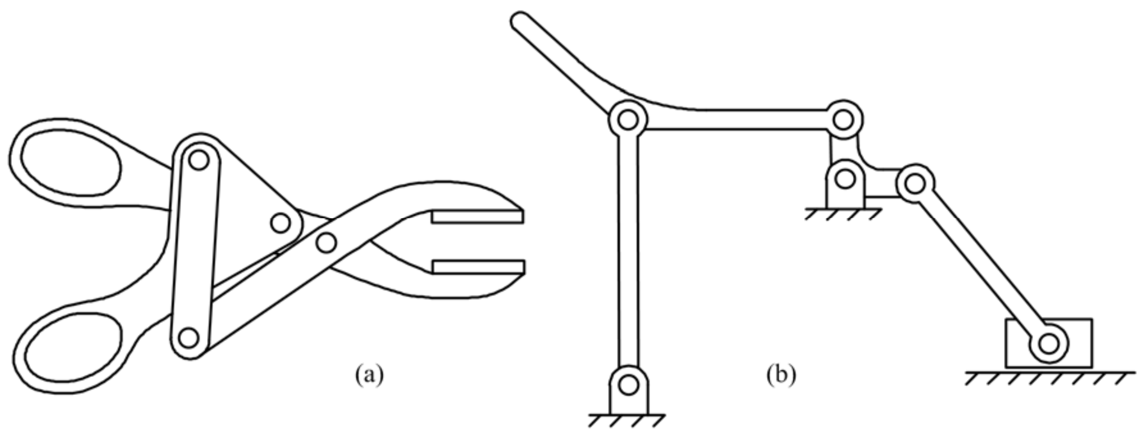
Since the shortest link is the coupler, the mechanism is a type 1 double-rocker.

Problem 1.45

The mechanisms shown below are drawn to scale.

(a) Sketch kinematic schematics showing the relationships between the members and joints.

(b) Determine the Grashof type of each four-bar linkage in each mechanism.



Solution:

(a) ℓ = 0.93 in

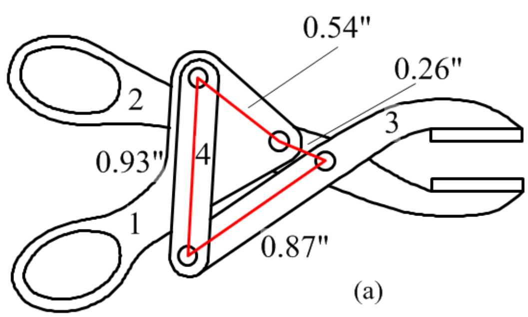
s = 0.26 in

p = 0.54 in

q = 0.87 in

$s+\ell < p+q \Rightarrow$ Grashof type 1

$0.26+0.93 < 0.54+0.87 \Rightarrow 1.19 < 1.41$



The mechanism is a crank rocker if link 1 or link 3 is fixed and link 2 is the driver.

(b) Links 1-2-3-4

ℓ = 1.56 in

Links 4-5-6-1

a = 0.37 in

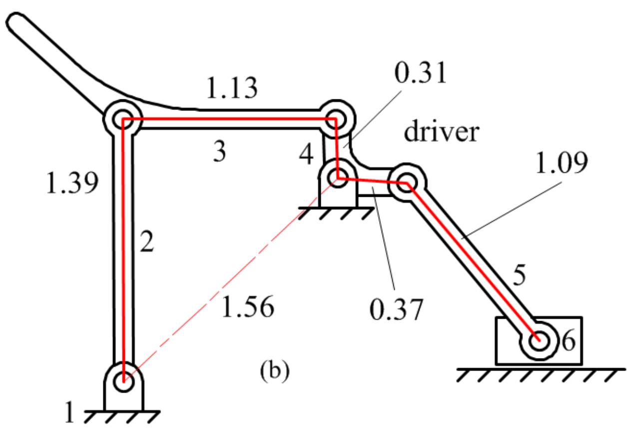
s = 0.31 in

p = 1.13 in

q = 1.39 in

b = 1.09 in

c = 0.86 in



$s + \ell < p + q \Rightarrow$ Grashof type 1

Links 1-2-3-4

$0.31 + 1.56 < 1.13 + 1.39 \Rightarrow 1.87 < 2.52$

Links 1-4-5-6

$1.09 > 0.37 \Rightarrow b > a$

$1.09 - 0.37 < 0.86 \Rightarrow b - a < c$

The mechanism containing links 1-2-3-4 is a crank-rocker mechanism because link 4 is the driver. The mechanism containing links 4-5-6-1 is a non Grashof, slider-crank mechanism. The crank cannot make a continuous rotation relative to the other links.