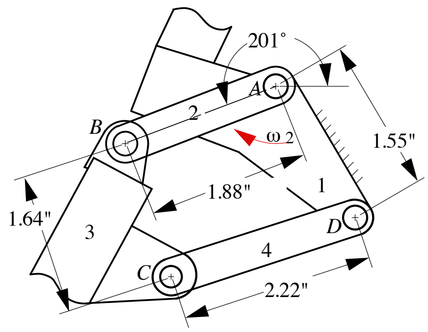
# Solutions to Chapter 1 Exercise Problems

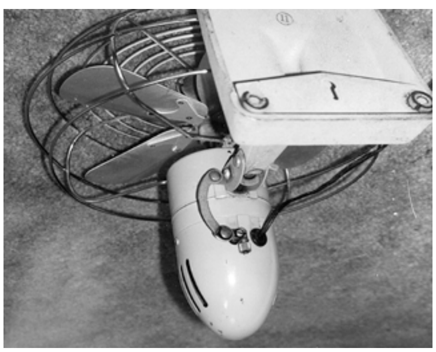
## Problem 1.1

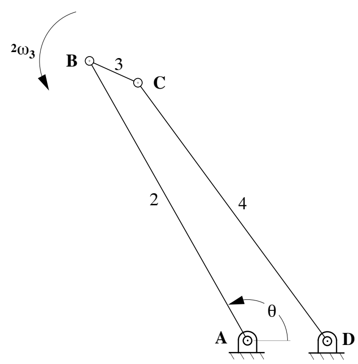
Find a mechanism as an isolated device or in a machine and make a realistic sketch of the mechanism. Then make a freehand sketch of the kinematic schematics for the mechanism chosen.

Typical examples of solutions for this problem are given in the problem definitions of Chapter 3. Some examples are:

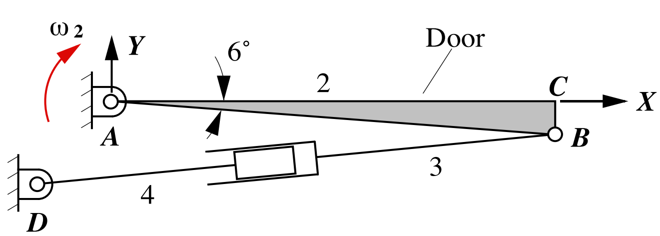



Bicycle suspension






Oscillating fan

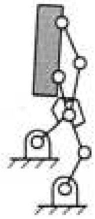


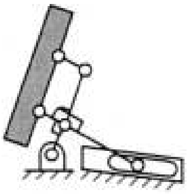

Door closing linkage

## 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.

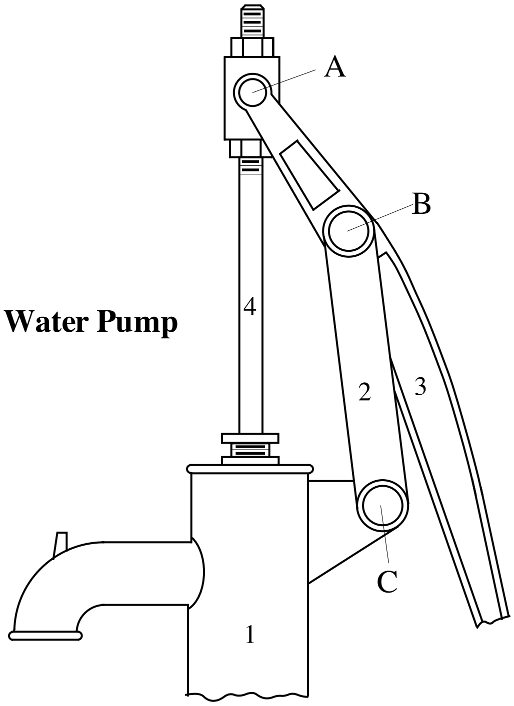
There are a large number of mechanisms that are used to obtain various types of hinge motions. Below are three of them. The first is a 6-bar Watt's linkage used for chest lids. The hinge guides the chest lid such that no part of the lid crosses the plane of the back of the chest. The second example is 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.



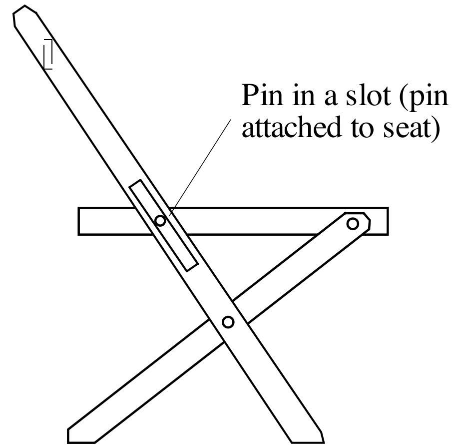


## Problem 1.3

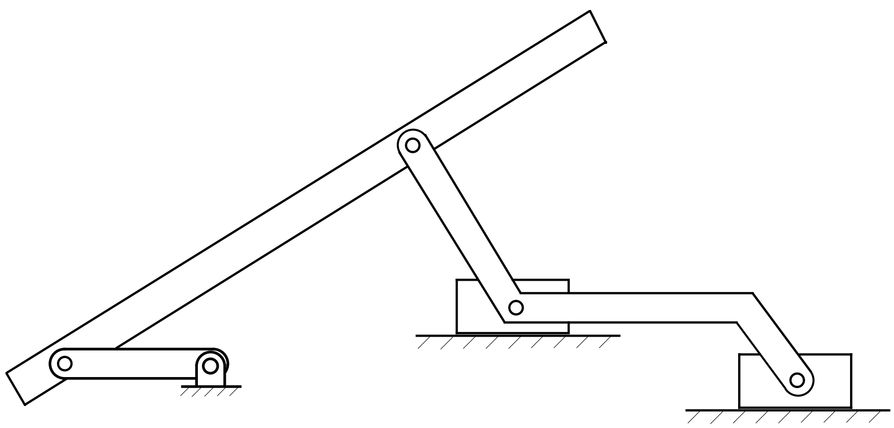
The drawings shown below are pictorial representations of real mechanisms that are commonly encountered. Make a freehand sketch of the kinematic schematic representation of each mechanism.




**Water Pump**

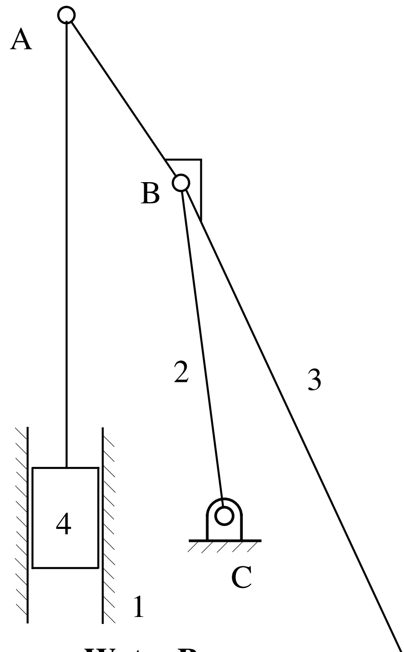



**Folding Chair**

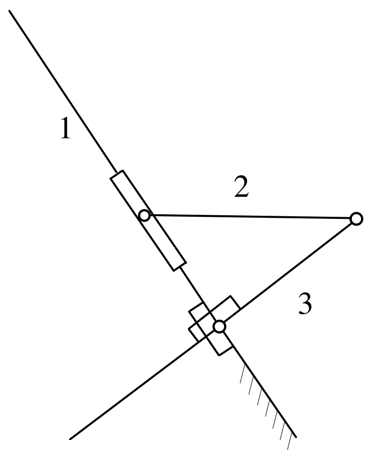


**Casement window mechanism**

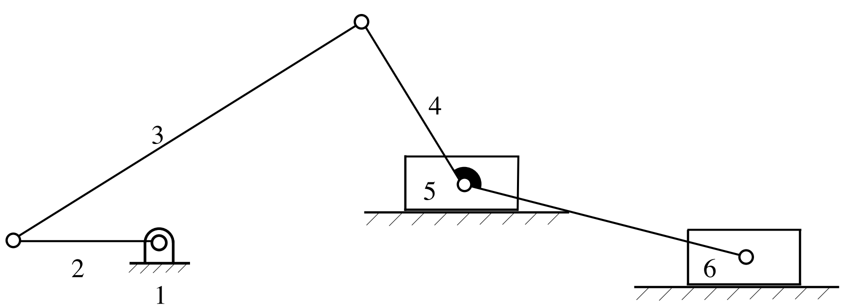
Solution




**Water Pump**



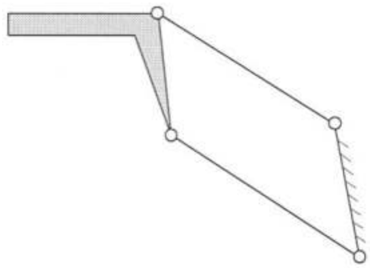

**Folding Chair**



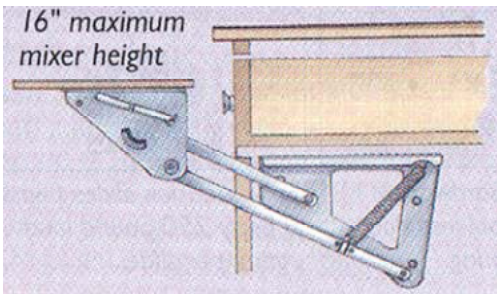

**Casement window mechanism**

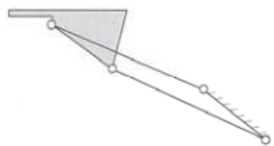
## Problem 1.4

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.

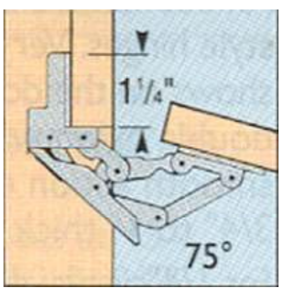


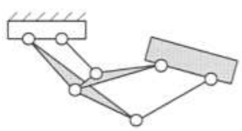
Typewriter desk linkage



Under drawer swing up mechanism



Overhead bin hinge

## Problem 1.5

Fourbar 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 fourbar linkage moves the leg and wing.

Door closer.  The fourbar linkage is connected to a damper mechanism

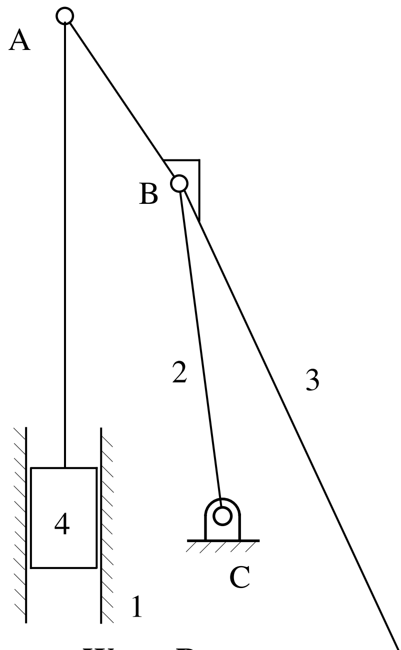
Kickback protector on table saw.  The fourbar linkage is a parallelogram linkage.

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

Vicegrips. The fourbar linkage is a toggle mechanism

## Problem 1.6

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




**Water Pump**

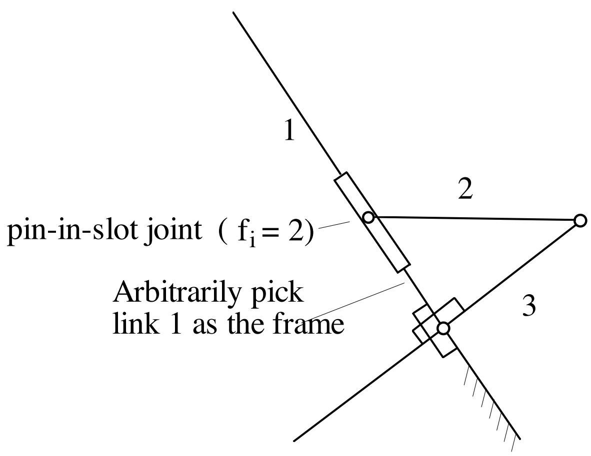
$n = 4$

$j = 4$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1




$n = 3$

$j = 3$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(3 - 3 - 1) + 4 = 1$$

Mobility = 1

**Folding Chair**

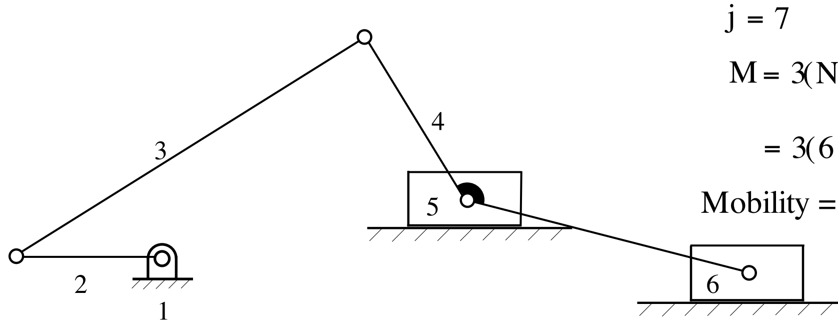
$n = 6$

$j = 7$

$$M = 3(N_L - N_J - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(6 - 7 - 1) + 7 = -6 + 7 = 1$$

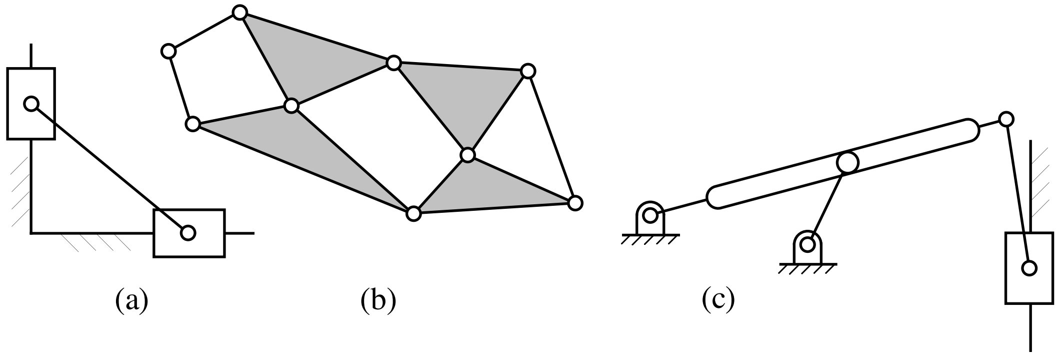
Mobility = 1



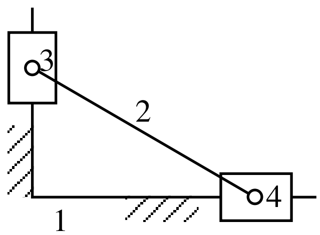

**Casement window mechanism**

## Problem 1.7

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



(a) (b) (c)




(a)

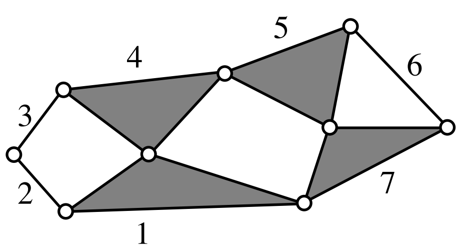
$$n = 4$$

$$j = 4$$

$$\sum_{i=1}^{j} f_i = 4 \ \text{x} \ 1 = 4$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1




(b)

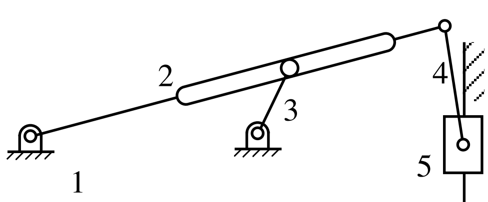
$$n = 7$$

$$j = 9$$

$$\sum_{i=1}^{j} f_i = 9 \times 1 = 9$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 3(7 - 9 - 1) + 9 = -9 + 9 = 0$$

Mobility = 0




(c)

$$n = 5$$

$$j = 6$$

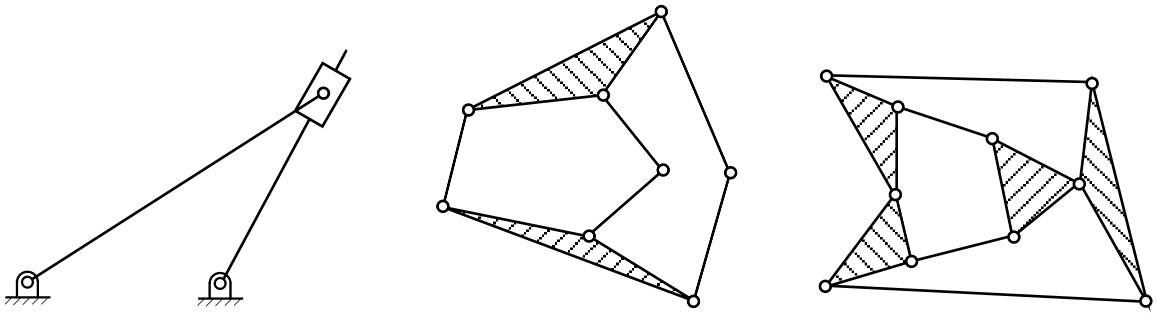
$$\sum_{i=1}^{j} f_i = 5 \times 1 + 1 \times 2 = 7$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 3(5 - 6 - 1) + 7 = -6 + 7 = 1$$

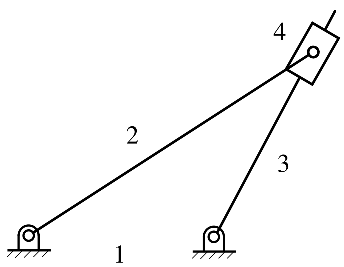
Mobility = 1

## Problem 1.8

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



(a) (b) (c)




(a)

$n = 4$

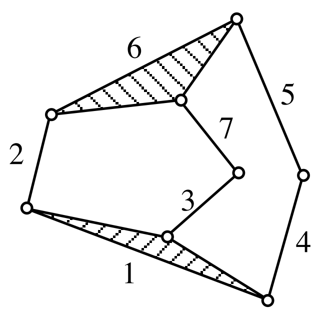
$j = 4$

$$\sum_{i=1}^{j} f_i = 4 \times 1 = 4$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1




(b)

$n = 7$

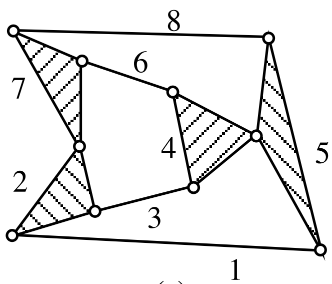
$j = 8$

$$\sum_{i=1}^{j} f_i = 8 \times 1 = 8$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(7 - 8 - 1) + 8 = -6 + 8 = 2$$

Mobility = 2




(c)

$n = 8$

$j = 10$

$$\sum_{i=1}^{j} f_i = 10 \times 1 = 10$$

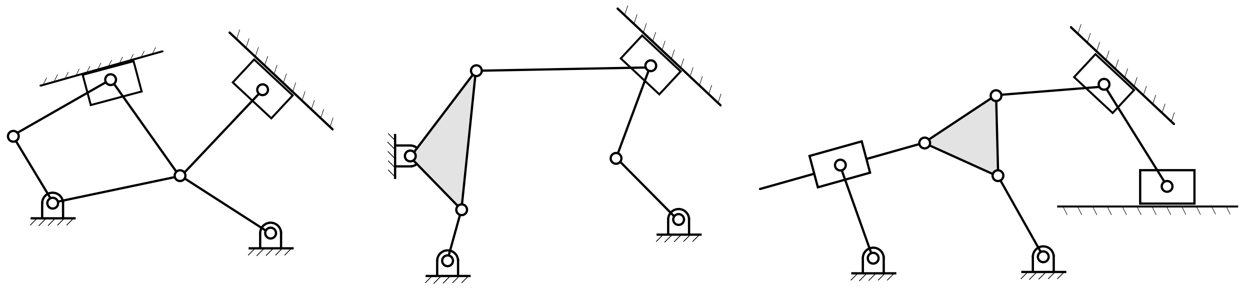
$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(8 - 10 - 1) + 10 = -9 + 10 = 1$$

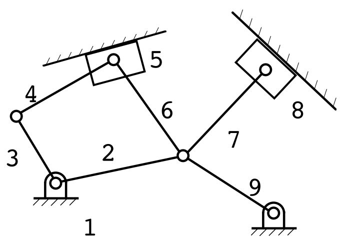
Mobility = 1

## Problem 1.9

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)




(a)

$n = 9$

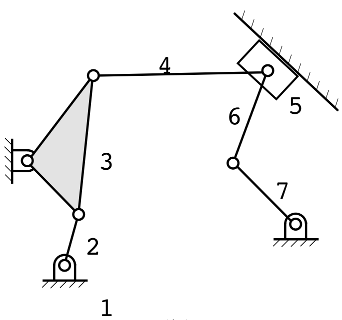
$j = 12$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(9 - 12 - 1) + 12 = -12 + 12 = 0$$

Mobility = 0

Idle DOF = 0




(b)

$n = 7$

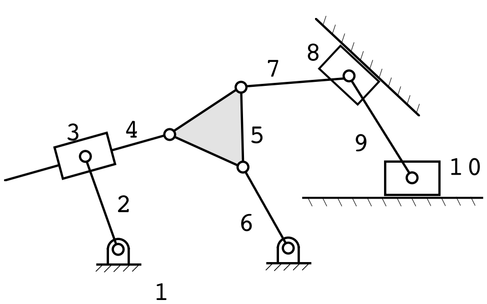
$j = 9$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(7 - 9 - 1) + 9 = -9 + 9 = 0$$

Mobility = 0

Idle DOF = 0




(c)

$n = 10$

$j = 12$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

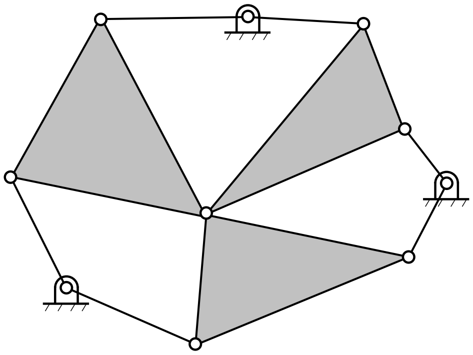
$$= 3(10 - 12 - 1) + 12 = -9 + 12 = 3$$

Mobility = 3

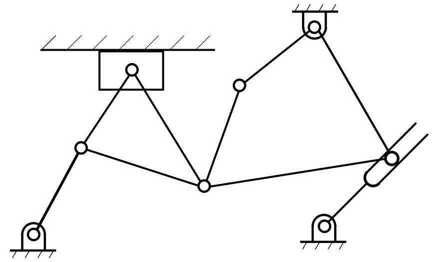
Idle DOF = 0

## Problem 1.10

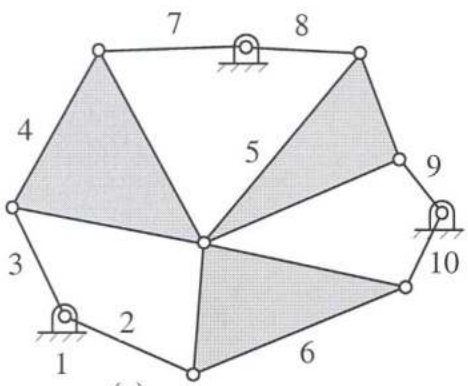
Determine the mobility and the number of idle degrees of freedom of the linkages shown below. Show the equations used and identify any assumptions made when determining your answers.



(a)



(b)




(a)

$n = 10$

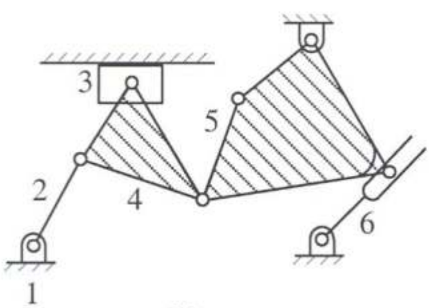
$j = 14$

$$\sum_{i=1}^{j} f_i = 14 \times 1 = 14$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(10 - 14 - 1) + 14 = -15 + 14 = -1$$

Mobility = -1




(b)

$n = 6$

$j = 8$

$$\sum_{i=1}^{j} f_i = 8 + 1 = 9$$

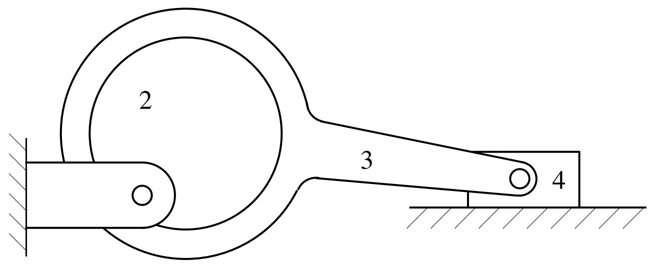
$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

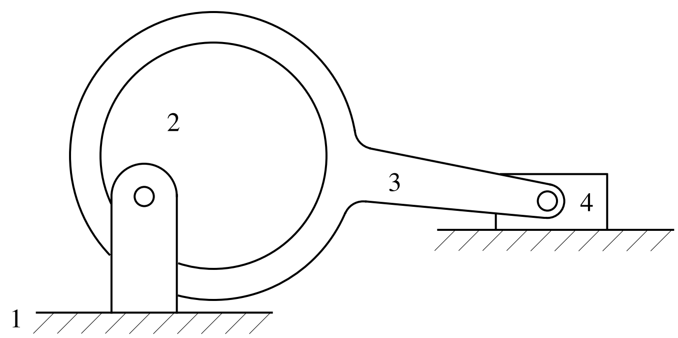
$$= 3(6 - 8 - 1) + 9 = -9 + 9 = 0$$

Mobility = 0

## Problem 1.11

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.




$$n = 4$$

$$j = 4$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

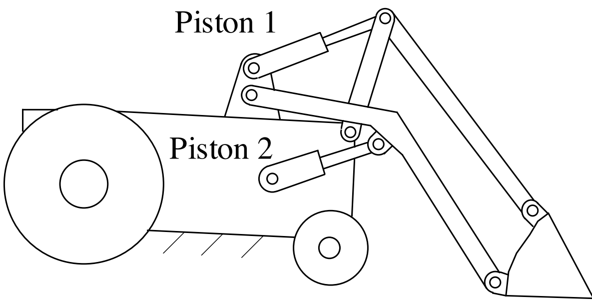
$$= 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1

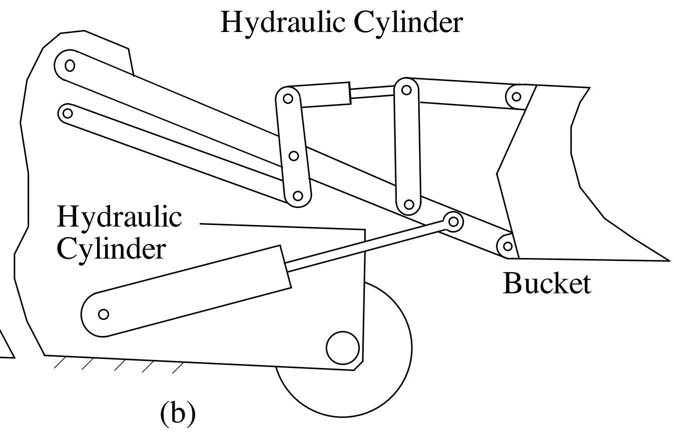
Idle DOF = 1

## Problem 1.12

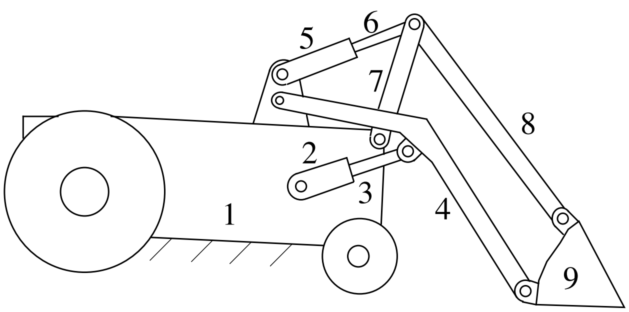
Determine the mobility of each of the planar linkages shown below. Show the equations used to determine your answers.




(a)




(b)




(a)

$n = 9$

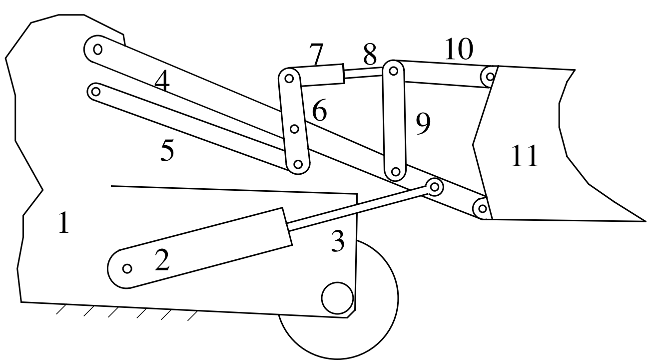
$j = 11$

$$\sum_{i=1}^{j} f_i = 11 \times 1 = 11$$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(9 - 11 - 1) + 11 = -9 + 11 = 2$$

Mobility = 2




(b)

$n = 11$

$j = 14$

$$\sum_{i=1}^{j} f_i = 14 \times 1 = 14$$

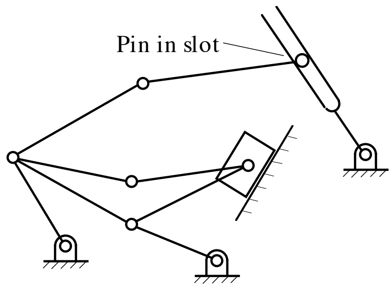
$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(11 - 14 - 1) + 14 = -12 + 14 = 2$$

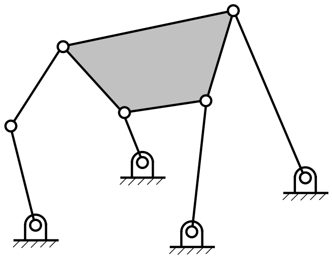
Mobility = 2

## Problem 1.13

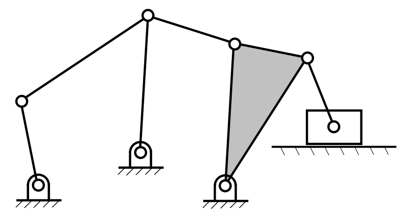
Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used to determine your answers.



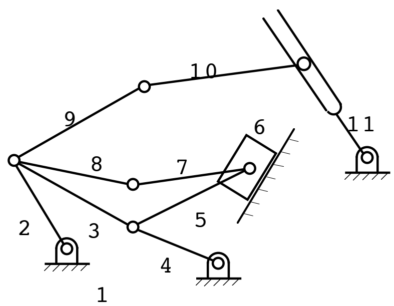

(a)



(b)



(c)




(a)

$n = 11$

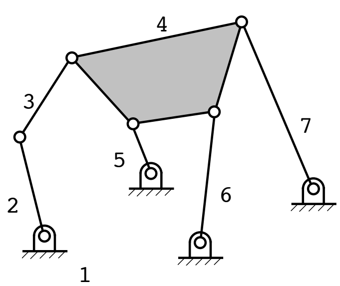
$j = 14$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(11 - 14 - 1) + 15 = -12 + 15 = 3$$

Mobility = 3

Idle DOF = 0




(b)

$N = 7$

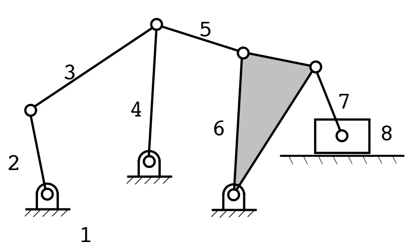
$j = 9$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(7 - 9 - 1) + 9 = -9 + 9 = 0$$

Mobility = 0

Idle DOF = 0




(c)

$n = 8$

$j = 10$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

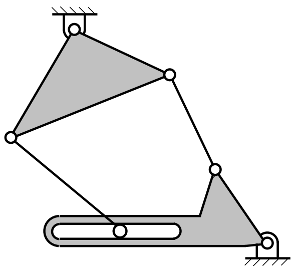
$$= 3(8 - 10 - 1) + 10 = -9 + 10 = 1$$

Mobility = 1

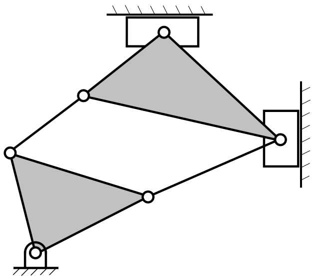
Idle DOF = 0

## Problem 1.14

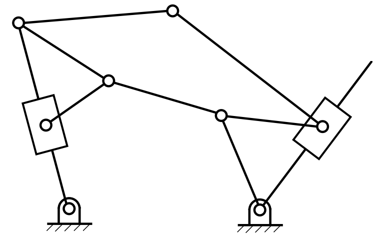
Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used to determine your answers.



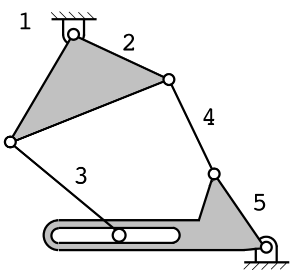
(a)



(b)



(c)




(a)

$n = 5$

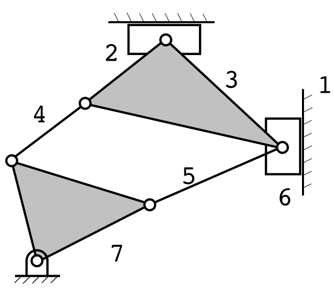
$j = 6$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(5 - 6 - 1) + 7 = -6 + 7 = 1$$

Mobility = 1

Idle DOF = 0




(b)

$n = 7$

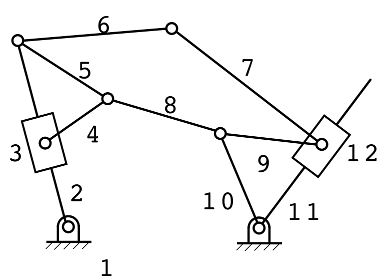
$j = 9$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(7 - 9 - 1) + 9 = -9 + 9 = 0$$

Mobility = 0

Idle DOF = 0




(c)

$n = 12$

$j = 15$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

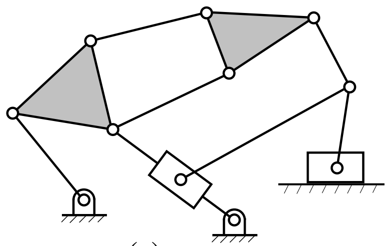
$$= 3(12 - 15 - 1) + 15 = -12 + 15 = 3$$

Mobility = 3

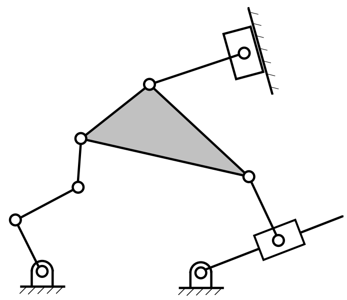
Idle DOF = 0

## Problem 1.15

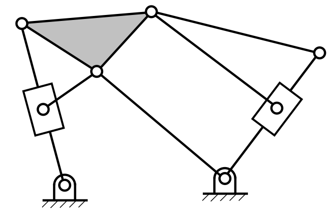
Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used to determine your answers.



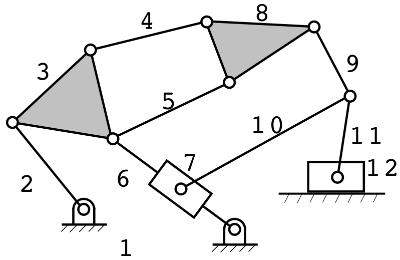
(a)



(b)



(c)




(a)

$n = 12$

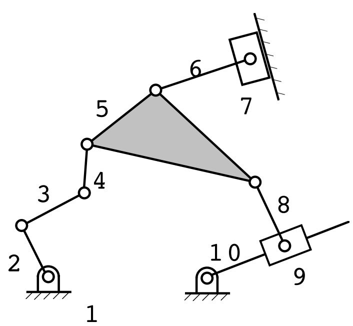
$j = 15$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(12 - 15 - 1) + 15 = -12 + 15 = 3$$

Mobility = 3

Idle DOF = 0




(b)

$n = 10$

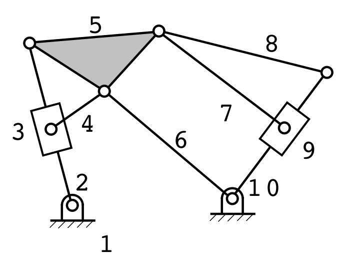
$j = 11$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(10 - 11 - 1) + 11 = -6 + 11 = 5$$

Mobility = 5

Idle DOF = 0




(c)

$n = 10$

$j = 13$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

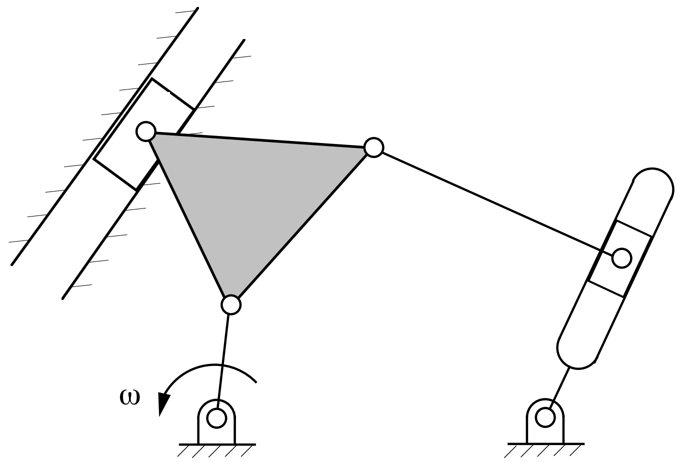
$$= 3(10 - 13 - 1) + 13 = -12 + 13 = 1$$

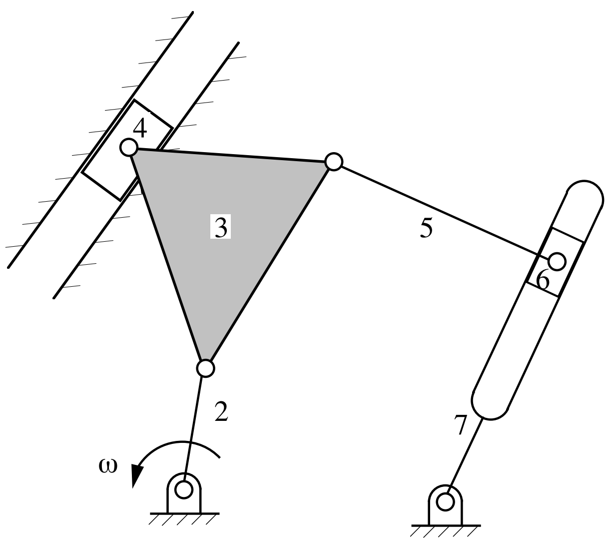
Mobility = 1

Idle DOF = 0

## Problem 1.16

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




$n = 7$

$j = 8$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

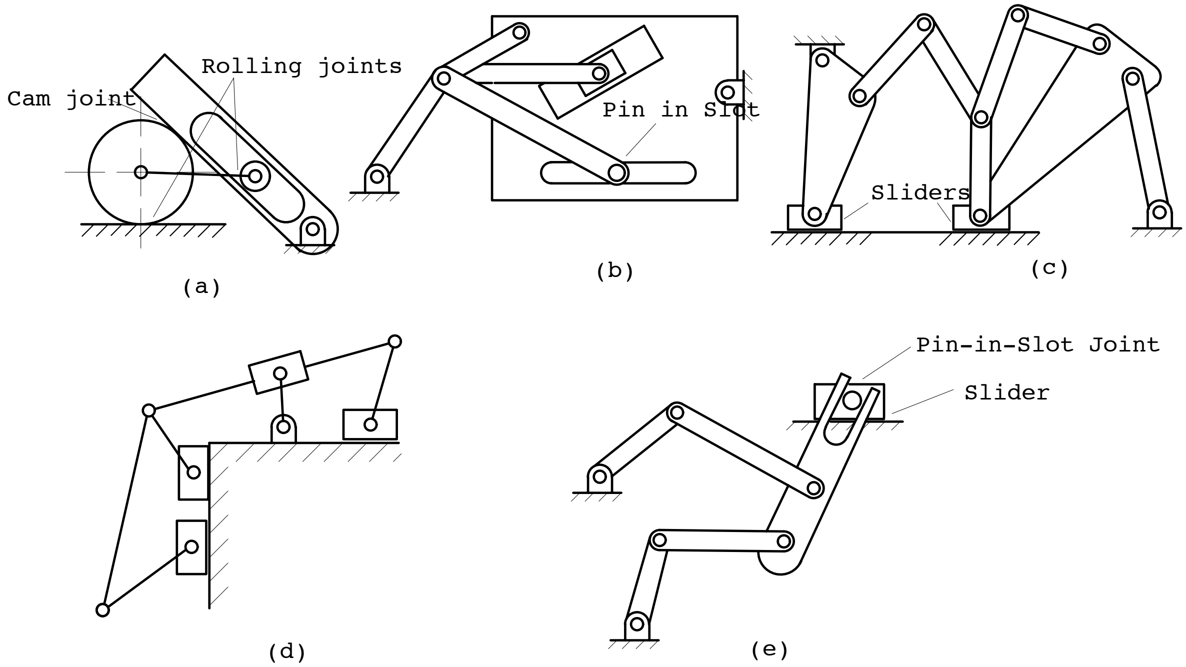
$$= 3(7 - 8 - 1) + 8 = -6 + 8 = 2$$

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 must be determined.

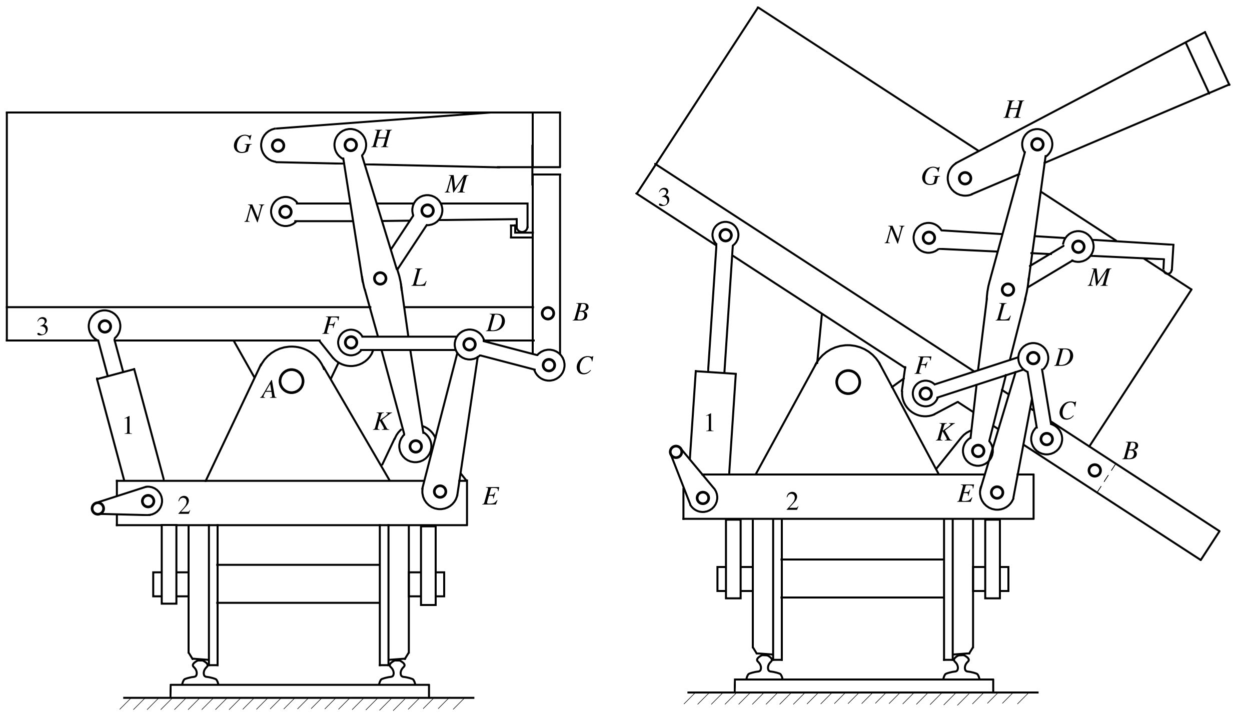
## Problem 1.17

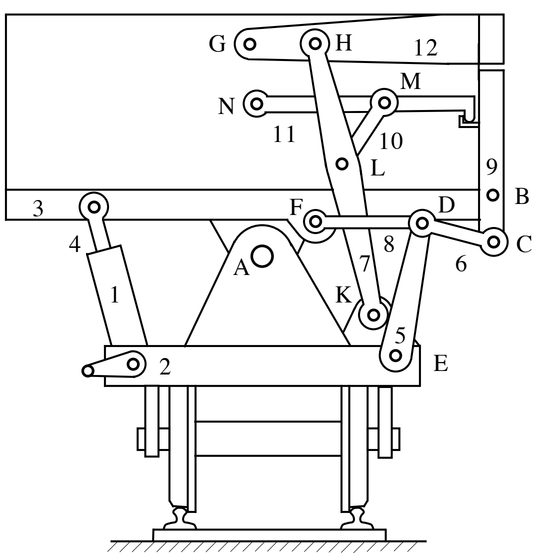
Determine the mobility and the number of idle degrees of freedom associated with each mechanism. Show the equations used and identify any assumptions made when determining your answers.



## Problem 1.18[1]

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.




$n = 12$

$j = 16$

$$M = 3(n - j - 1) + \sum_{i=1}^{N} f_i$$

$$= 3(12 - 16 - 1) + 16 = -15 + 16 = 1$$

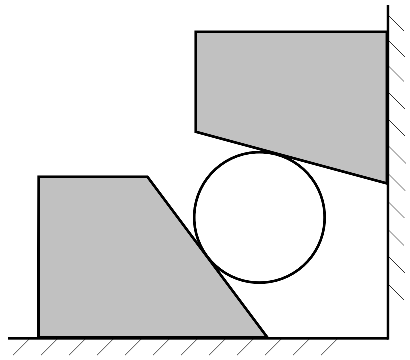
Mobility = 1

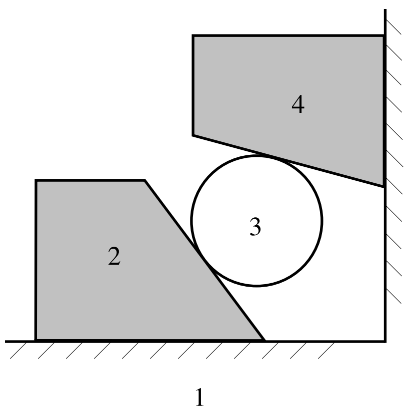
Idle DOF = 0

[1] Problem courtesy of Joseph Davidson, Arizona State University

## Problem 1.19

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.






$n = 4$

$j = 4$

$$DF = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

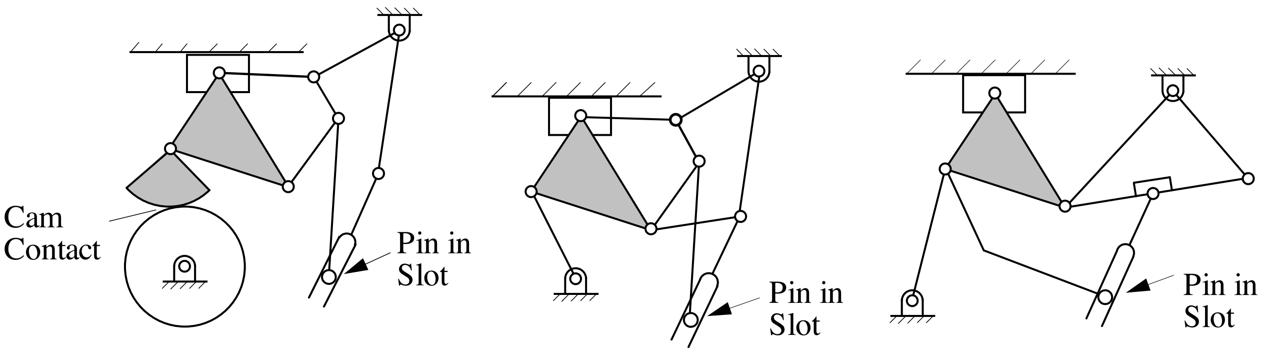
$$= 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1

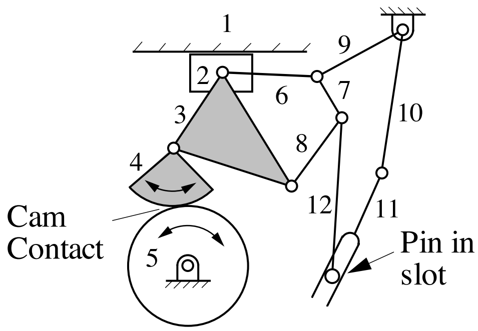
Idle DOF = 0

## Problem 1.20

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)




(a)

$n = 12$

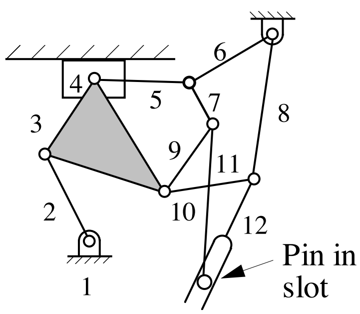
$j = 15$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(12 - 15 - 1) + 17 = -12 + 17 = 5$$

Mobility = 5

Idle DOF = 2




(b)

$n = 12$

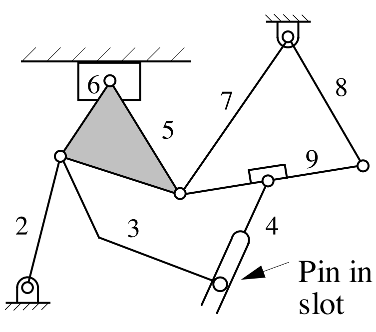
$j = 16$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(12 - 16 - 1) + 17 = -15 + 17 = 2$$

Mobility = 2

Idle DOF = 0




(c)

$n = 9$

$j = 12$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

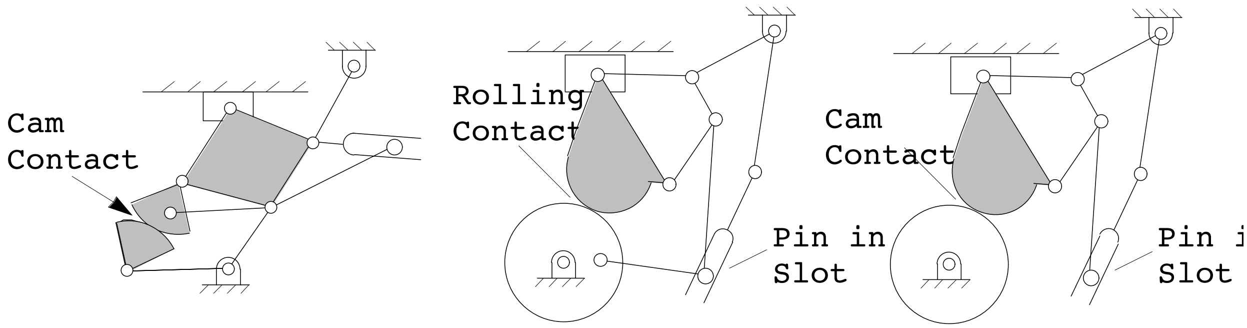
$$= 3(9 - 12 - 1) + 13 = -12 + 13 = 1$$

Mobility = 1

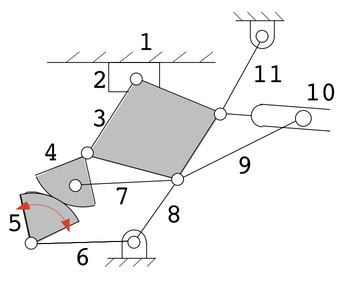
Idle DOF = 0

# Problem 1.21

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.




(a) (b) (c)




(a)

$n = 11$

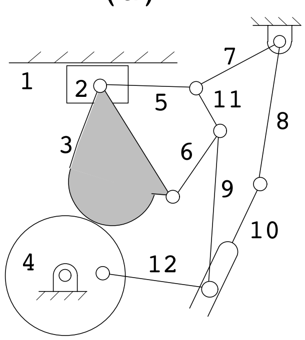
$j = 15$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(11 - 15 - 1) + 17 = -15 + 17 = 2$$

Mobility = 2

Idle DOF = 1




(b)

$n = 12$

$j = 16$

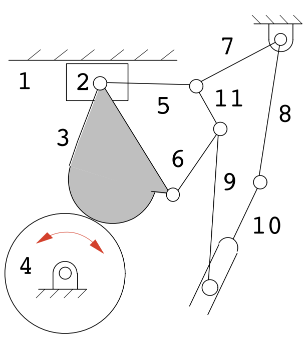
$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(12 - 16 - 1) + 14(1) + 2(2)$$

$$= -15 + 18 = 3$$

Mobility = 3

Idle DOF = 0




(c)

$n = 11$

$j = 14$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

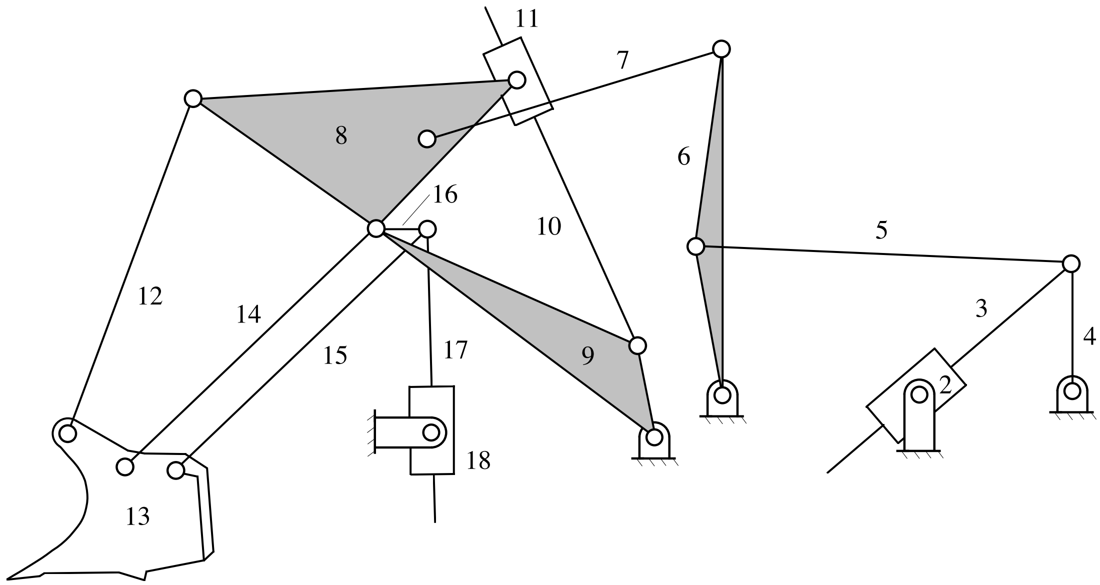
$$= 3(11 - 14 - 1) + 16 = -12 + 16 = 4$$

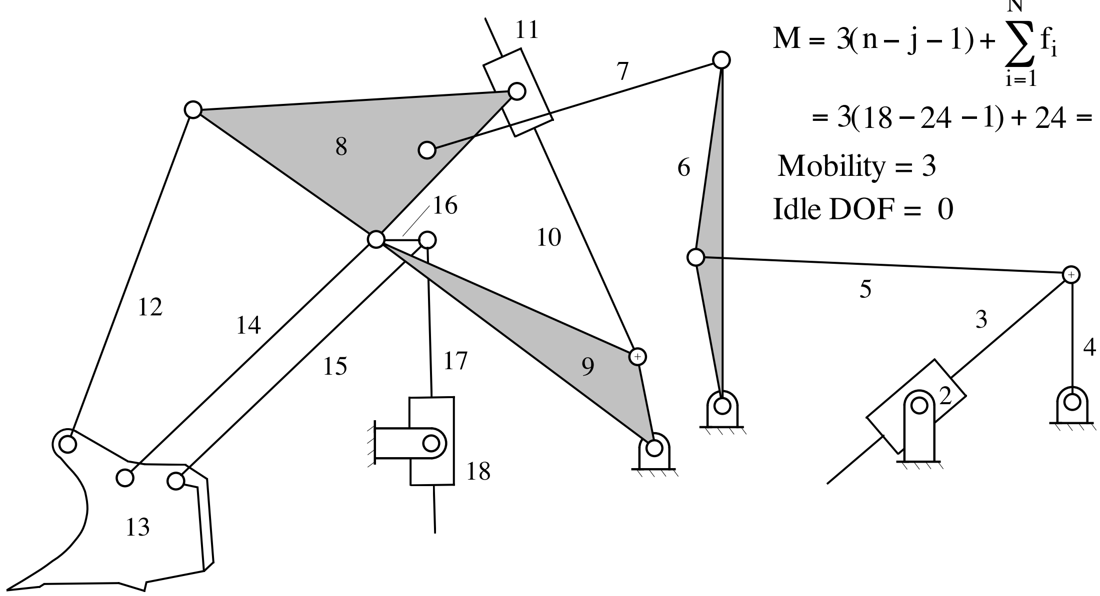
Mobility = 4

Idle DOF = 1

## Problem 1.22[2]

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.




$n = 18$

$j = 24$

$$M = 3(n - j - 1) + \sum_{i=1}^{N} f_i$$

$$= 3(18 - 24 - 1) + 24 = -21 + 24 = 3$$

Mobility = 3

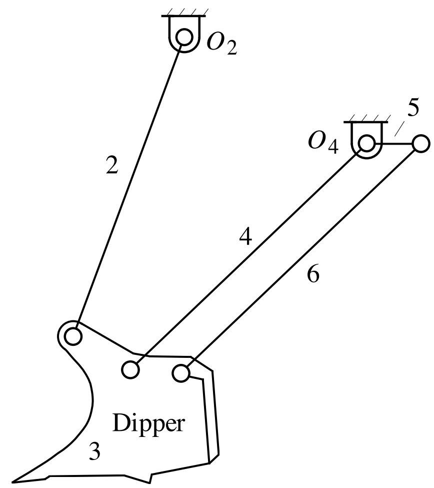
Idle DOF = 0

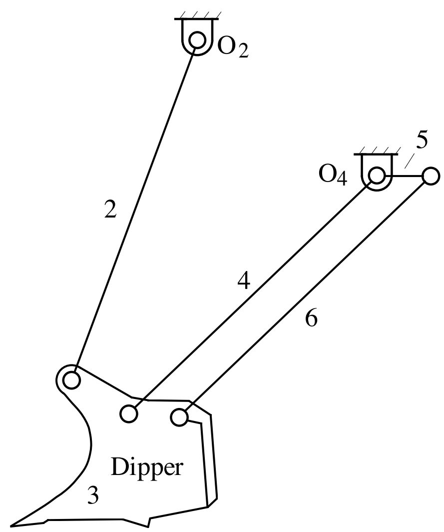
---

[2] Problem courtesy of Joseph Davidson, Arizona State University

## Problem 1.23

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.




$n = 6$

$j = 7$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

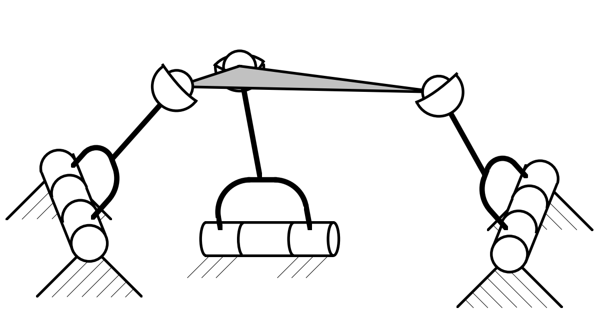
$$= 3(6 - 7 - 1) + 7 = -6 + 7 = 1$$

Mobility = 1

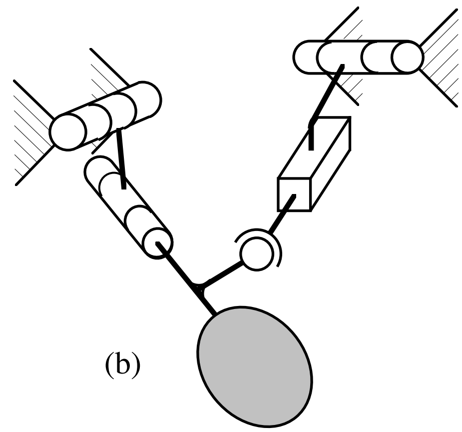
Idle DOF = 0

## Problem 1.24

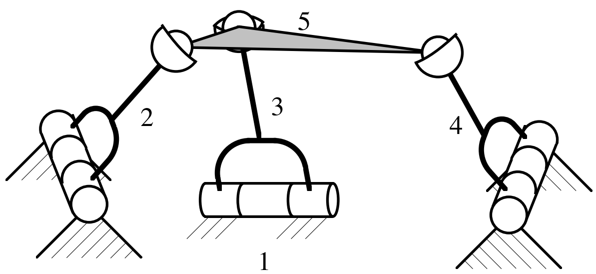
What is the number of members, number of joints, mobility, and the number of idle degrees of freedom of each of the spatial linkages shown below?



(a)



(b)




(a)

$$n = 5$$

$$j = 6$$

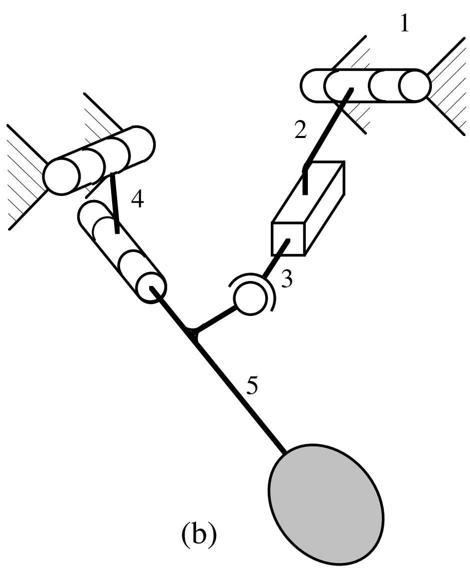
$$\sum_{i=1}^{j} f_i = 3(3) + 3(1) = 12$$

$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(5 - 6 - 1) + 12 = -12 + 12 = 0$$

Mobility = 0

Idle DOF = 0




(b)

$$n = 5$$

$$j = 5$$

$$\sum_{i=1}^{j} f_i = 4(1) + 1(3) = 7$$

$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

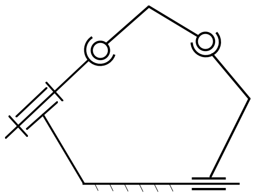
$$= 6(5 - 5 - 1) + 7 = -6 + 7 = 1$$

Mobility = 1

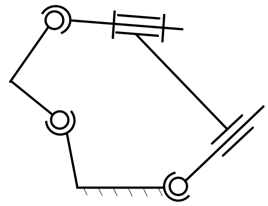
Idle DOF = 0

## Problem 1.25

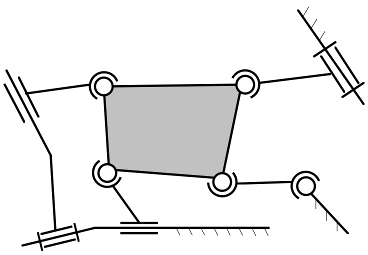
Determine the mobility and the number of idle degrees of freedom of the spatial linkages shown below. Show the equations used to determine your answers.



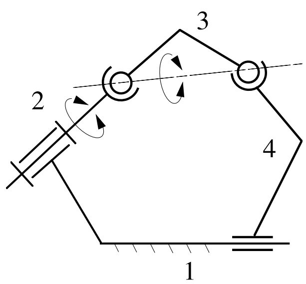
(a)



(b)



(c)




(a)

$n = 4$

$j = 4$

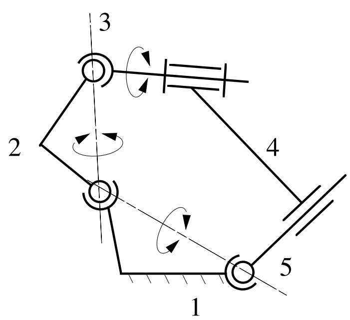
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(4 - 4 - 1) + (3 + 3 + 2 + 1)$$

$$= -6 + 9 = 3$$

Mobility = 3

Idle DOF = 2




(b)

$n = 5$

$j = 5$

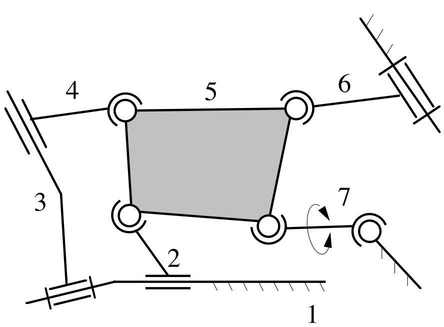
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(5 - 5 - 1) + (3 + 3 + 3 + 1 + 2)$$

$$= -6 + 12 = 6$$

Mobility = 6

Idle DOF = 3




(c)

$n = 7$

$j = 9$

$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(7 - 9 - 1) + 5(3) + 2(2) + 2(1)$$

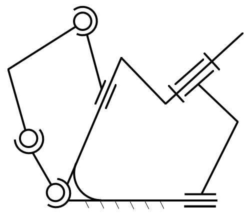
$$= -18 + 21 = 3$$

Mobility = 3

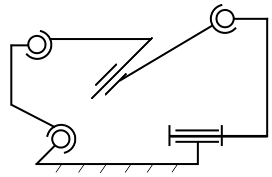
Idle DOF = 1

## Problem 1.26

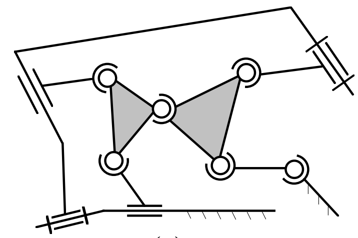
Determine the mobility and the number of idle degrees of freedom of the spatial linkages shown below. Show the equations used to determine your answers.



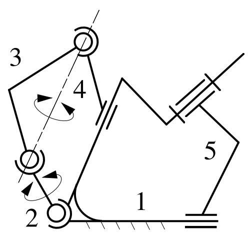
(a)



(b)



(c)




(a)

$n = 5$

$j = 6$

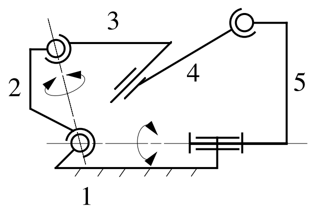
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(5 - 6 - 1) + (3 + 3 + 3 + 1 + 2 + 2)$$

$$= -12 + 14 = 2$$

Mobility = 2

Idle DOF = 2




(b)

$n = 5$

$j = 5$

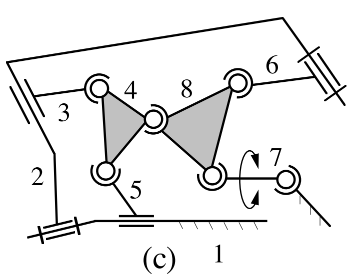
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(5 - 5 - 1) + (3 + 3 + 3 + 1 + 2)$$

$$= -6 + 12 = 6$$

Mobility = 6

Idle DOF = 2




(c)

$n = 8$

$j = 10$

$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(8 - 10 - 1) + 6(3) + 2(1) + 2(2)$$

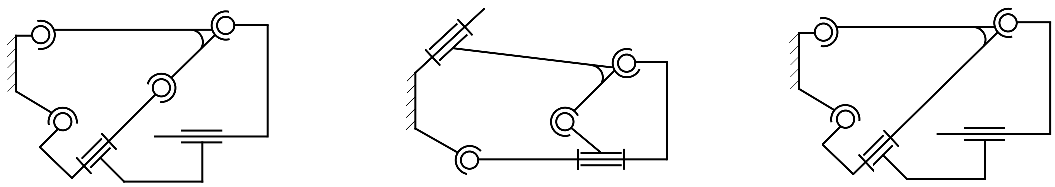
$$= -18 + 24 = 6$$

Mobility = 6

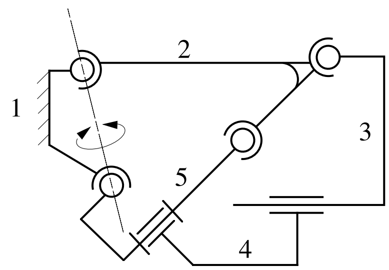
Idle DOF = 1

## Problem 1.27

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)

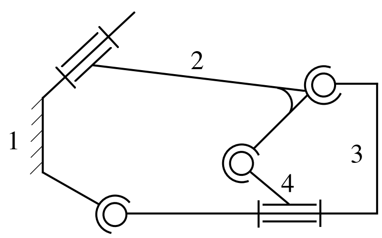



(a)

$$n = 5$$
$$j = 6$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(5 - 6 - 1) + 4(3) + 2 + 1$$
$$= -12 + 15 = 3$$

Mobility = 3

Idle DOF = 1

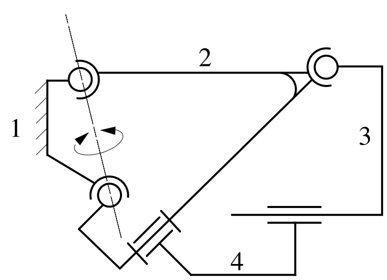



(b)

$$n = 4$$
$$j = 5$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 5 - 1) + (3 + 3 + 3 + 1 + 1)$$
$$= -12 + 11 = -1$$

Mobility = -1

Idle DOF = 0




(c)

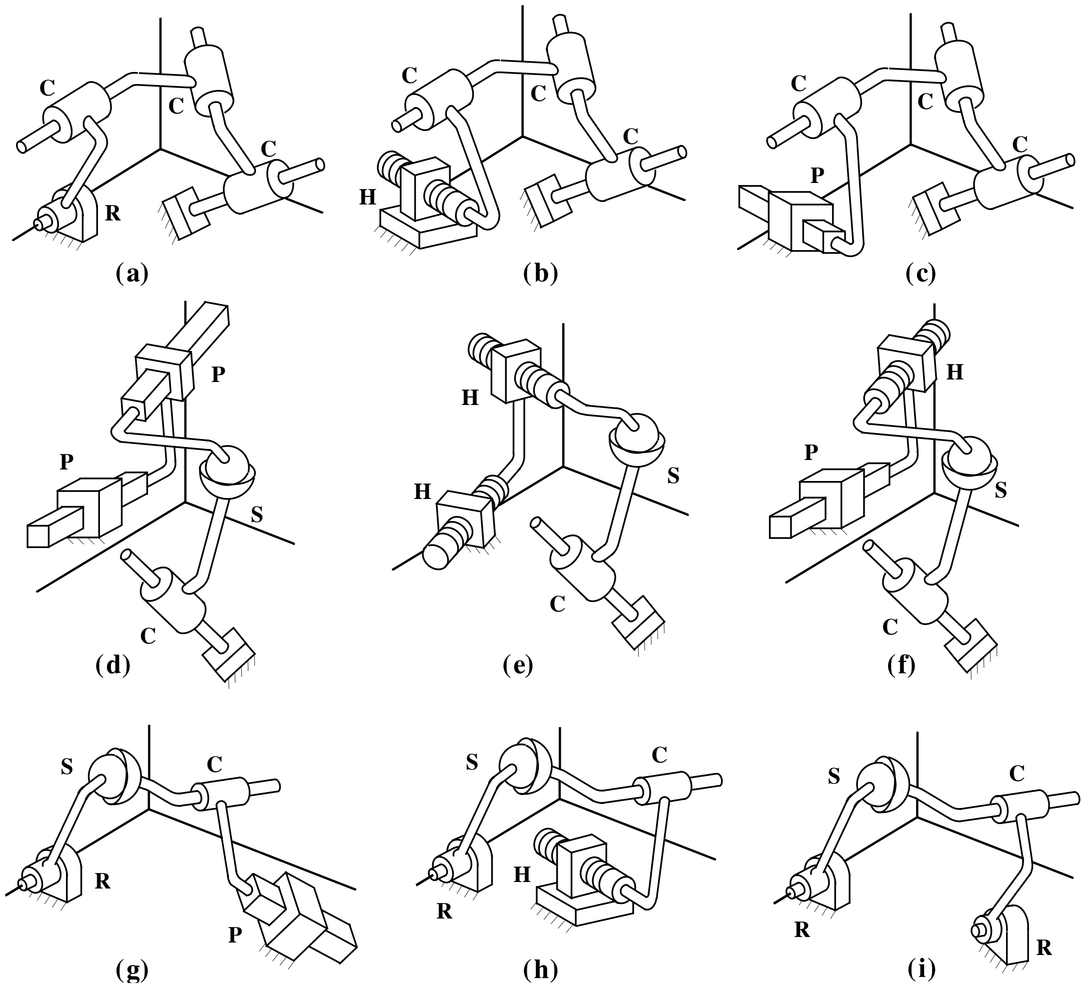
$$n = 4$$
$$j = 5$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 5 - 1) + 3(3) + 2 + 1$$
$$= -12 + 12 = 0$$

Mobility = 0

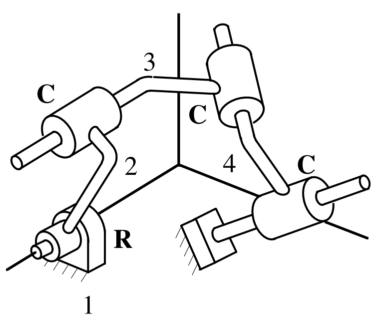
Idle DOF = 1

## Problem 1.28

Determine the mobility and the number of idle degrees of freedom associated with each mechanism.[3] Show the equations used to determine your answers.




(a)




$$
\begin{aligned}
n &= 4\\
j &= 4\\
M &= 6(n - j - 1) + \sum_{i=1}^{j} f_i\\
&= 6(4 - 4 - 1) + 3(2) + 1\\
&= -6 + 7 = 1
\end{aligned}
$$

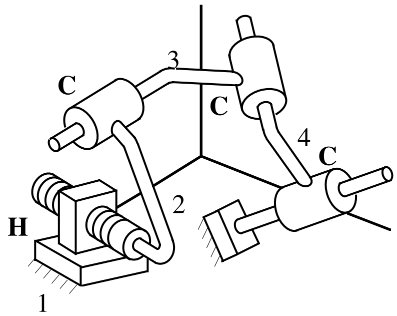
Mobility = 1

Idle DOF = 0

---

[3] 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.

(b)

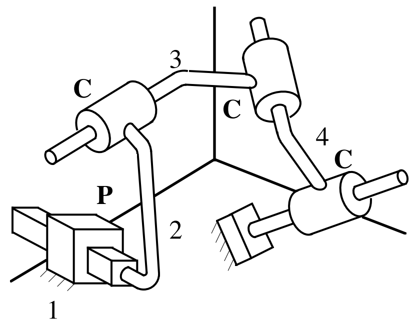



$$n = 4$$
$$j = 4$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 4 - 1) + 3(2) + 1$$
$$= -6 + 7 = 1$$

Mobility = 1

Idle DOF = 0

(c)

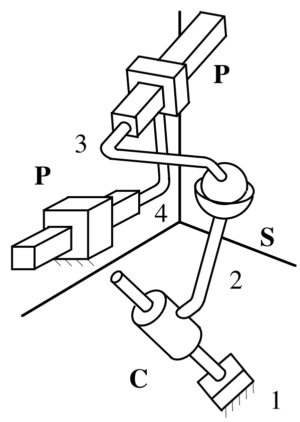



$$n = 4$$
$$j = 4$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 4 - 1) + 3(2) + 1$$
$$= -6 + 7 = 1$$

Mobility = 1

Idle DOF = 0

(d)

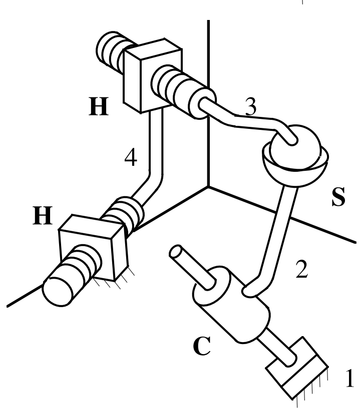



$$n = 4$$
$$j = 4$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 4 - 1) + 3 + 2 + 1 + 1$$
$$= -6 + 7 = 1$$

Mobility = 1

Idle DOF = 0

(e)

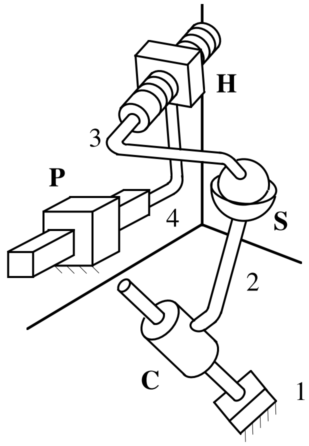



$$n = 4$$
$$j = 4$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 4 - 1) + 3 + 2 + 1 + 1$$
$$= -6 + 7 = 1$$

Mobility = 1

Idle DOF = 0

(f)

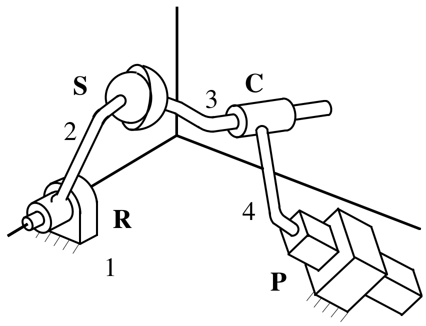



$$
\begin{aligned}
n &= 4\\
j &= 4\\
M &= 6(n - j - 1) + \sum_{i=1}^{j} f_i\\
&= 6(4 - 4 - 1) + 3 + 2 + 1 + 1\\
&= -6 + 7 = 1
\end{aligned}
$$

Mobility = 1

Idle DOF = 0

(g)

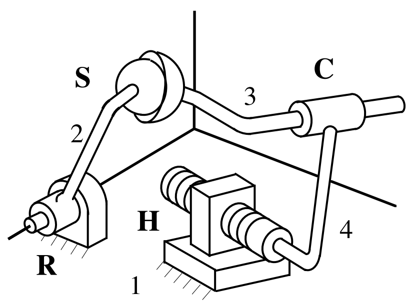



$$
\begin{aligned}
n &= 4\\
j &= 4\\
M &= 6(n - j - 1) + \sum_{i=1}^{j} f_i\\
&= 6(4 - 4 - 1) + 3 + 2 + 1 + 1\\
&= -6 + 7 = 1
\end{aligned}
$$

Mobility = 1

Idle DOF = 0

(h)

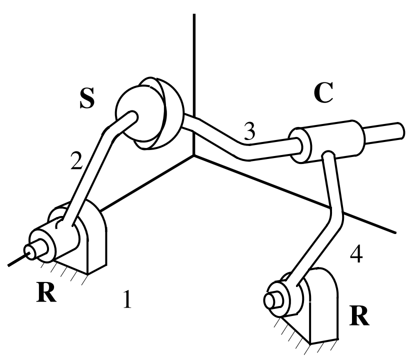



$$
\begin{aligned}
n &= 4\\
j &= 4\\
M &= 6(n - j - 1) + \sum_{i=1}^{j} f_i\\
&= 6(4 - 4 - 1) + 3 + 2 + 1 + 1\\
&= -6 + 7 = 1
\end{aligned}
$$

Mobility = 1

Idle DOF = 0

(i)



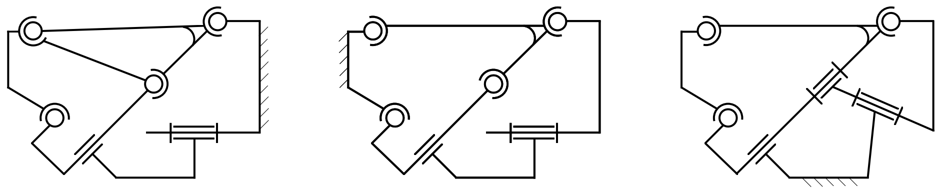

$$
\begin{aligned}
n &= 4\\
j &= 4\\
M &= 6(n - j - 1) + \sum_{i=1}^{j} f_i\\
&= 6(4 - 4 - 1) + 3 + 2 + 1 + 1\\
&= -6 + 7 = 1
\end{aligned}
$$

Mobility = 1

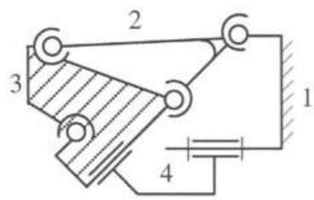
Idle DOF = 0

## Problem 1.29

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)

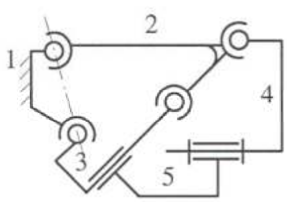



(a)

$$n = 4$$
$$j = 5$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 5 - 1) + 3(3) + 2 + 1$$
$$= -12 + 12 = 0$$

Mobility = 0

Idle DOF = 0

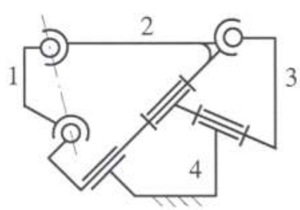



(b)

$$n = 5$$
$$j = 6$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(5 - 6 - 1) + 4(3) + 2 + 1$$
$$= -12 + 15 = 3$$

Mobility = 3

Idle DOF = 1




(c)

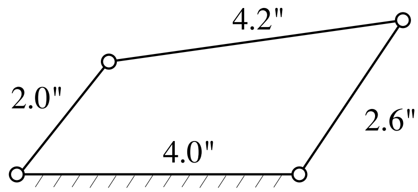
$$n = 4$$
$$j = 6$$
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$
$$= 6(4 - 6 - 1) + (3 + 3 + 3 + 2 + 1 + 1)$$
$$= -18 + 13 = -5$$

Mobility = -5

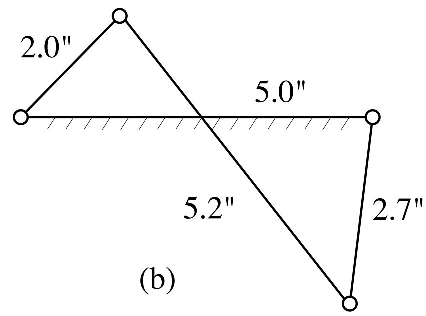
Idle DOF = 1

## Problem 1.30

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.

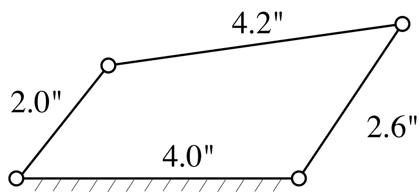



(a)




(b)

(a)



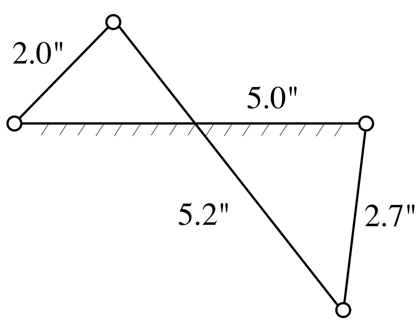

$s + \ell < p + q$ Grashof type 1

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

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

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

(b)




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

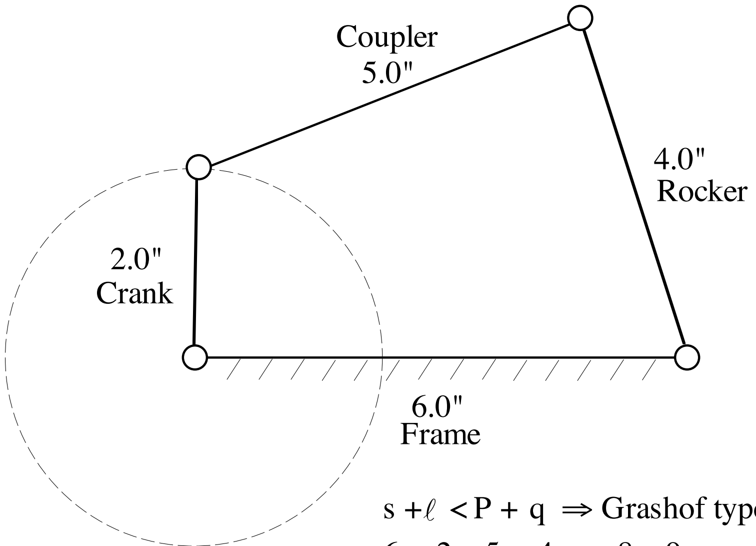
$s = 2.0;\ \ \ell = 5.2;\ \ \ p = 2.7;\ \ \ q = 5.0$

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

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

## Problem 1.31

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).




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

$6 + 2 < 5 + 4 \Rightarrow 8 < 9$

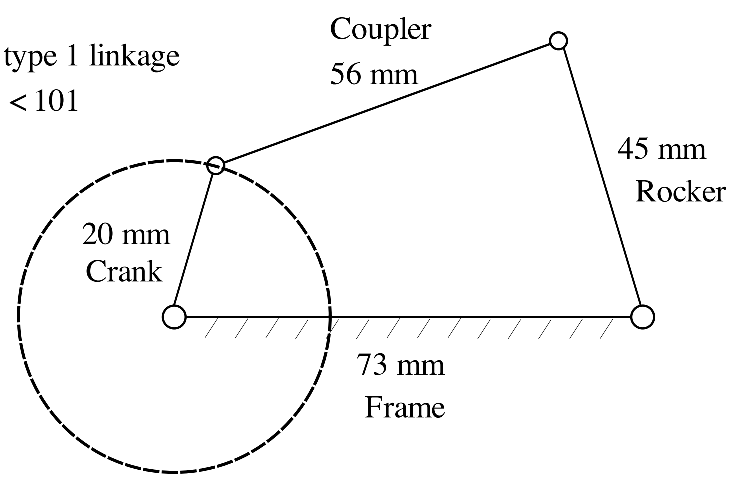
Therefore the linkage is a type 1 linkage and a crank rocker

## Problem 1.32

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).

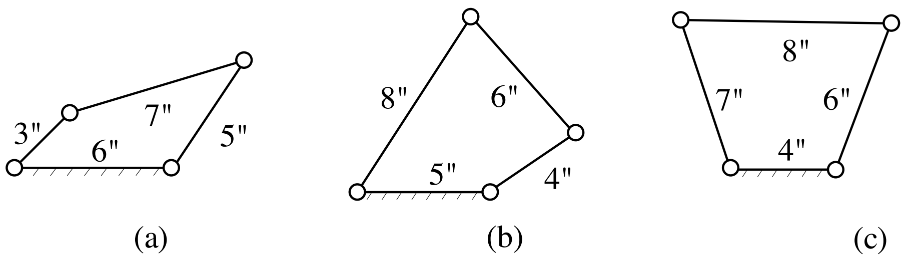
$s + \ell < p + q \Rightarrow$ Grashof type 1 linkage

$20 + 73 < 45 + 56 \Rightarrow 93 < 101$



## Problem 1.33

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.




a)

$$s+\ell<p+q \quad Grashof\ type\ 1$$
$$s+\ell>p+q \quad nonGrashof\ type\ 2$$
$$s=3; \quad \ell=7; \quad p=5; \quad q=6$$
$$3+7<5+6 \Rightarrow 10<11 \Rightarrow Grashof\ type\ 1$$

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

b)

$$s+\ell<p+q \quad Grashof\ type\ 1$$
$$s+\ell>p+q \quad nonGrashof\ type\ 2$$
$$s=4; \quad \ell=8; \quad p=5; \quad q=6$$
$$4+8>5+6 \Rightarrow 12>11 \Rightarrow nonGrashof\ type\ 2$$

All Grashof type 2 linkages are double rockers

c)

$$s+\ell<p+q \quad Grashof\ type\ 1$$
$$s+\ell>p+q \quad nonGrashof\ type\ 2$$
$$s=4; \quad \ell=8; \quad p=6; \quad q=7$$
$$4+8<6+7 \Rightarrow 12<13 \Rightarrow Grashof\ type\ 1$$

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

## Problem 1.34

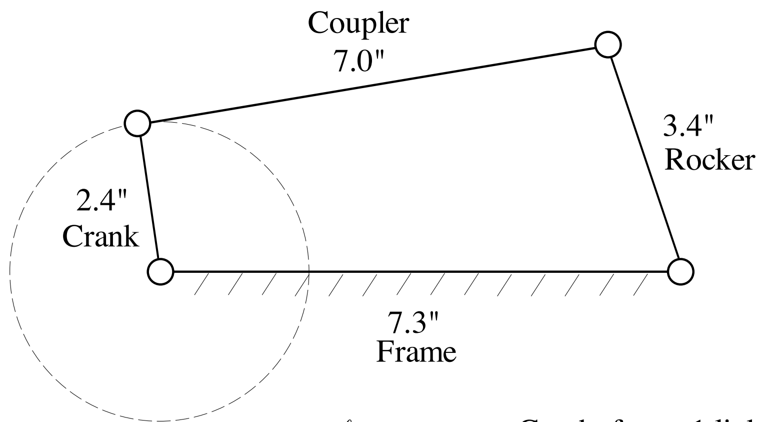
You are given a set of three links with lengths 2.4 in, 7.2 in, and 3.4 in. Select the length of a fourth link and assemble a linkage that can be driven by a continuously rotating motor. Is your linkage a Grashof type 1 or Grashof type 2 linkage? (Show your work.) Is it a crank-rocker, double-rocker,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

Let: $\ell = 7.2$ in

$s = 2.4$ in

$p = 3.4$ in

$q = x$ in




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

$2.4 + 7.2 < 3.4 + x$

$9.6 < 3.4 + x \Rightarrow 7.2 < x$

Let $x = 7.3$

This is a crank-rocker because the shortest link is the driver.

## Problem 1.35

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"

Let: $\ell = 9.5$ in

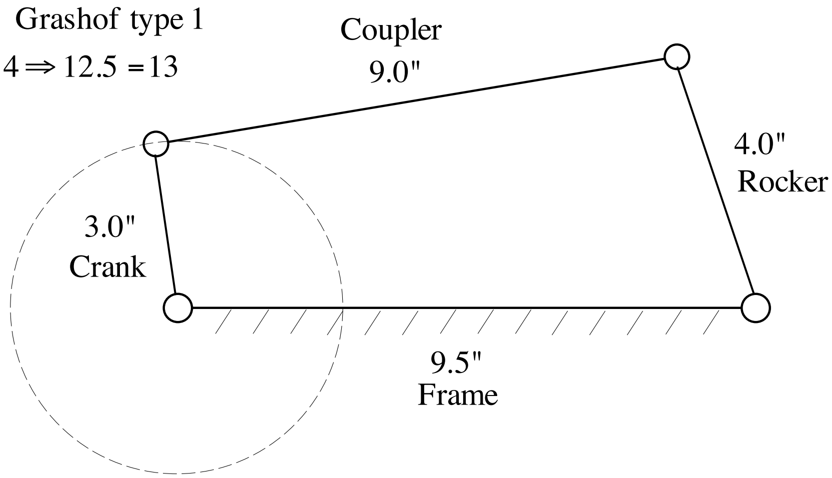
$s = 3.0$ in

$p = 9.0$ in

$q = 4.0$ in

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

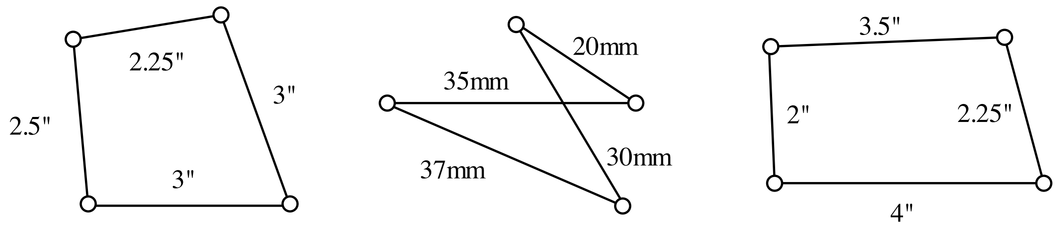
$9.5 + 3 < 9 + 4 \Rightarrow 12.5 = 13$




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

## Problem 1.36

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




(a) (b) (c)

(a) $\ell$ = 3.0 in

s = 2.25 in

p = 3.0 in

q = 2.5 in

$$s+\ell<p+q \quad \textit{Grashof type 1}$$
$$3+2.25<3+2.5 \Rightarrow 5.25<5.5$$

Choosing $\ell$ as the frame results in a double rocker with two fully rotating cranks.

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

(b) $\ell$ = 37.0 mm

s = 20.0 mm

p = 35.0 mm

q = 30.0 mm

$$s+\ell<p+q \quad \textit{Grashof type}\ 1$$
$$37+20<35+30 \Rightarrow 57<65$$

Choosing $\ell$ as the frame results in a double rocker with two fully rotating cranks.

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

(c) $\ell$ = 4.0 in

s = 2.0 in

p = 3.5 in

q = 2.25 in

$$s+\ell<p+q \quad \textit{Grashof type}\ 1$$
$$4.0+2.0>3.5+2.25 \Rightarrow 6.0>5.75$$

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

## Problem 1.37

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.

a)
$$\begin{array}{l} s + l < p + q \quad \text{Grashof type 1} \\ s + l > p + q \quad \text{nonGrashof type 2} \\ s = 1;\ \ l = 5;\ \ p = 3;\ \ q = 4 \\ 1 + 5 < 3 + 4 \Rightarrow 6 < 7 \Rightarrow \text{Grashof type 1} \end{array}$$

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

b)
$$\begin{array}{l} s + l < p + q \quad \text{Grashof type 1} \\ s + l > p + q \quad \text{nonGrashof type 2} \\ s = 2;\ \ l = 5;\ \ p = 3;\ \ q = 4 \\ 2 + 5 < 3 + 4 \Rightarrow 7 = 7 \Rightarrow \text{Transition linkage} \end{array}$$

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

**Problem 1.38**

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"

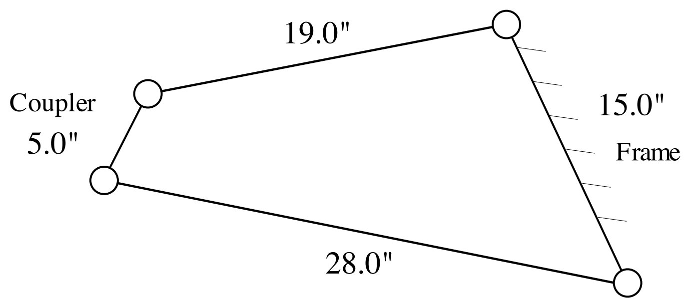
b) $L_1$ = 5", $L_2$ = 2", $L_3$ = 4", $L_4$ = 3.5", and $L_5$ = 2.5"

(a) Let: $l = 28.0$ in

$s = 5.0$ in

$p = 19.0$ in

$q = 15.0$ in




$s + l < p + q$   Grashof type 1

$5 + 28 < 19 + 15 \Rightarrow 33 < 34$

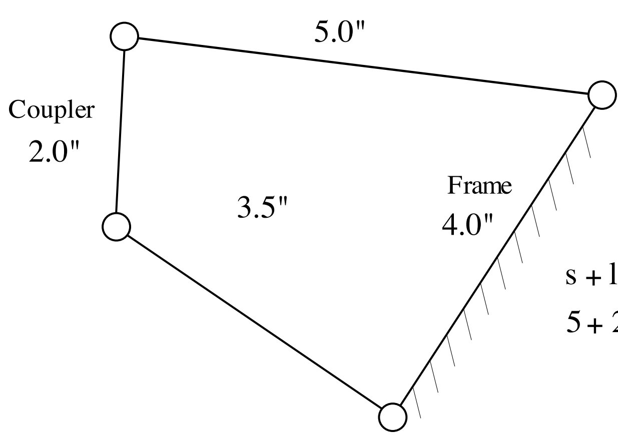
Since the shortest link is the coupler, the mechanism is a type 1 double-rocker.

(b) Let: $l = 5.0$ in

$s = 2.0$ in

$p = 4.0$ in

$q = 3.5$ in




$s + l \le p + q$   Grashof type 1

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

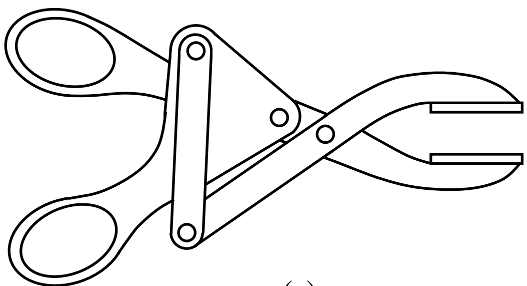
Since the shortest link is the coupler, the mechanism is a type 1 double-rocker.

## Problem 1.39

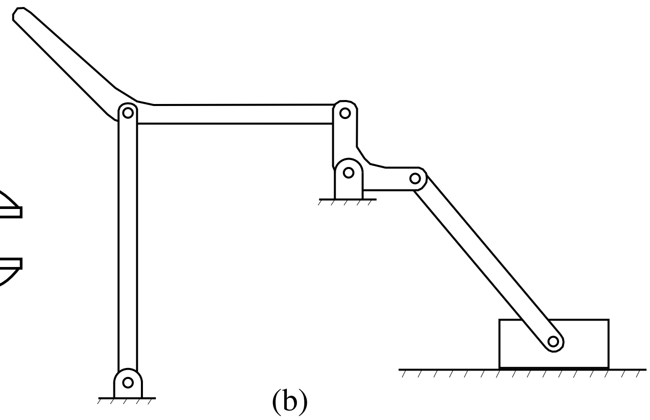
The mechanisms shown below are drawn to scale.

(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.



(a)



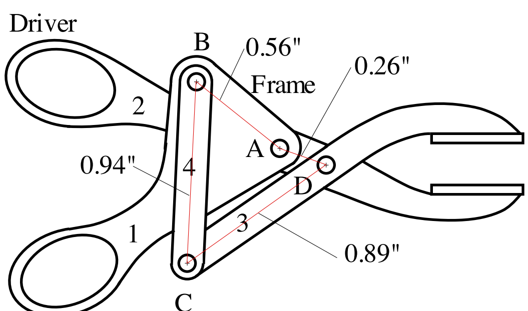
(b)

(a) $\ell = 0.94$ in

$s = 0.26$ in

$p = 0.56$ in

$q = 0.89$ in




(a)

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

$$0.26 + 0.94 < 0.56 + 0.89 \Rightarrow 1.20 < 1.45$$

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

$\ell = 1.59$ in

$s = 0.31$ in

$p = 1.13$ in

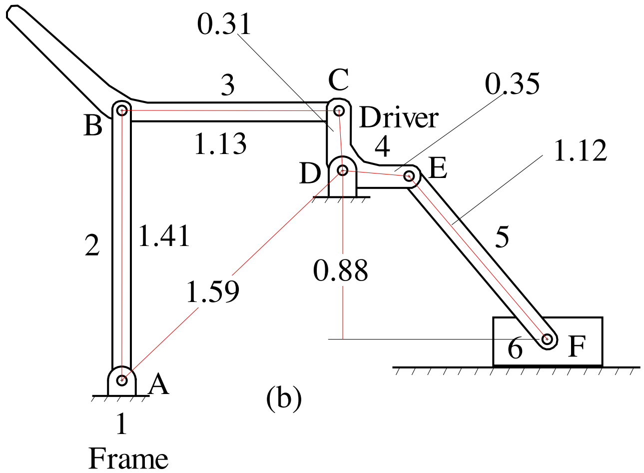
$q = 1.41$ in

Links 4-5-6-1

$a = 0.35$ in

$b = 1.12$ in

$c = 0.88$ in




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

Links 1-2-3-4

$0.31 + 1.59 < 1.13 + 1.41 \Rightarrow 1.90 < 2.54$

Links 4-5-6-1

$1.12 > 0.35 \Rightarrow b > a$

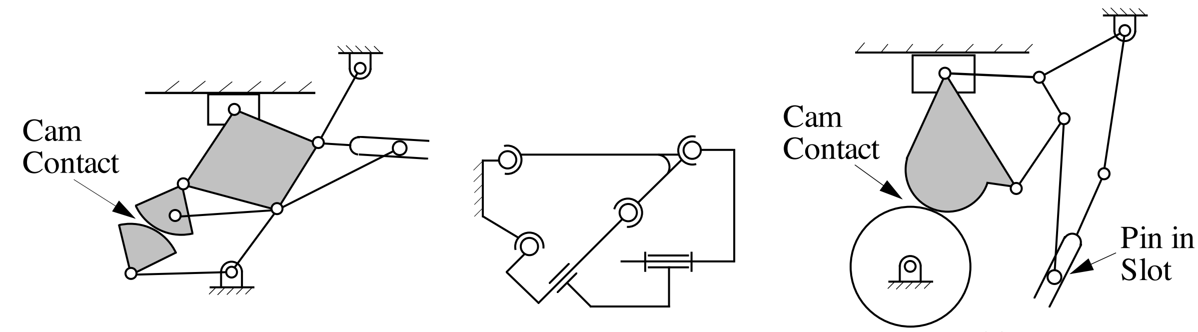
$1.12 - 0.35 < 0.88 \Rightarrow b - a < c$

The mechanism containing links 1-2-3-4 is a crank-rocker mechanism because link 4 is the driver.

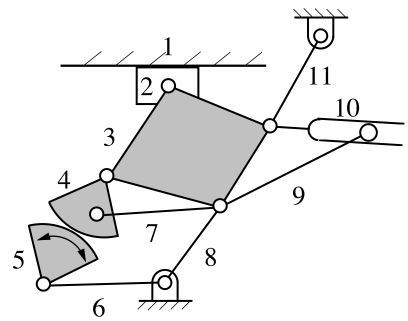
The mechanism containing links 4-5-6-1 is a non Grashof, slider-crank mechanism. The crank cannot make a continuous rotation relative to the other links.

## Problem 1.14

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)




(a)

$n = 11$

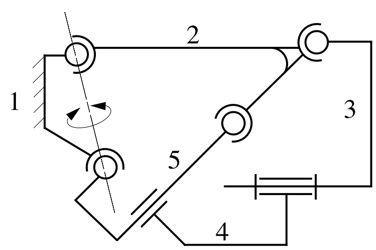
$j = 15$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(11 - 15 - 1) + 17 = -15 + 17 = 2$$

Mobility = 2

Idle DOF = 1




(b)

$n = 5$

$j = 6$

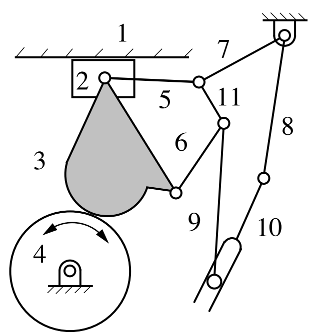
$$M = 6(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 6(5 - 6 - 1) + 4(3) + 2 + 1$$

$$= -12 + 15 = 3$$

Mobility = 3

Idle DOF = 1




(c)

$n = 11$

$j = 14$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

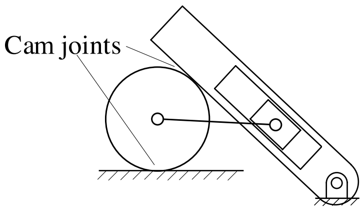
$$= 3(11 - 14 - 1) + 16 = -12 + 16 = 4$$

Mobility = 4

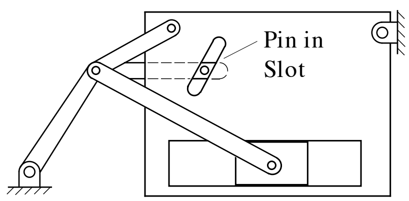
Idle DOF = 1

## Problem 1.16

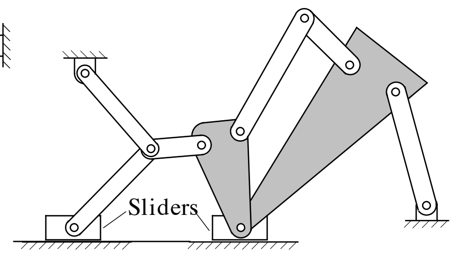
Determine the mobility and the number of idle degrees of freedom associated with each mechanism. Show the equations used to determine your answers.



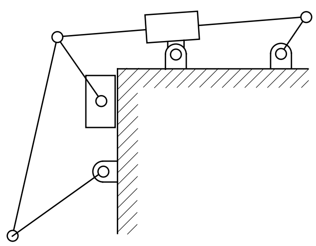

(a)



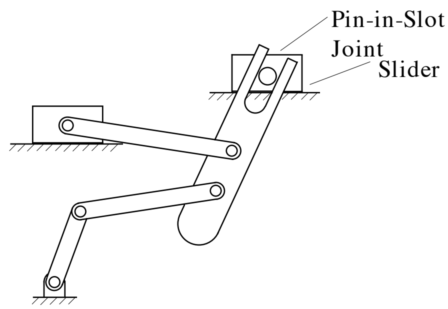

(b)



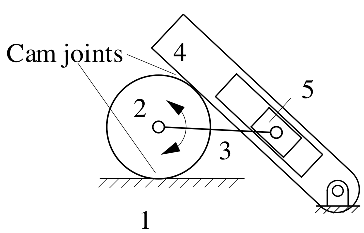

(c)



(d)




(e)




(a)

$n = 5$

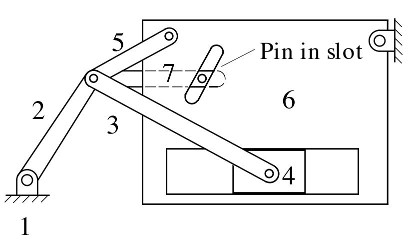
$j = 6$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(5 - 6 - 1) + 8 = -6 + 8 = 2$$

Mobility = 2

Idle DOF = 1




(b)

$n = 7$

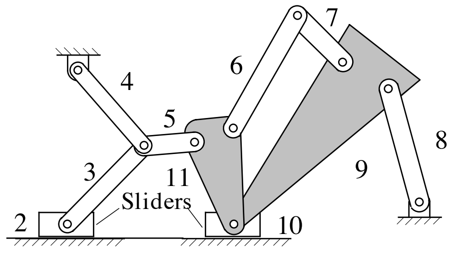
$j = 9$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(7 - 9 - 1) + 10 = -9 + 10 = 1$$

Mobility = 1

Idle DOF = 0



(c)

$n = 11$

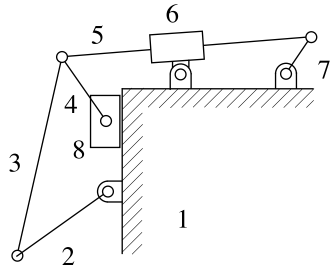
$j = 14$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(11 - 14 - 1) + 14 = -12 + 14 = 2$$

Mobility = 2

Idle DOF = 0



(d)

$n = 8$

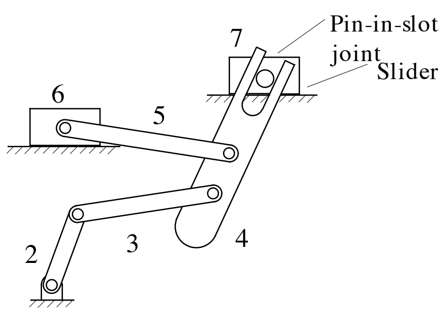
$j = 10$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(8 - 10 - 1) + 10 = -9 + 10 = 1$$

Mobility = 1

Idle DOF = 0



(e)

$n = 7$

$j = 8$

$$M = 3(n - j - 1) + \sum_{i=1}^{j} f_i$$

$$= 3(7 - 8 - 1) + 9 = -6 + 9 = 3$$

Mobility = 3

Idle DOF = 0