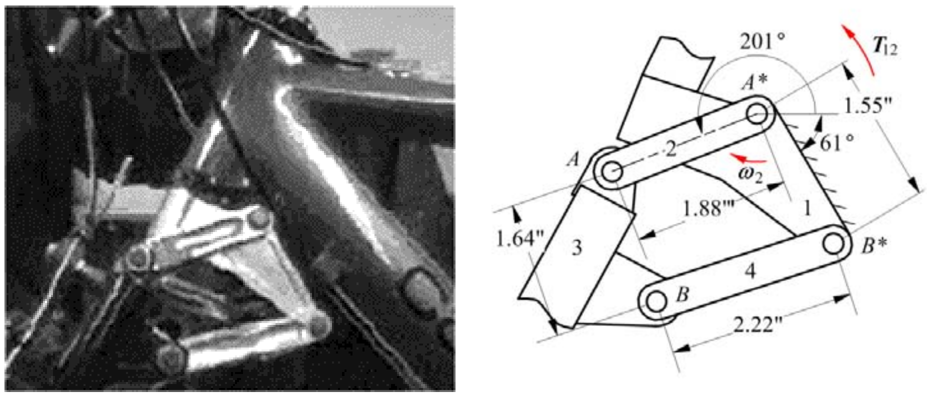
Solutions to Chapter 1 Exercise Problems

Problem 1.1

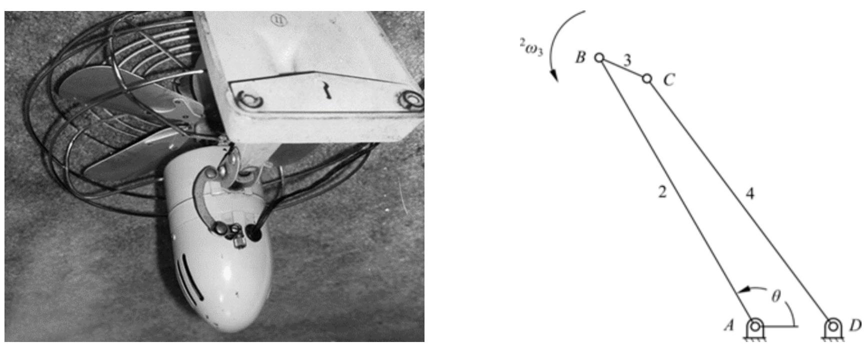
Find a mechanism as an isolated device or in a machine and make a realistic sketch of the mechanism. Then make a freehand sketch of the kinematic schematics for the mechanism chosen.

Solution:

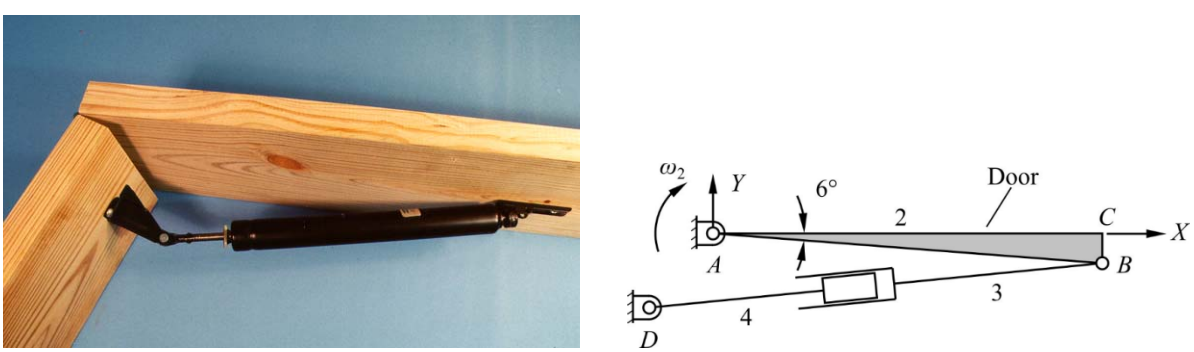
Typical examples of solutions for this problem are given in the problem definitions of Chapter 1. Some examples are:



Bicycle suspension



Oscillating fan



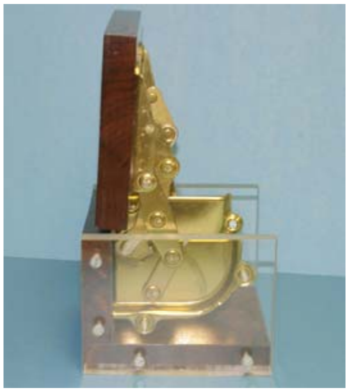
Door closing linkage

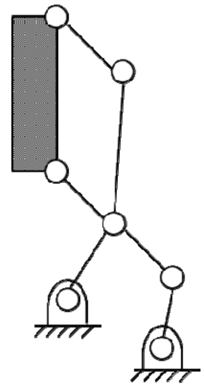
Problem 1.2

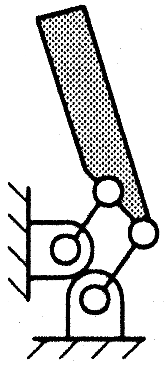
Cabinet hinges use various types of linkages for the folding mechanism. Identify three types of cabinet hinges and make a freehand sketch of the kinematic mechanism used.

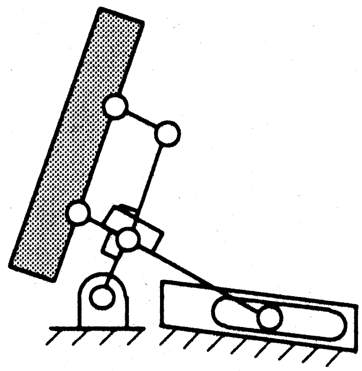
Solution:

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.



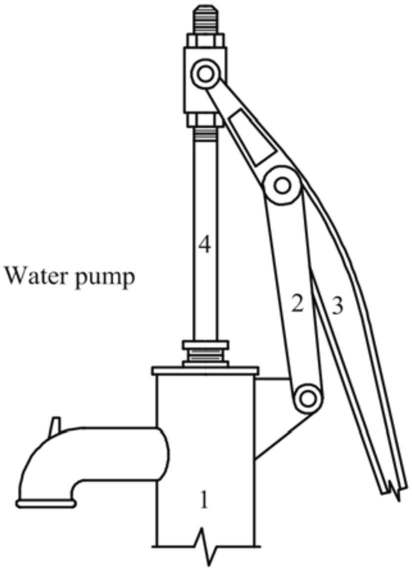




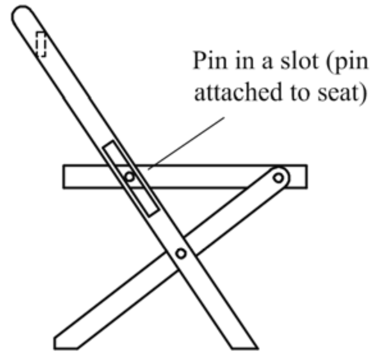


Problem 1.3

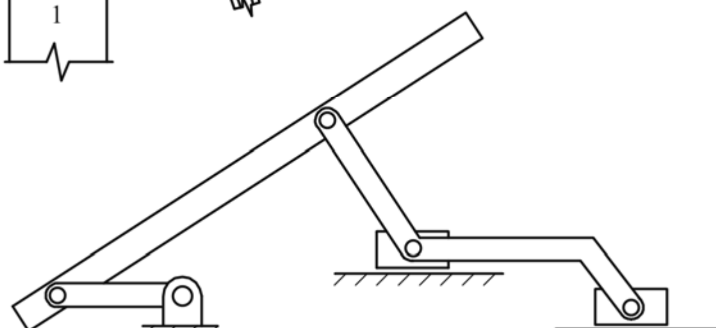
The drawings shown below are pictorial representations of real mechanisms that are commonly encountered. Make a freehand sketch of the kinematic schematic representation of each mechanism.



Water pump

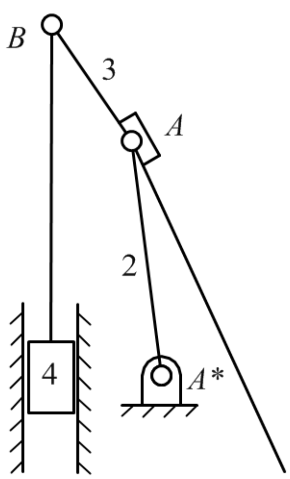


Folding chair

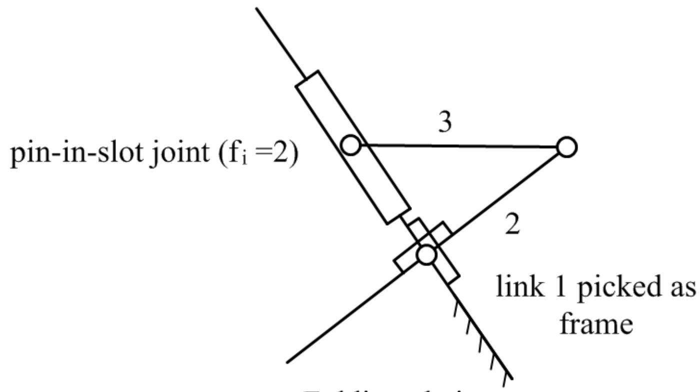


Casement window mechanism

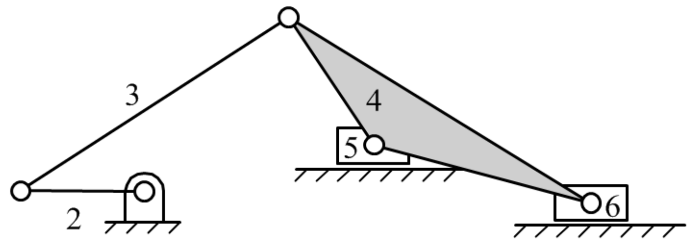
Solution



Water pump



Folding chair



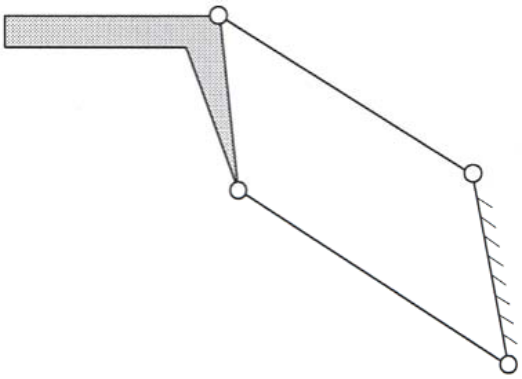
Casement window mechanism

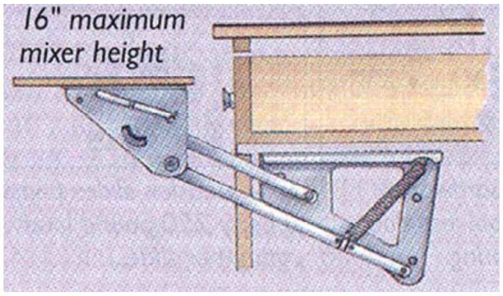
Problem 1.4

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.

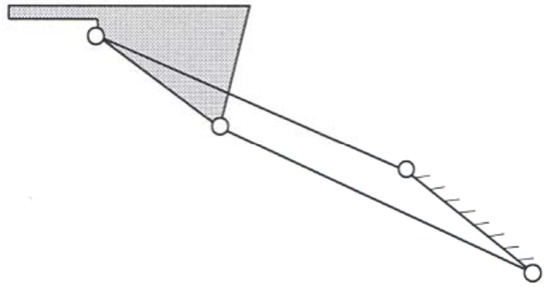
Solution:

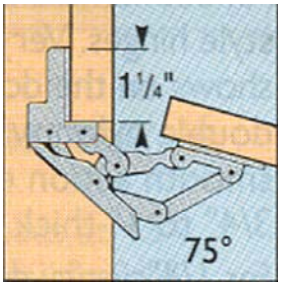
Typewriter desk linkage



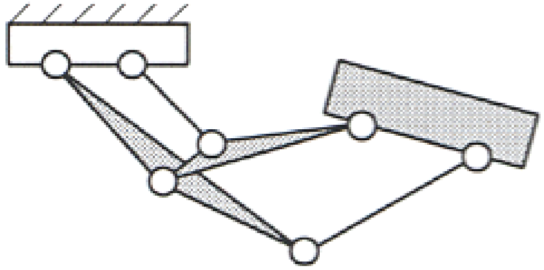


Under drawer swing up mechanism





Overhead bin hinge

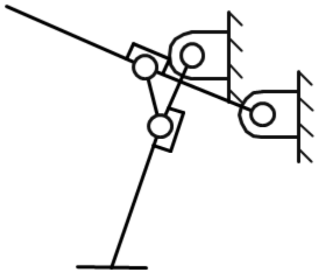


Problem 1.5

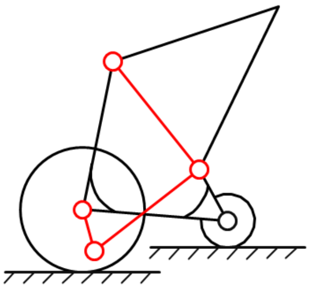
Four bar linkages are used in common devices around the home and businesses. Locate six such devices and make a freehand sketch of each device and describe its function.

Solution:

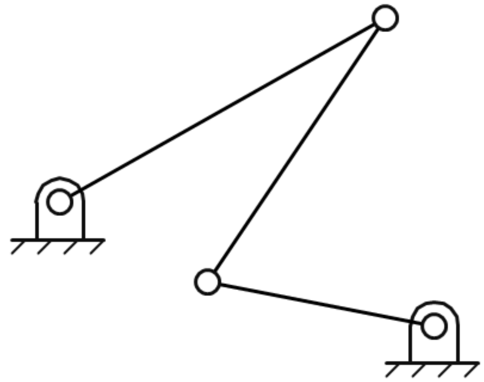
Sample examples are given in the following:



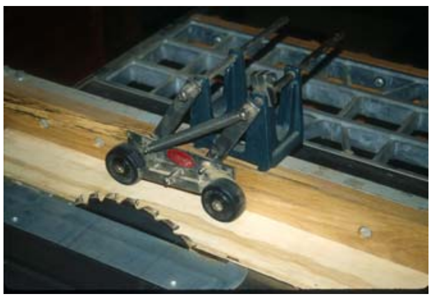
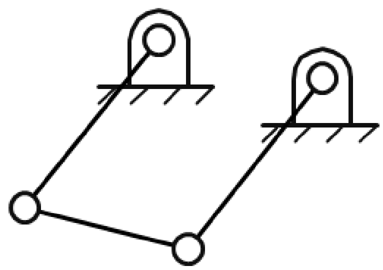
Brake for wheelchair. The mechanism exhibits a toggle motion



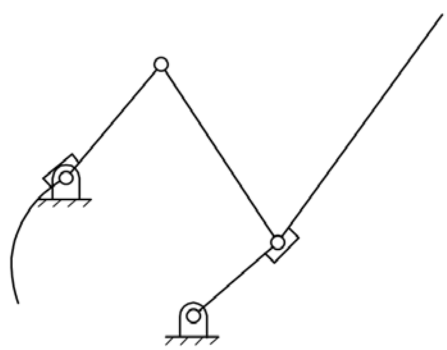
Walking toy. The four bar linkage moves the leg and wing.

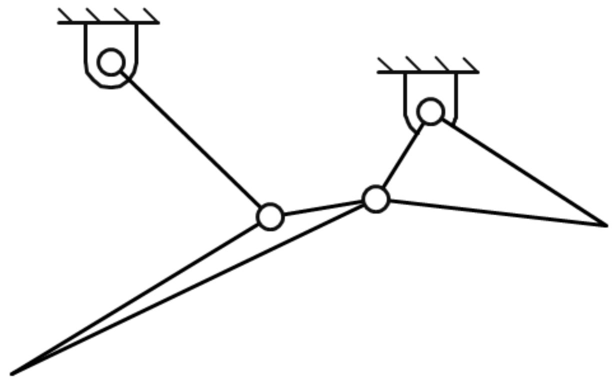
Door closer.   The four bar linkage is connected to a damper mechanism

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

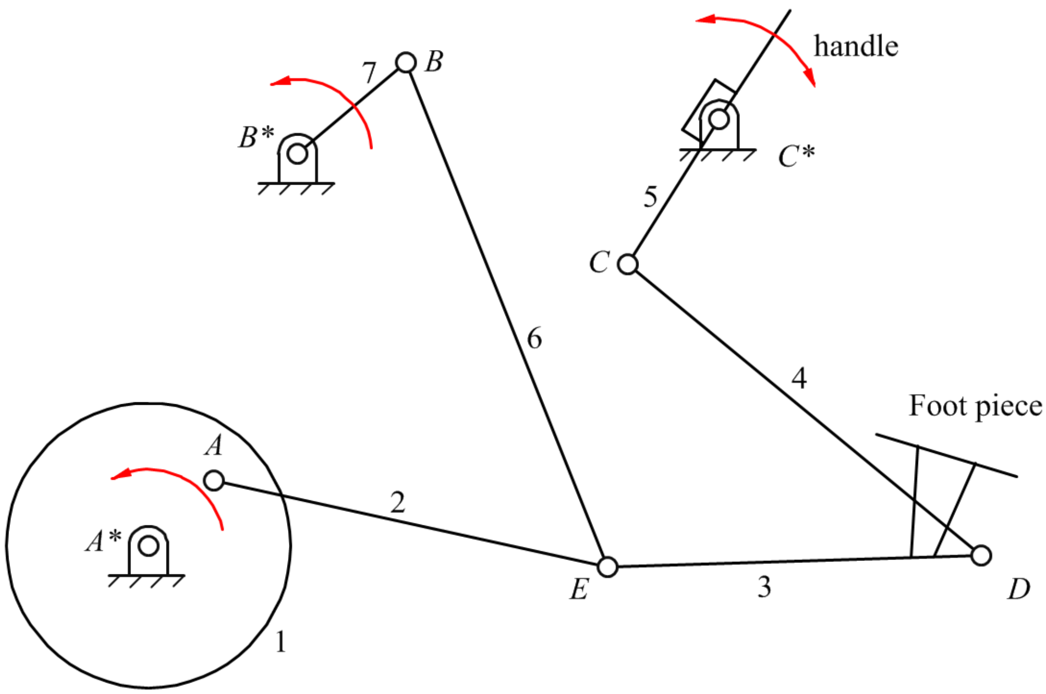
Vice grips. The four bar linkage is a toggle mechanism

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 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? 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).

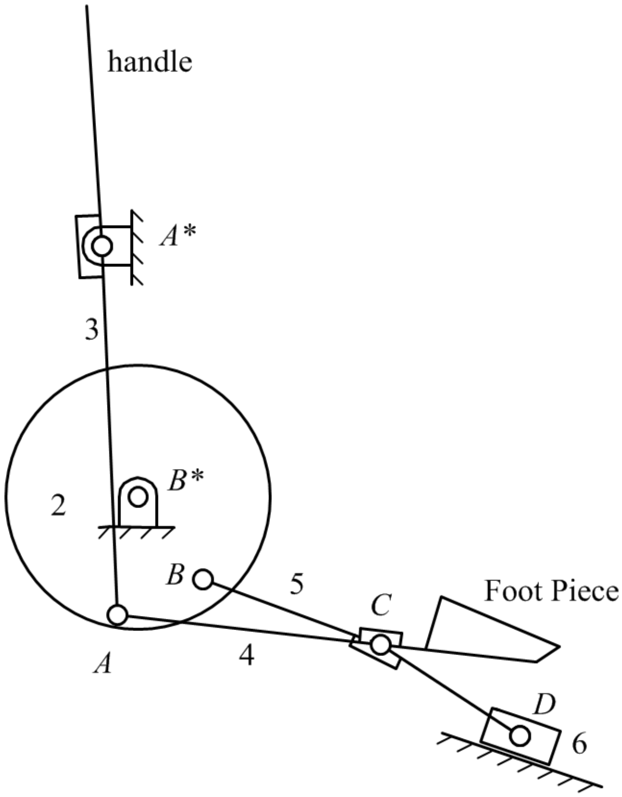


Problem 1.7

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.

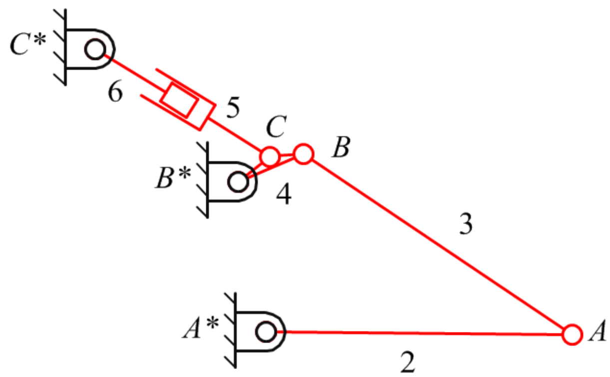
Solution:

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

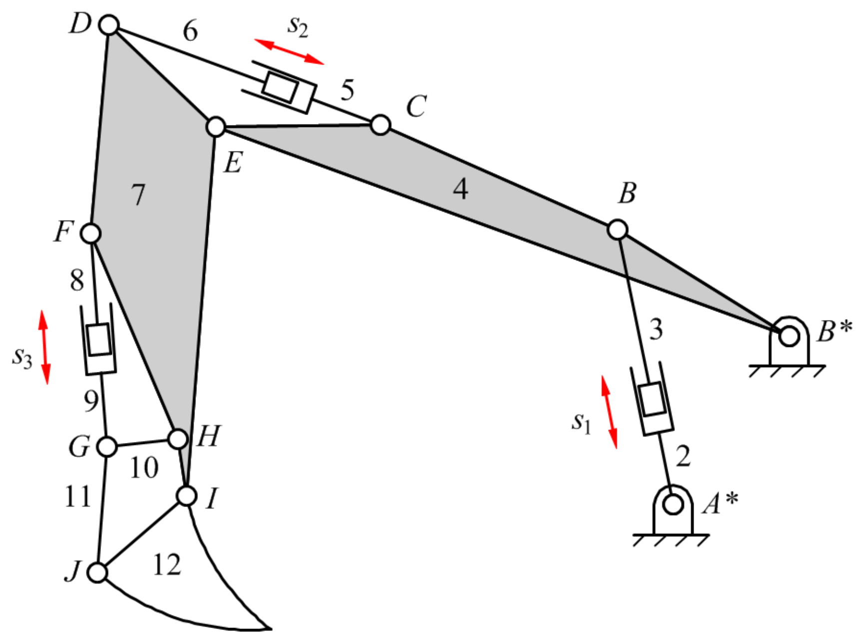
The figure shows a bicycle suspension linkage. If the shock absorber is considered, the linkage can be represented as a six bar mechanism. Draw the back suspension linkage and identify the chain in Fig. 1.23 to which the topography corresponds.



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

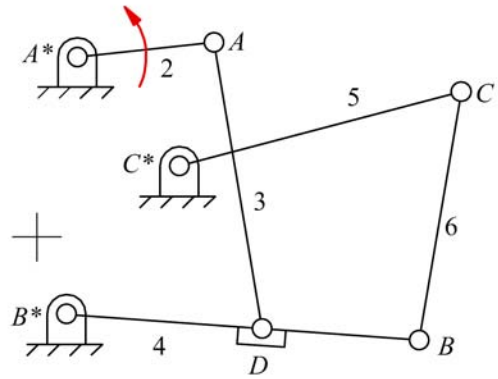
A small excavator is shown in the photograph. The machine has a swing linkage but the main mechanism is planar. Draw the planar excavation linkage. Treat each hydraulic cylinders as a slider in a tube.



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

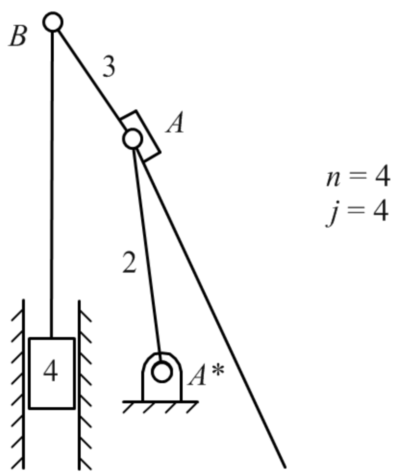
1.10 Since the mid 1940's, modern tractors used for farming, construction, and landscape work have used a 3-point hitch to attach implements to the rear of the tractor. This allows the operator to control the height and orientation of the implement using the tractor hydraulic system. A 3-point hitch 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

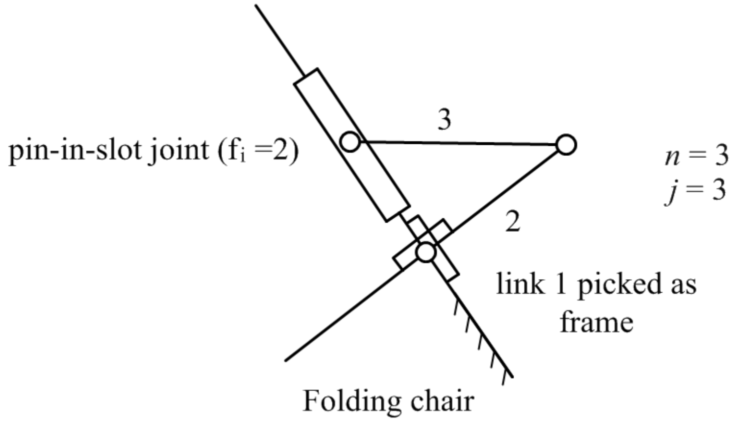
Calculate the mobility, or number of degrees of freedom, of each of the mechanisms in Problem 1.3.



Water pump

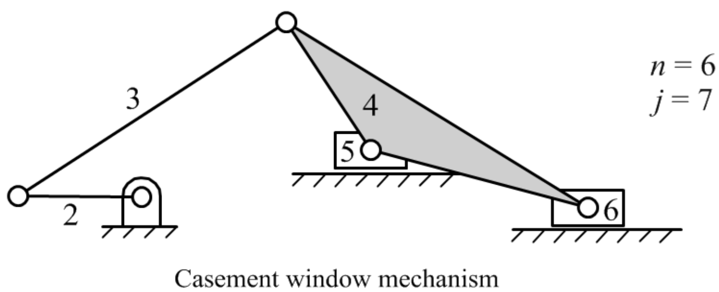
$$M = 3(n - j - 1) + \sum f_i = 3(4 - 4 - -1) + 4 = -3 + 4 = 1$$

Mobility = 1.



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

Mobility = 1.

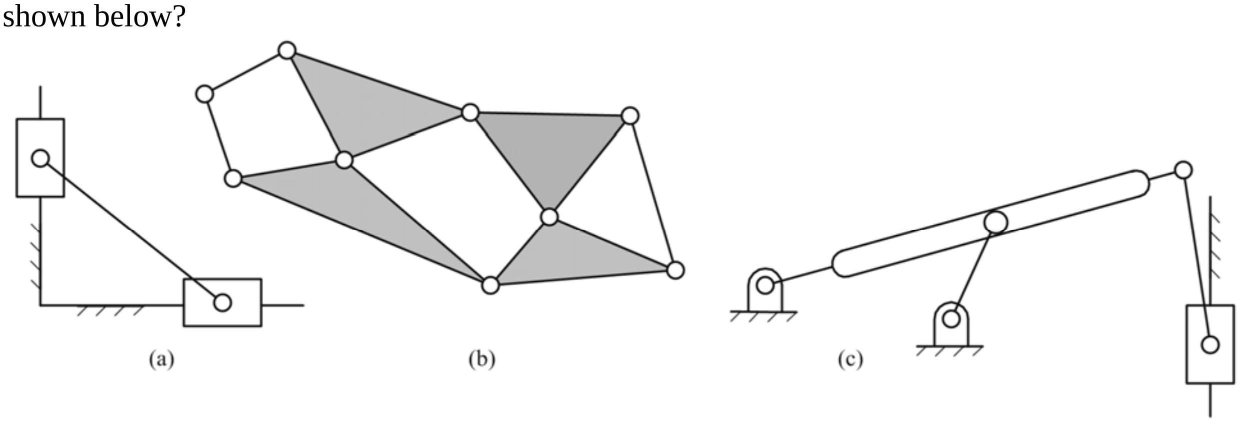


$$M = 3(n - j - 1) + \sum f_i = 3(6 - 7 - 1) + 7 = -6 + 7 = 1$$

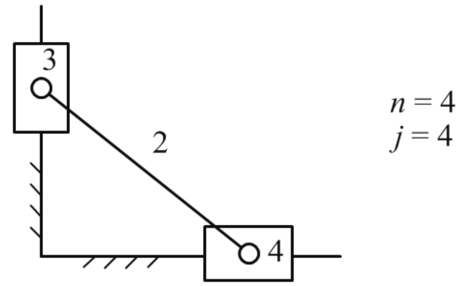
Mobility = 1.

Problem 1.12

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



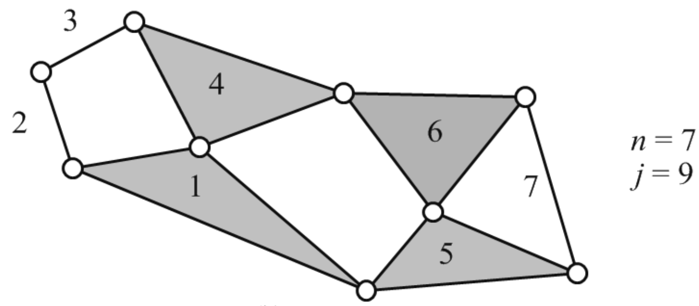
Solution:



(a)

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

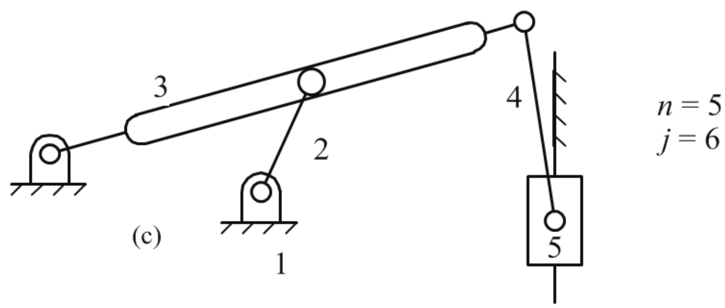
Mobility = 1.



(b)

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

Mobility = 0.



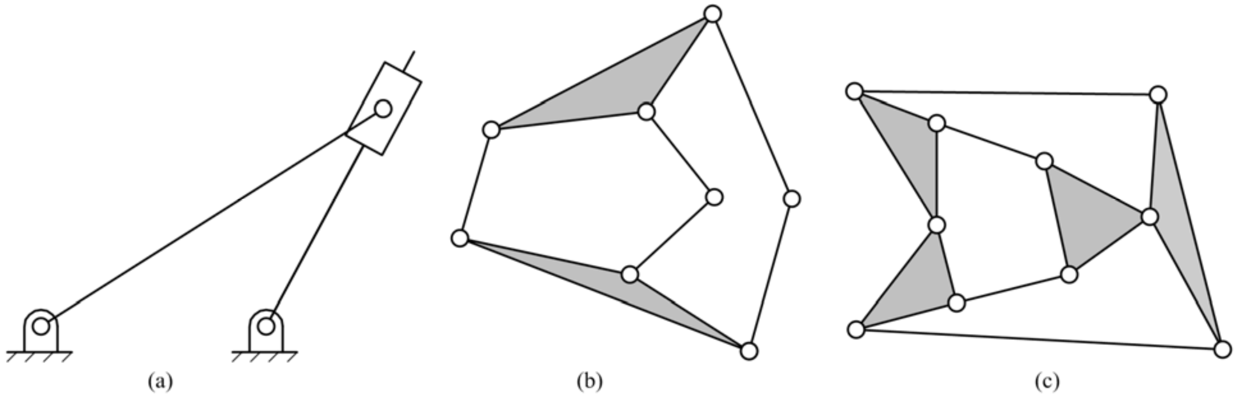
(c)

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

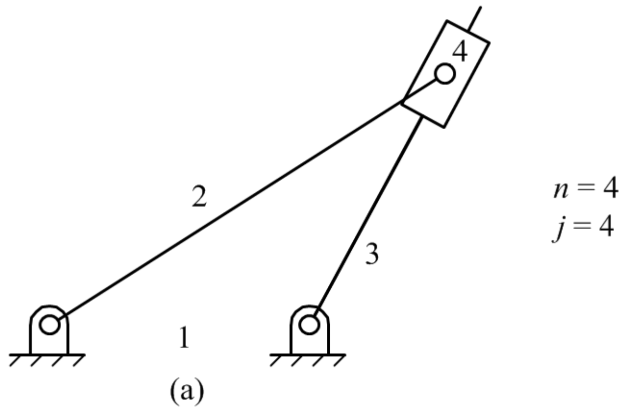
Mobility = 1.

Problem 1.13

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

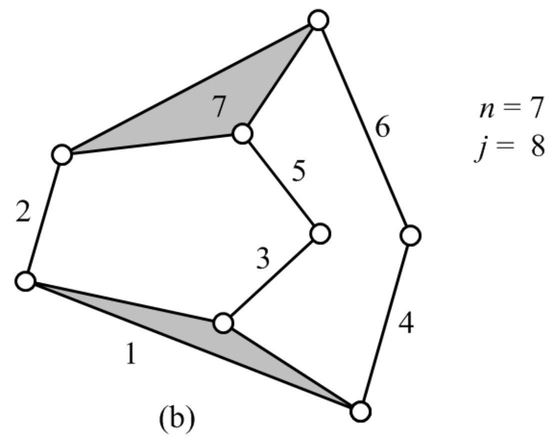


Solution:



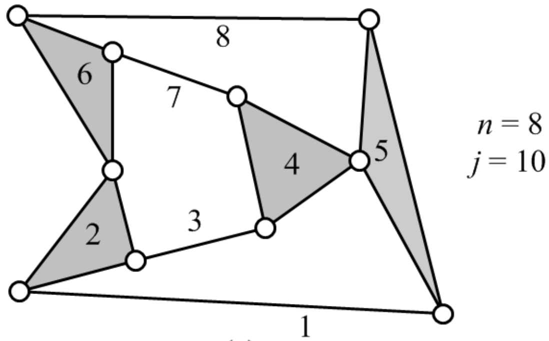
$$M = 3(n - j - 1) + \sum f_i = 3(4 - 4 - 1) + 4 = -3 + 4 = 1$$

Mobility = 1.



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

Mobility = 2.



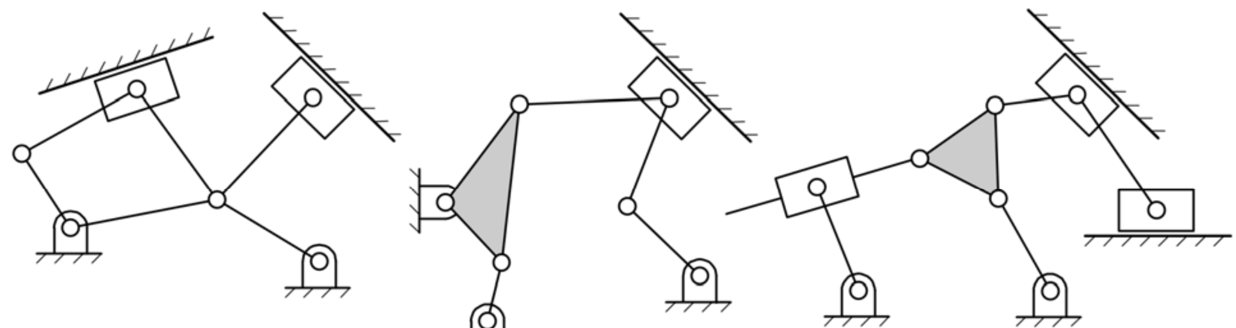
(c)

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

Mobility = 1.

Problem 1.14

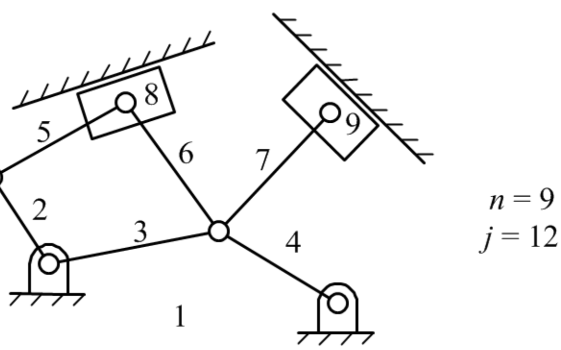
Determine the mobility and the number of idle degrees of freedom of each of the planar linkages shown below. Show the equations used and identify the input and output links assumed when determining your answers.



(a) (b) (c)

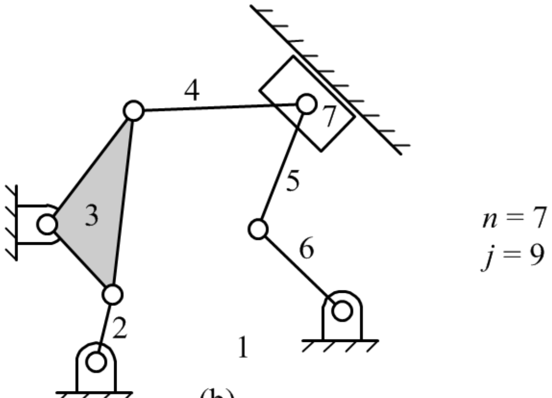
Solution:

(a)



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

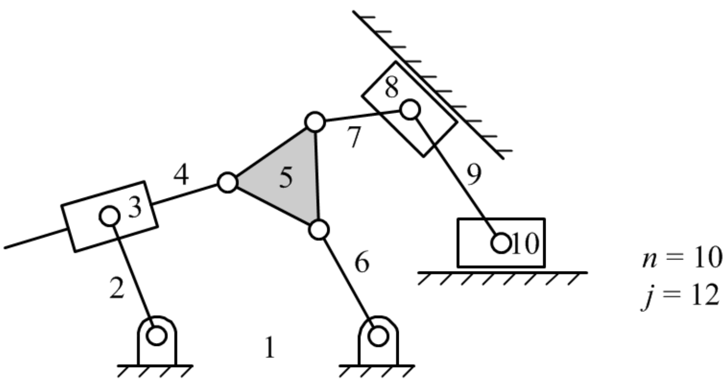
Mobility = 0.
Idle DOF = 0



(b)

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

Mobility = 0.
Idle DOF = 0



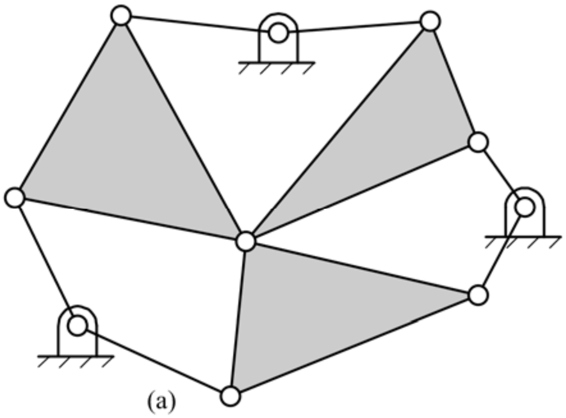
(c)

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

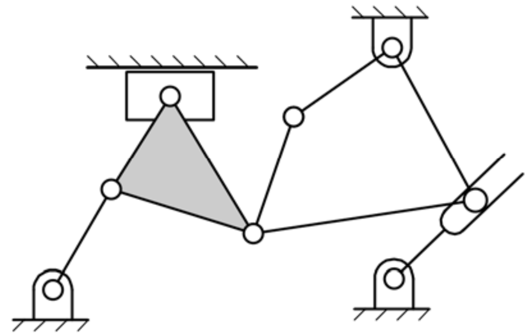
Mobility = 3.
Idle DOF = 0

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.

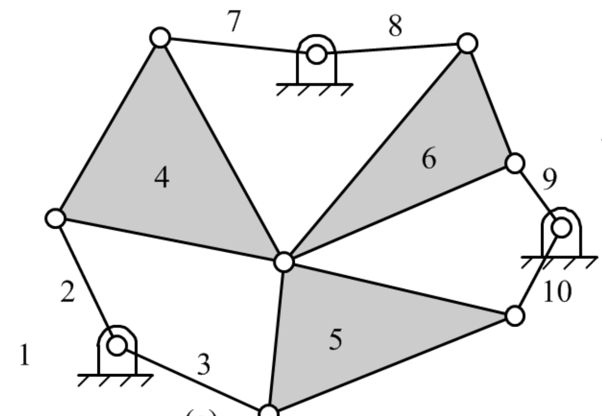


(a)



(b)

Solution:

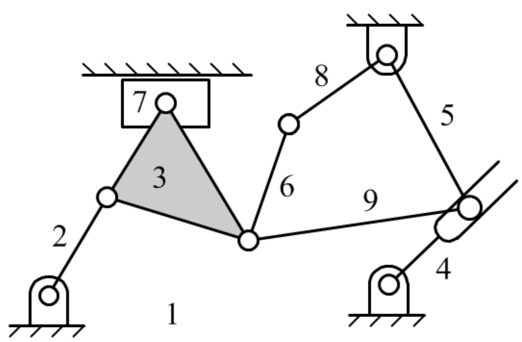


(a)

$n = 10$
$j = 14$

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

Mobility = -1.
Idle DOF = 0



(b)

$n = 9$
$j = 12$

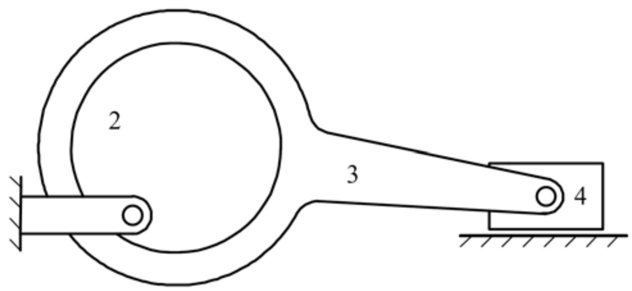
$$\sum f_i = 10 \times 1 + 2 \times 2 = 14$$

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

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:

$n = 4$

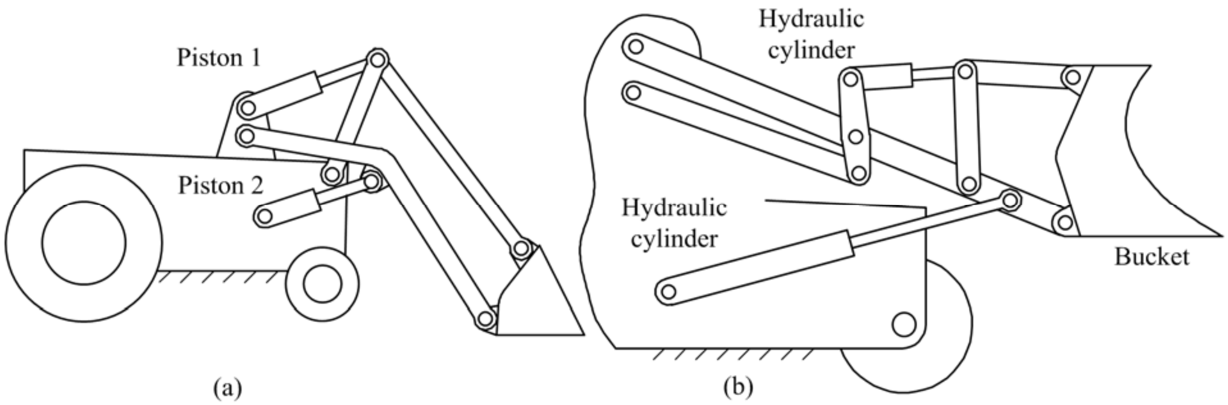
$j = 4$

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

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

Problem 1.17

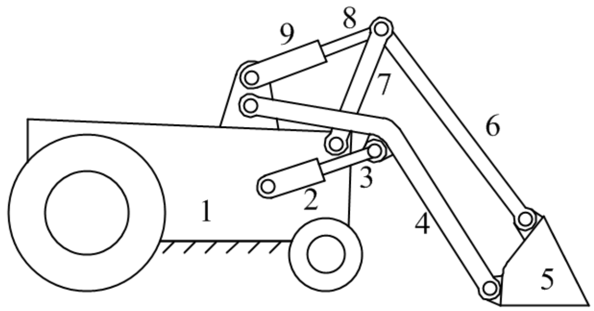
Determine the mobility of each of the planar linkages shown below. Show the equations used to determine your answers.



(a) (b)

Solution:

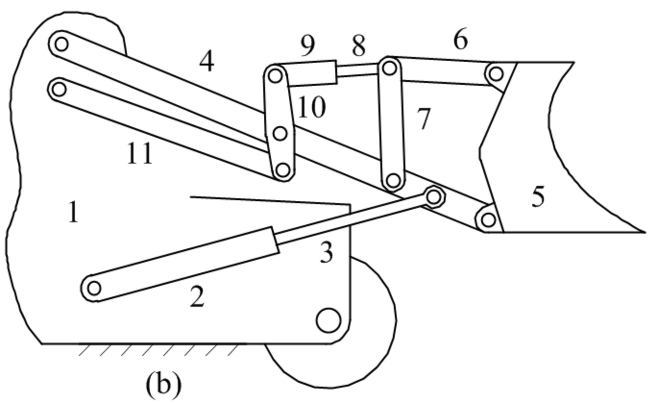
(a)



$n = 9$
$j = 11$

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

Mobility = 2.
Idle DOF = 0



(b)

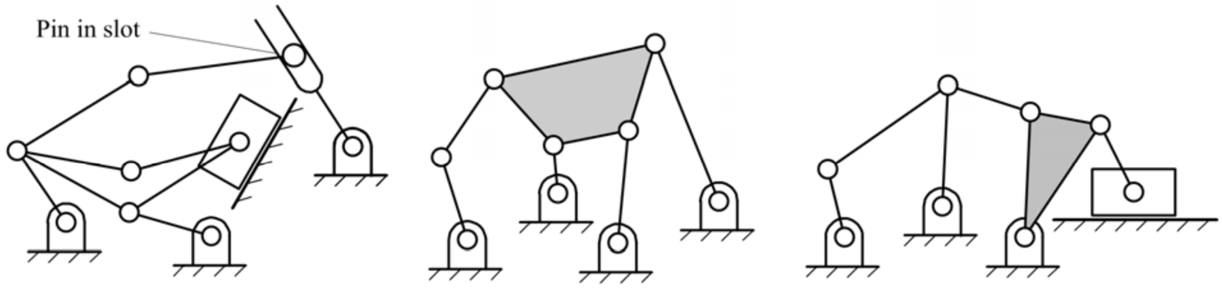
$n = 11$
$j = 14$

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

Mobility = 2.
Idle DOF = 0

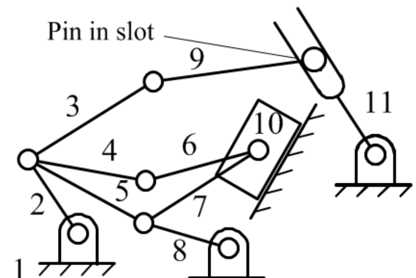
Problem 1.18

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)

<u>Solution:</u>



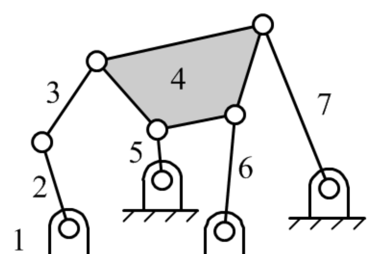
(a)

$n = 11$
$j = 14$

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

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

Mobility = 3.
Idle DOF = 0

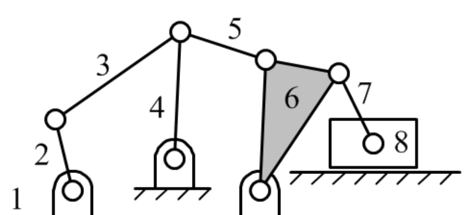


(b)

$n = 7$
$j = 9$

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

Mobility = 0.
Idle DOF = 0



(c)

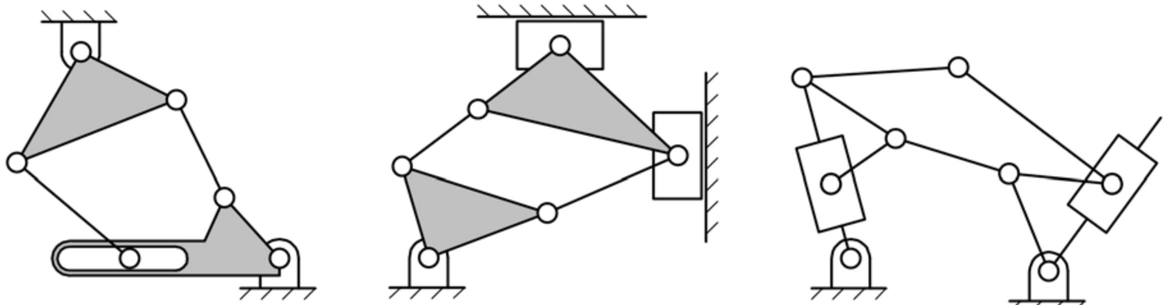
$n = 8$
$j = 10$

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

Mobility = 1.
Idle DOF = 0

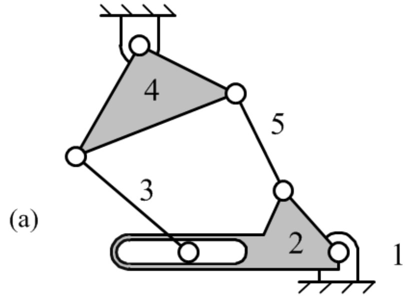
Problem 1.19

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)

Solution:

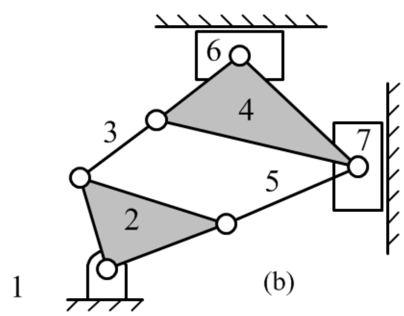


$n = 5$
$j = 6$

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

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

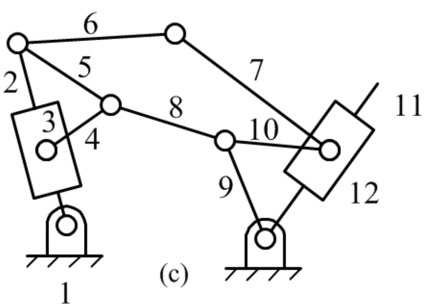
Mobility = 1.
Idle DOF = 0



$n = 7$
$j = 9$

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

Mobility = 0.
Idle DOF = 0



$n = 12$
$j = 15$

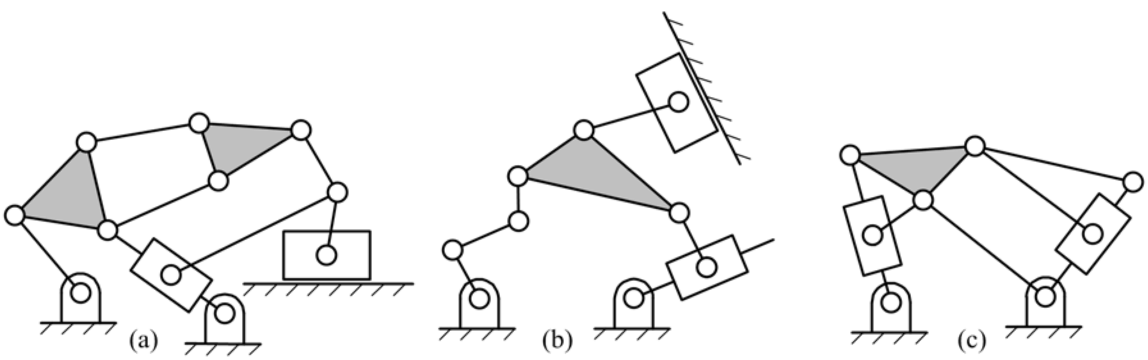
$$M = 3(n - j - 1) + \sum f_i = 3(12 - 15 - 1) + 15 = -12 + 15 = 3$$

Mobility = 3.
Idle DOF = 0

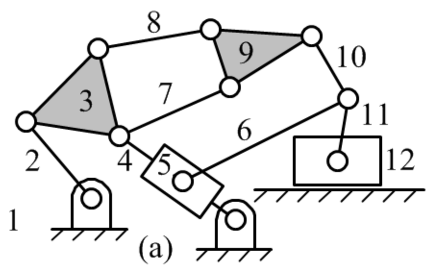
Problem 1.20

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:



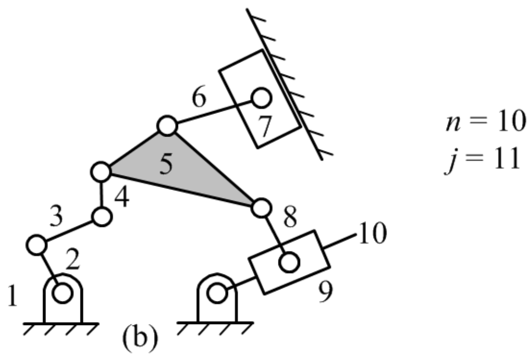
Solution:



$n = 12$
$j = 15$

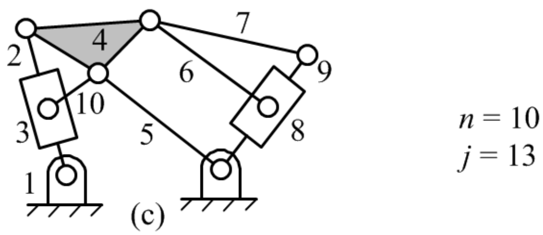
$$M = 3(n - j - 1) + \sum f_i = 3(12 - 15 - 1) + 15 = -12 + 15 = 3$$

Mobility = 3.
Idle DOF = 0



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

Mobility = 5.
Idle DOF = 0

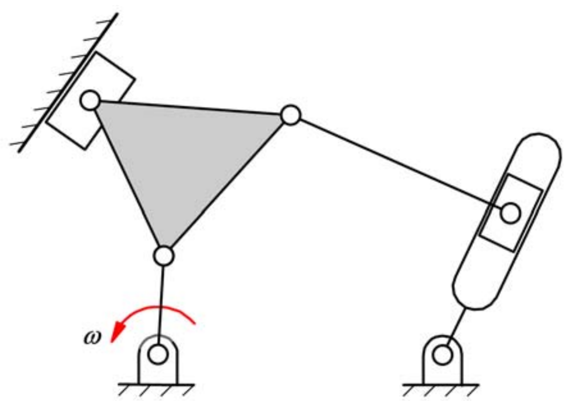


$$M = 3(n - j - 1) + \sum f_i = 3(10 - 13 - 1) + 13 = -12 + 13 = 1$$

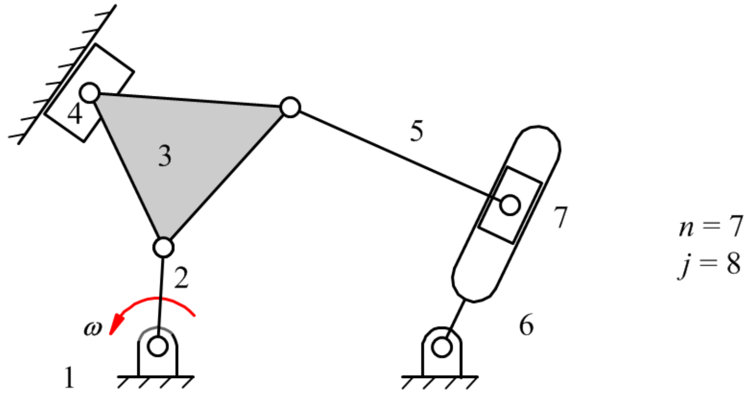
Mobility = 1.
Idle DOF = 0

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:



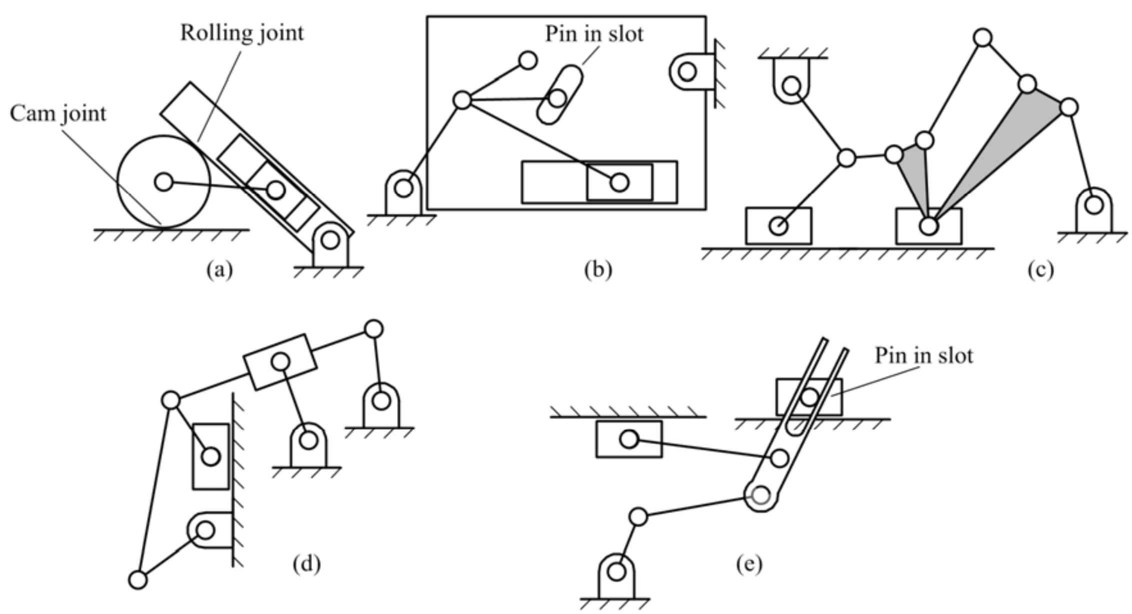
$$M = 3(n - j - 1) + \sum f_i = 3(7 - 8 - 1) + 8 = -6 + 8 = 2$$

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: