COMP0205 Mechatronics and Making

Joints, Links and Mechanisms

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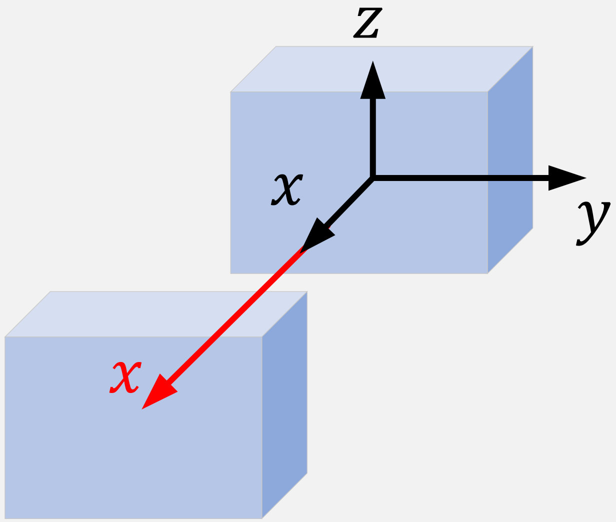
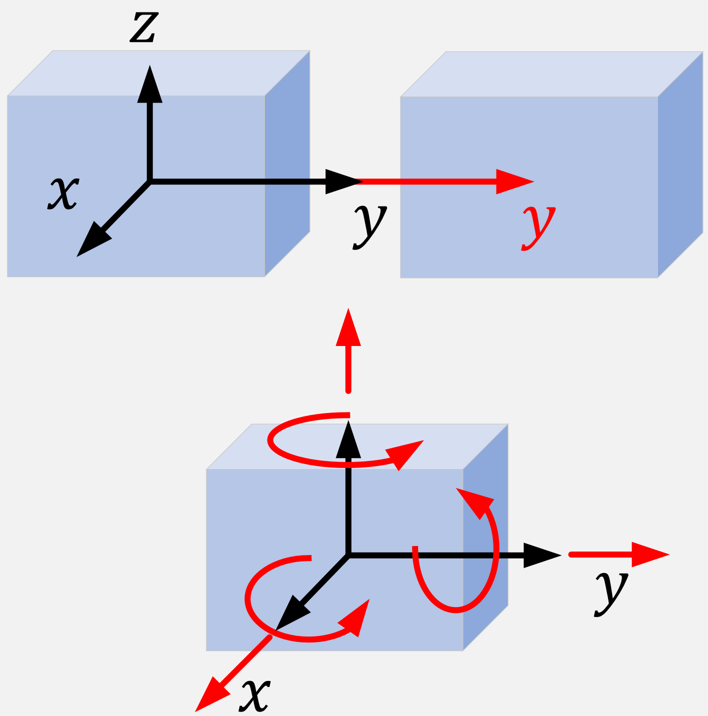
Today’s Objectives

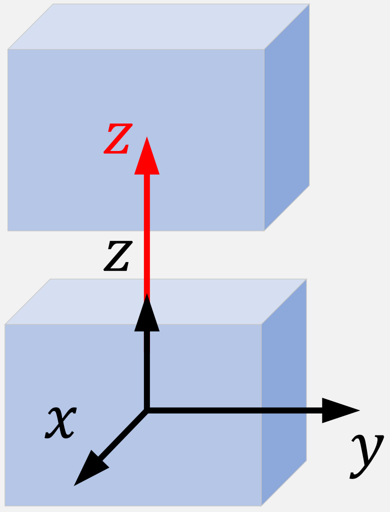
- Define and discuss **degrees of freedom**
- Become familiar with **links and joints**
- Become familiar with **basic planar mechanisms**

Degrees of Freedom

Degrees of freedom (DoF) are the sets of independent displacements and/or rotations that specify completely the displaced or deformed position and orientation of the body or system.





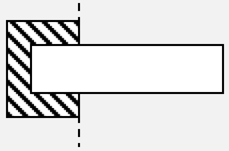
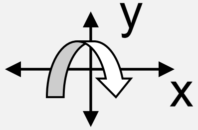
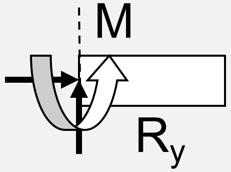
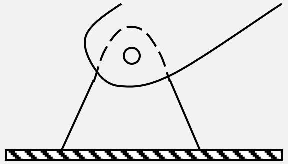
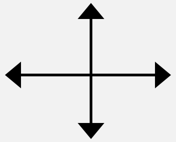
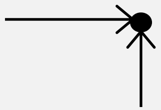
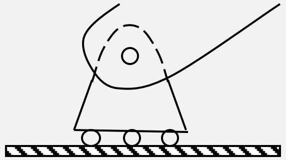
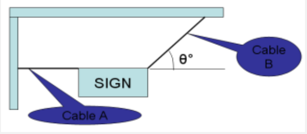


Kinematic Pairs

In classical mechanics, a **kinematic pair** is a connection between two physical objects that imposes constraints on their relative movement (kinematics). German engineer Franz Reuleaux introduced the kinematic pair as a new approach to the study of machines back in 1876.

- In **kinematics**, the two connected physical objects, forming a kinematic pair, are called ‘**rigid bodies**’.
- In studies of mechanisms, manipulators or **robots**, the two objects are typically called ‘**links**’.

Types of Support/Connection for Components

Supports		Constraints	Reaction forces
	Built-in fixed (cantilever) support		
	Pin connection		
	Roller support		
	Cable support	Defined by the cable	

Mechanical Joints

A **mechanical joint** is a section of a machine which is used to connect one (sometimes several) mechanical part to another. Mechanical joints may be temporary or permanent; most types are designed to be disassembled.

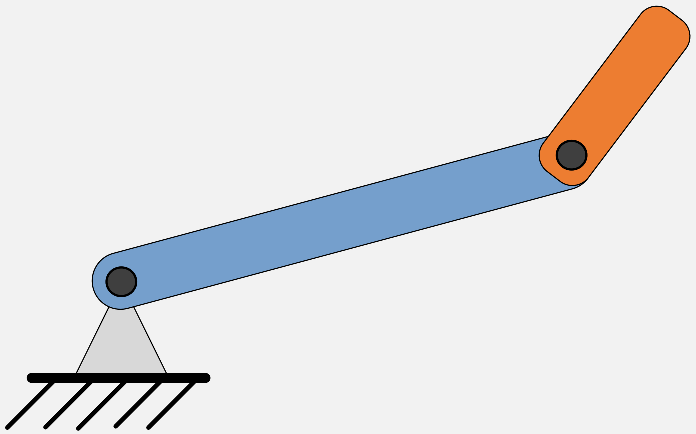
Most mechanical joints are designed to **allow** **relative movement of these mechanical parts** of the machine in **one degree of freedom** and **restrict** movement in one or more others.

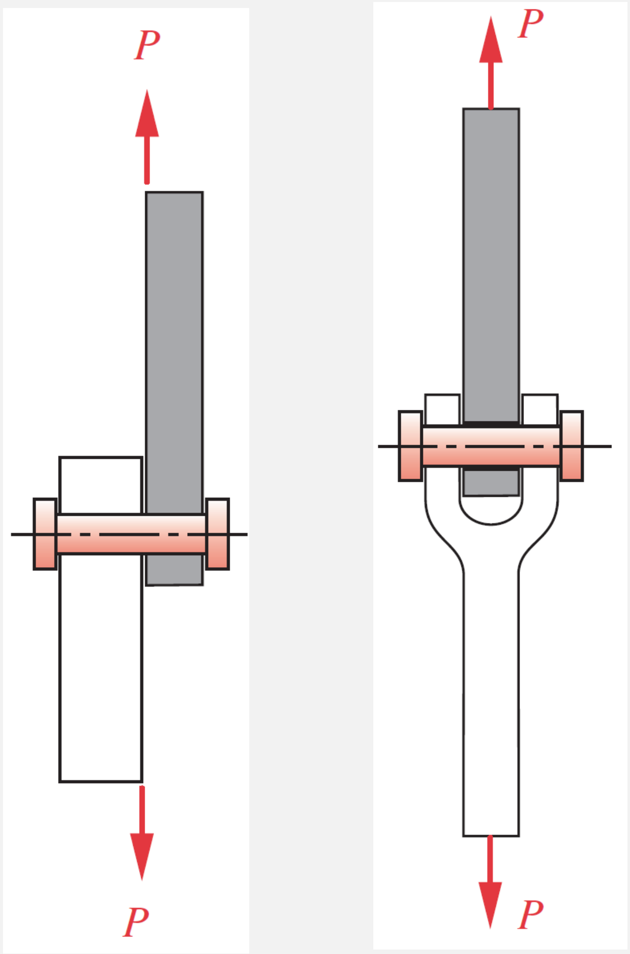
Revolute Joints

A **pin joint**, also called a **revolute joint**, is a 1 DoF kinematic pair.

- It constrains the motion of two bodies to **pure rotation along a common axis**.

The joint doesn't allow translation, or sliding linear motion.



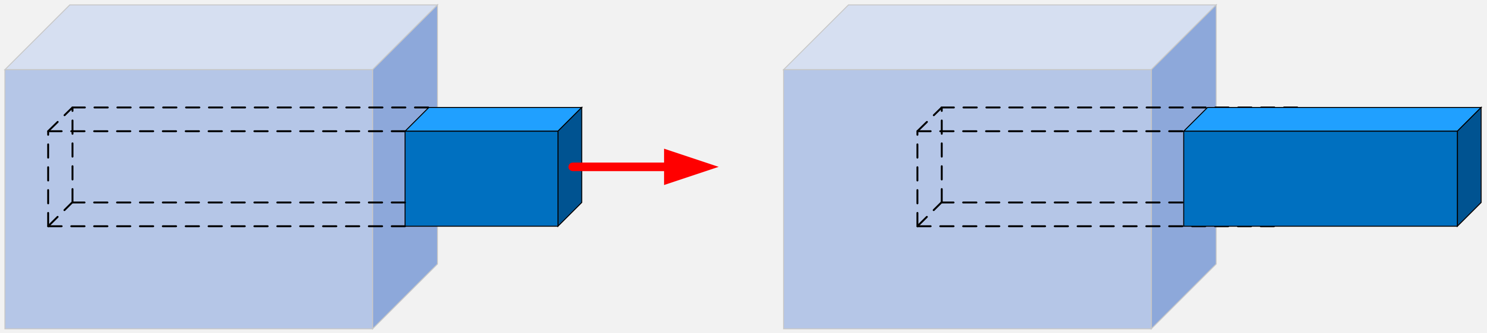


From: Norton, Robert L. (2008). Design of Machinery (4th ed.).

Prismatic Joints

A **prismatic joint** is a 1 DoF kinematic pair which constrains the motion of two bodies to **sliding along a common axis**, without rotation; for this reason, it is often called a slider or a sliding pair.

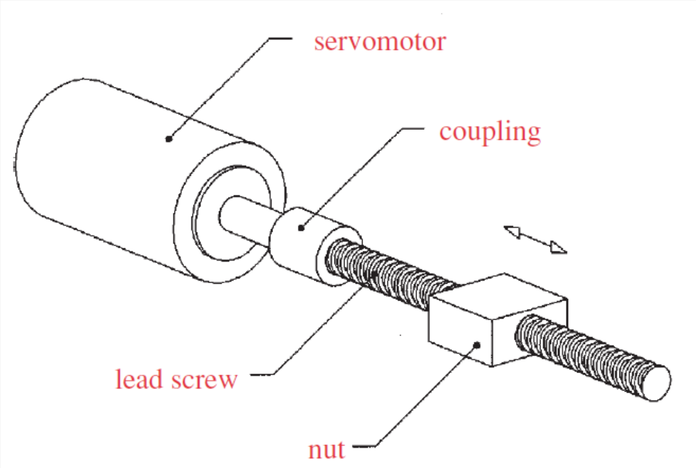
They are often utilized in **hydraulic and pneumatic cylinders**.

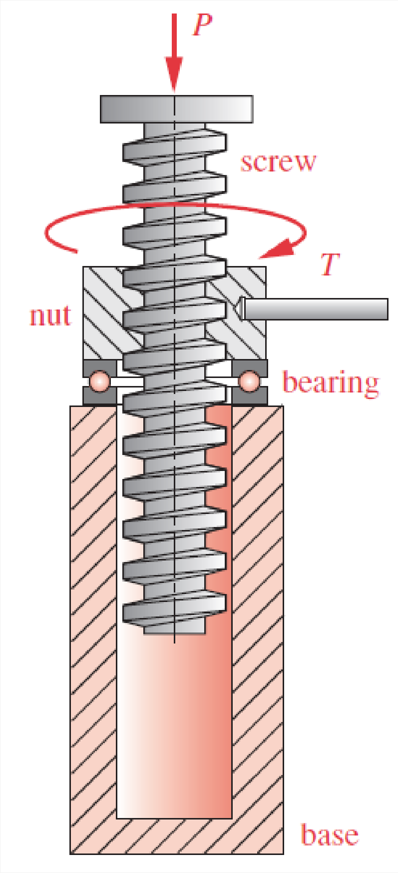


Screw Joint

A **screw joint** is a 1 DoF kinematic pair used in mechanisms. Screw joints provide single-axis translation by utilizing the threads of a lead screw to provide such translation.

This type of joint is used primarily on most types of **linear actuators** and certain types of cartesian robots.

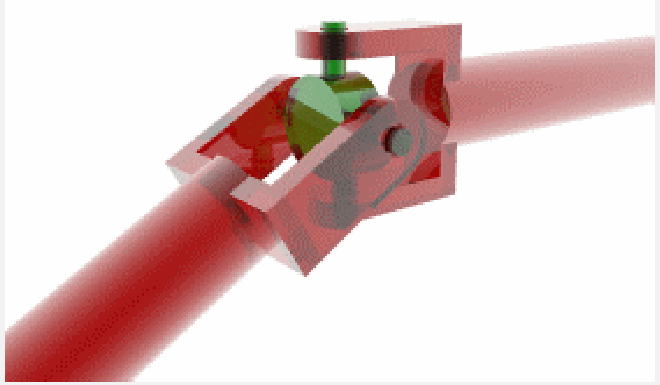


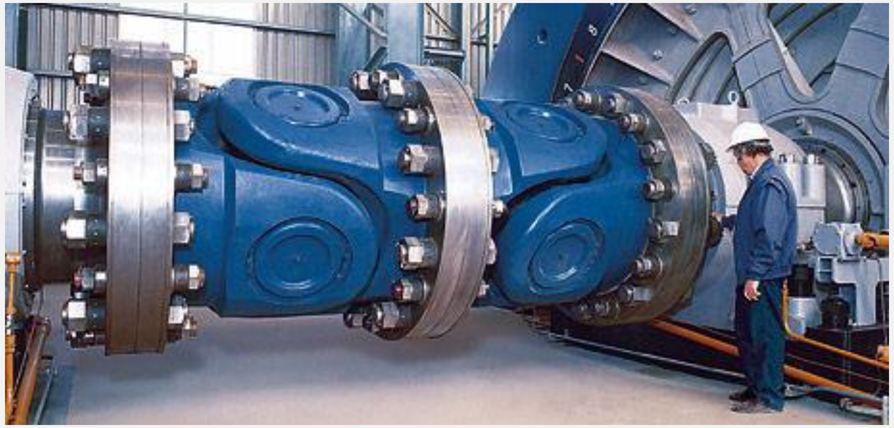


From: Norton, Robert L. (2008). Design of Machinery (4th ed.).

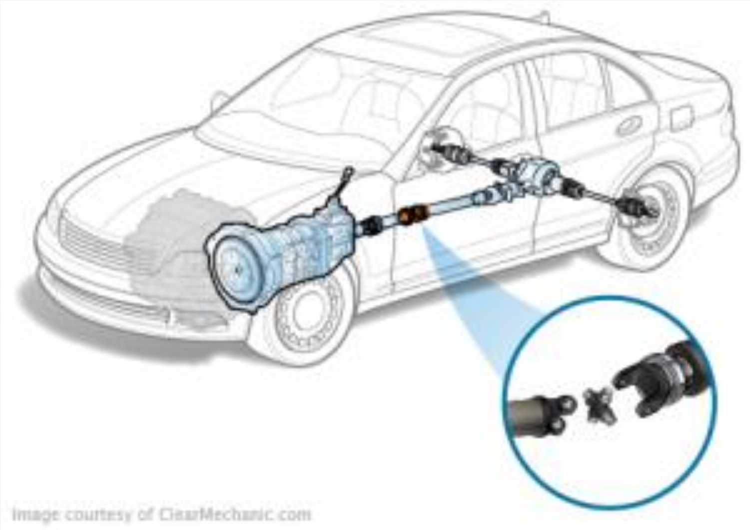
Universal Joint

A **universal joint** (also called a universal coupling or U-joint) is a joint or coupling connecting rigid shafts whose **axes are inclined to each other**. It is commonly used in shafts that transmit **rotary motion**.





Ships propeller drive shaft

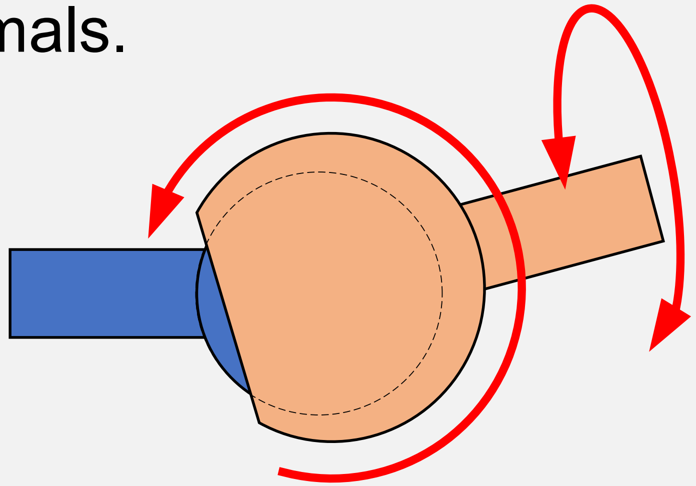


Car rear wheel drive shaft

Spherical Joint

A **spherical (ball) joint** consists of a bearing stud and socket enclosed in a casing. Widely used in automobiles and game controllers.

- They bionically resemble the ball-and-socket joints found in most tetrapod animals.

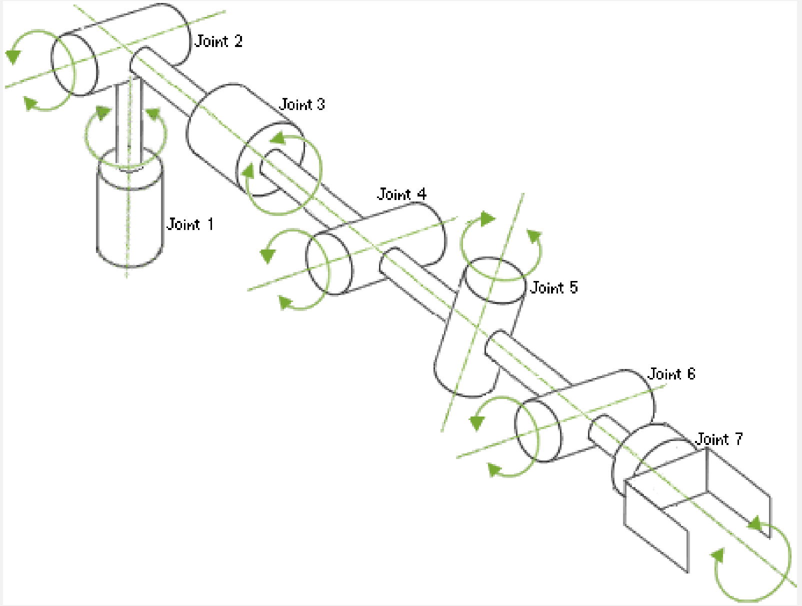


Source: Wiki

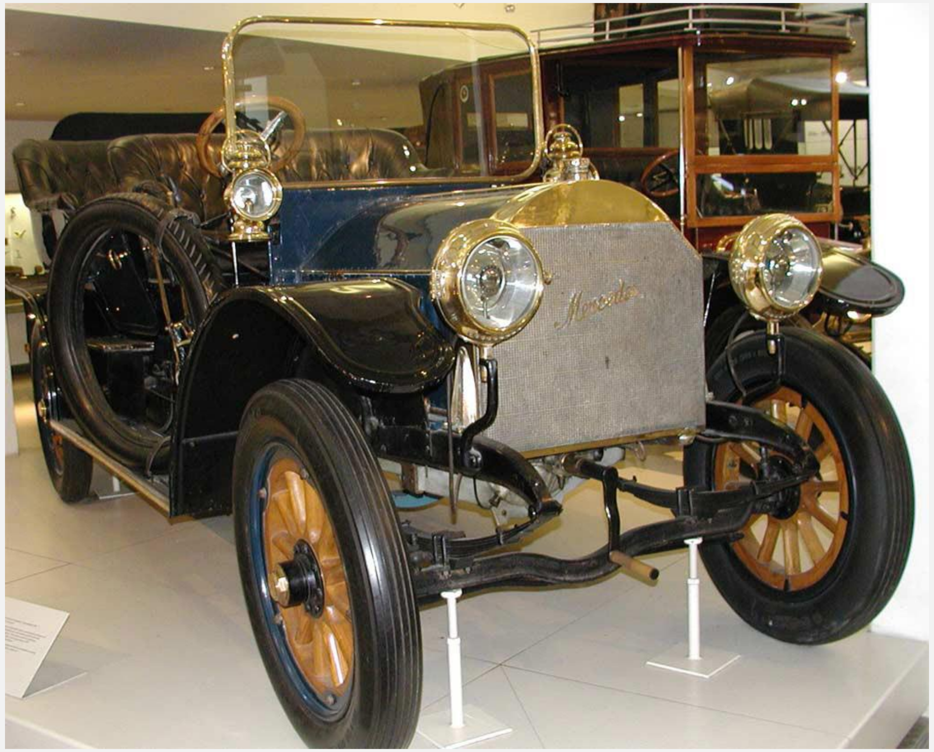
Robotic Arms

Robotic arms (manipulators) can be represented as a series of links connected by revolute joints and often have 6 or more DOF.

Source: [Wiki]

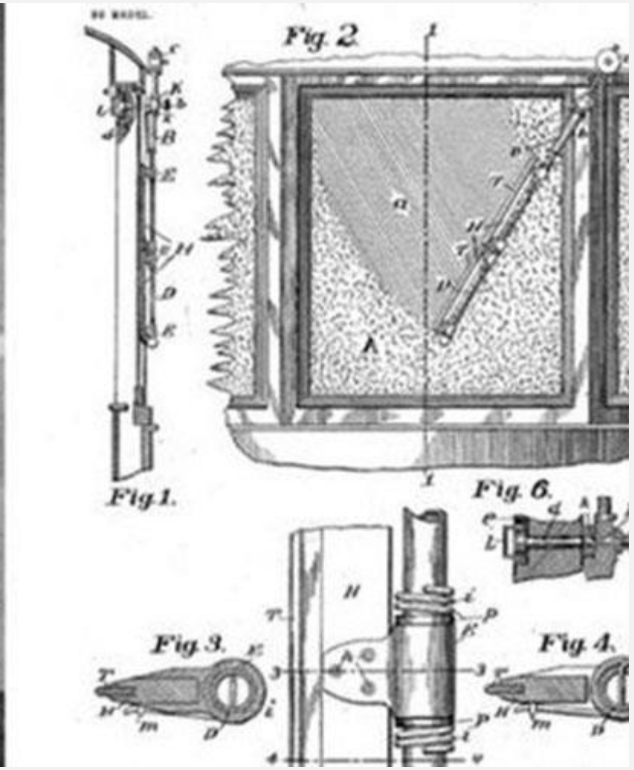


Case Study

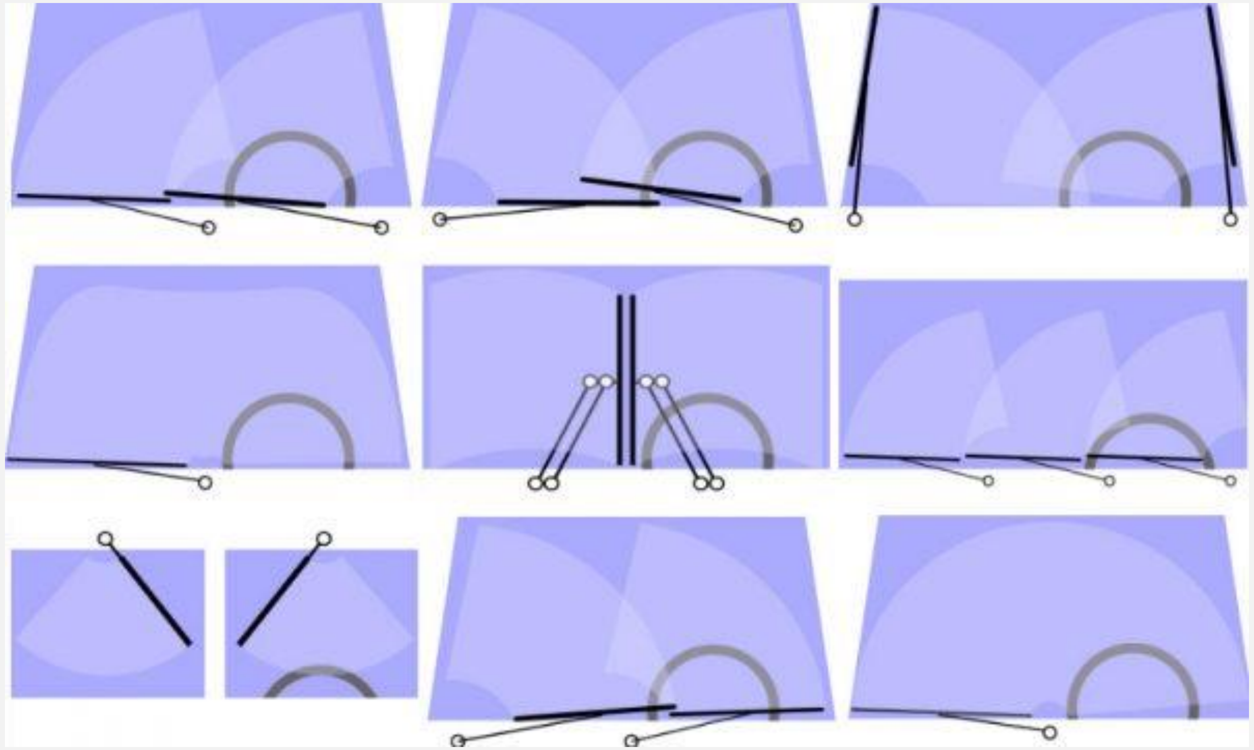


No windshield wipers? No problem!

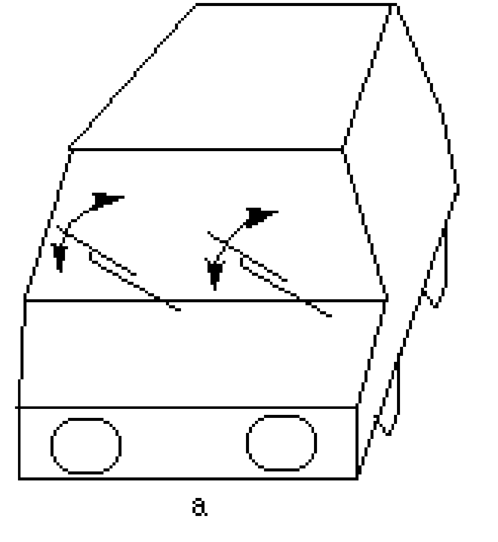
Case Study

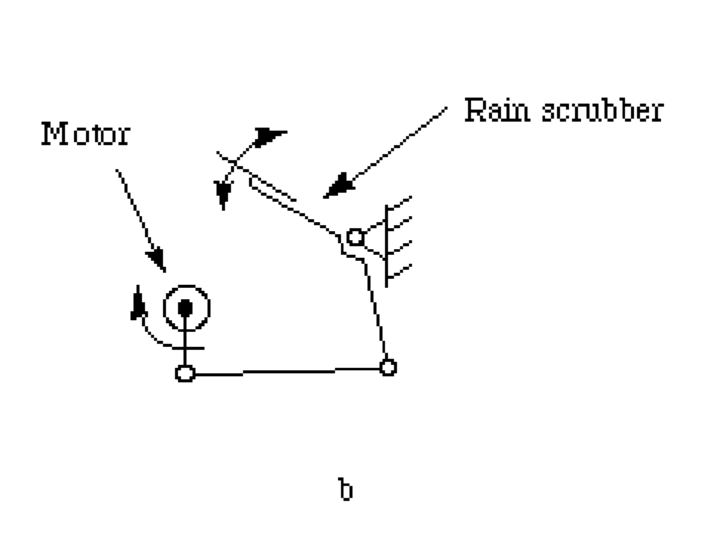


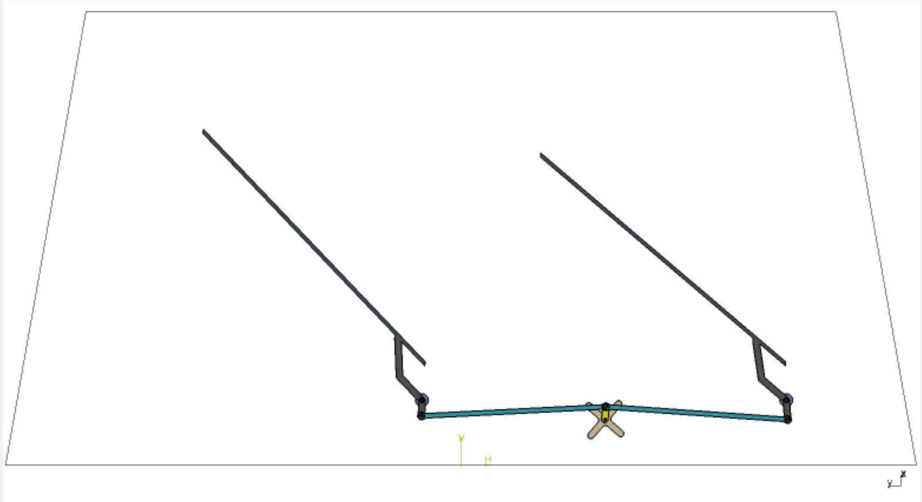
Case Study



Case Study







- Let’s start over

Basics of Mechanisms

Complex machines from internal combustion engines to helicopters and machine tools contain many mechanisms. However, it might not be as obvious that mechanisms can be found in consumer goods from toys and cameras to computer drives and printers. In fact,

- Many **common hand tools** such as scissors, screwdrivers, wrenches, jacks, and hammers **are** actually true **mechanisms**. Moreover,
- The **hands and feet, arms, legs**, and jaws of humans qualify as functioning **mechanisms** as do the paws and legs, flippers, wings, and tails of animals.

Representation of Mechanisms

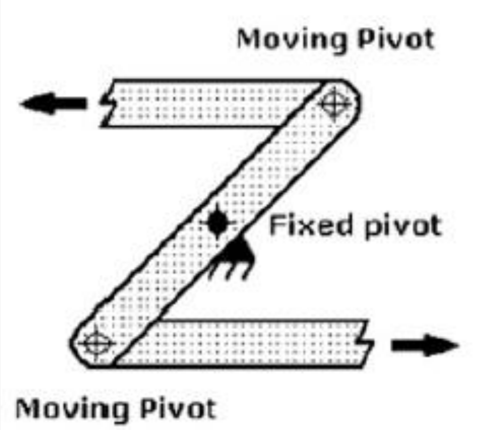
- ‘Stick’ diagrams are used to represent mechanisms
- The diagrams below show the components

Linkages (1)

Several mechanical parts (**links**) connected together are called a **linkage**. If all of the links move in the same plane this type of mechanism is known as **planar linkage**.

Reverse-motion linkage can make objects move in opposite directions; this can be done by using the input link as a lever.

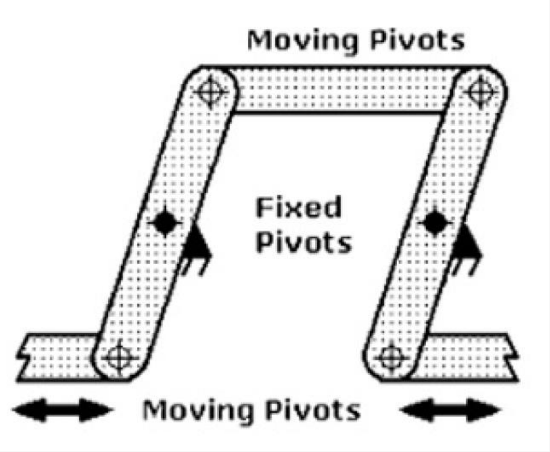
If the fixed pivot is equidistant from the moving pivots, output link movement will equal input link movement, but it will act in the opposite direction. By selecting the position of the fixed pivot, the linkage can be designed to produce specific mechanical advantages.



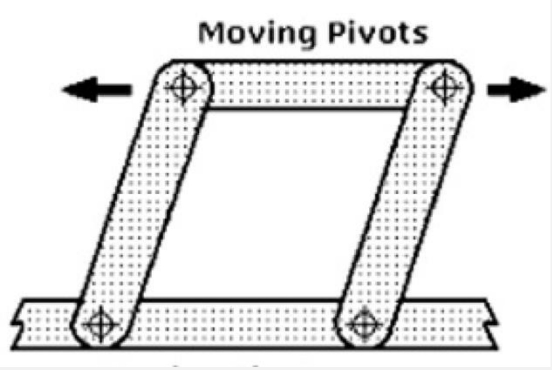
Linkages (2)

Push-pull linkage can make the objects or force move in the same direction; the output link moves in the same direction as the input link.

Technically classed as a four-bar linkage, it can be rotated through 360° without changing its function.



Parallel-motion linkage can make objects or forces move in the same direction, but at a set distance apart. The moving and fixed pivots on the opposing links in the parallelogram must be equidistant for this linkage to work correctly.



Parallel Linkages

Parallel-motion linkage were used extensively – for example, when designing **copying mechanisms** for handling dangerous substances (e.g. radioactive materials) at a set distance apart (and often behind a safety transparent wall) from the operator.

The mechanical couplers between the 2 arms were later replaced by electromechanical control systems (**telerobotics**).

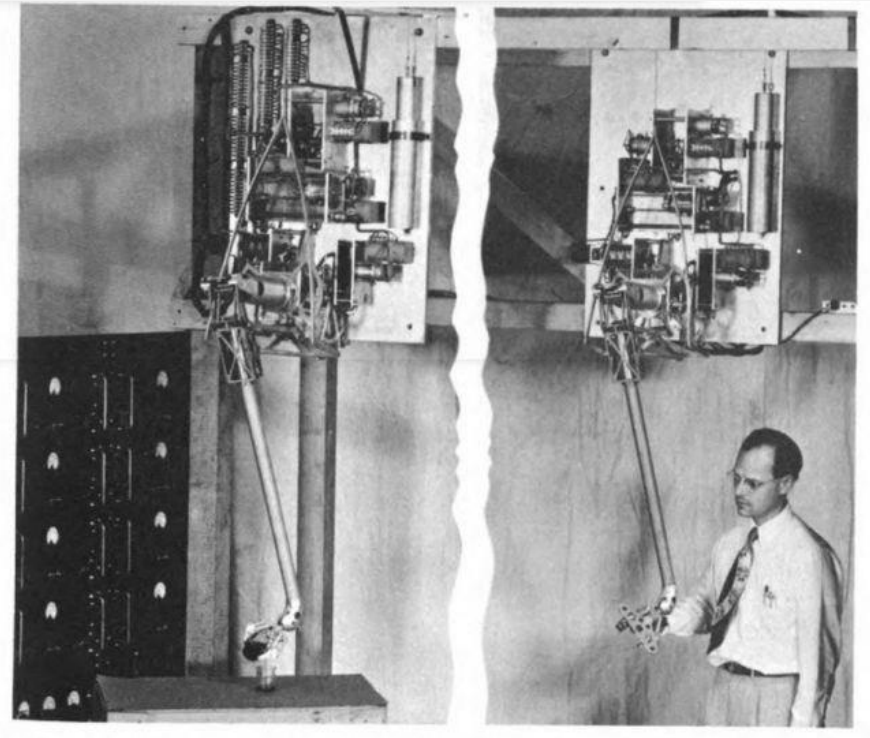


FIGURE 6.—The ANL Model E1 electric master slave. Used only for experimental purposes, this bilateral manipulator was developed in 1954. (Courtesy of Argonne National Laboratory.)

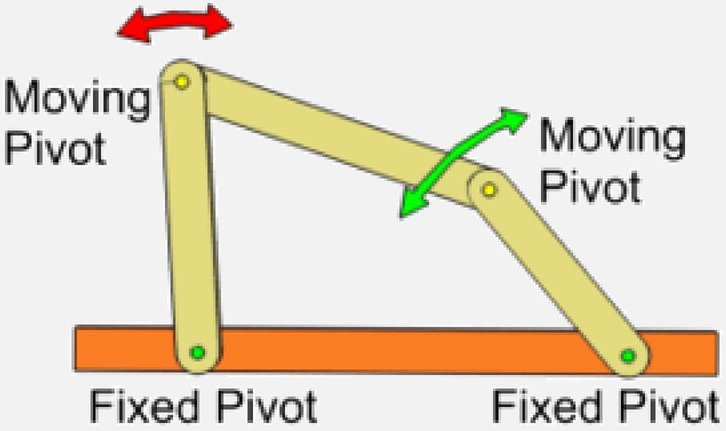
Specialised Linkages (1)

In addition to changing the motions of objects or forces, more complex linkages have been designed to perform many specialised functions.

These include:

- Drawing or tracing **straight lines**;
- Moving objects or tools **faster** in a retraction stroke than in an extension stroke;
- Converting **rotating motion into linear motion** and vice versa, and others.

Specialised Linkages (2)



The simplest specialised linkages are **four-bar linkages**.

- They have only three moving links, but they have **one fixed link** and **four pin joints** or pivots.

They are capable of producing rotating, oscillating, or reciprocating motion by the rotation of a crank. Linkages can be used to convert:

- Continuous **rotation** into another form of continuous **rotation**,
- Continuous **rotation** into **oscillation** or vice versa,
- One form of **oscillation** into another form of **oscillation**, or one form of **reciprocation** into another form of **reciprocation**,

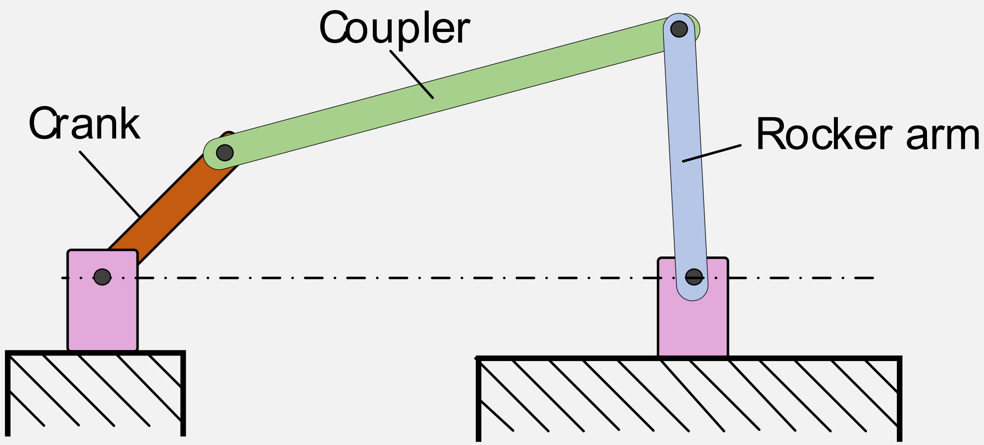
with a **constant or variable velocity ratio**.

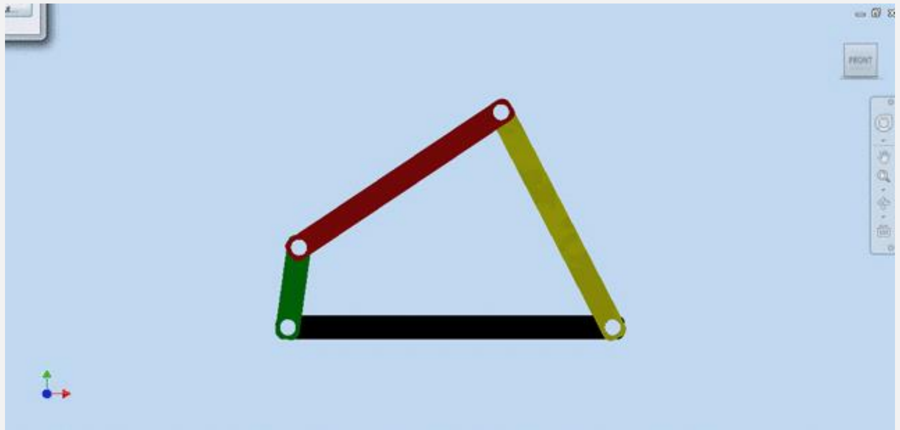
Crank-Rocker Mechanism (1)

Crank-rocker mechanism is a type of a four-bar linkage.

- The crank link can make a full 360-degree revolution while the opposite link (rocker) can only oscillate and describe an arc.

This linkage can thus convert the cyclic motion of the crank to the limited range cyclic motion of the rocker

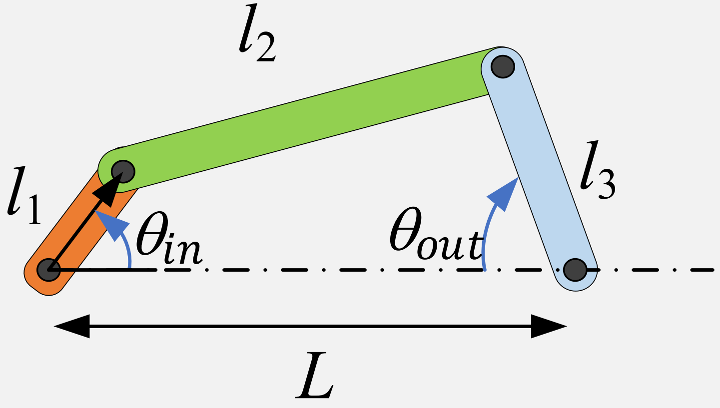


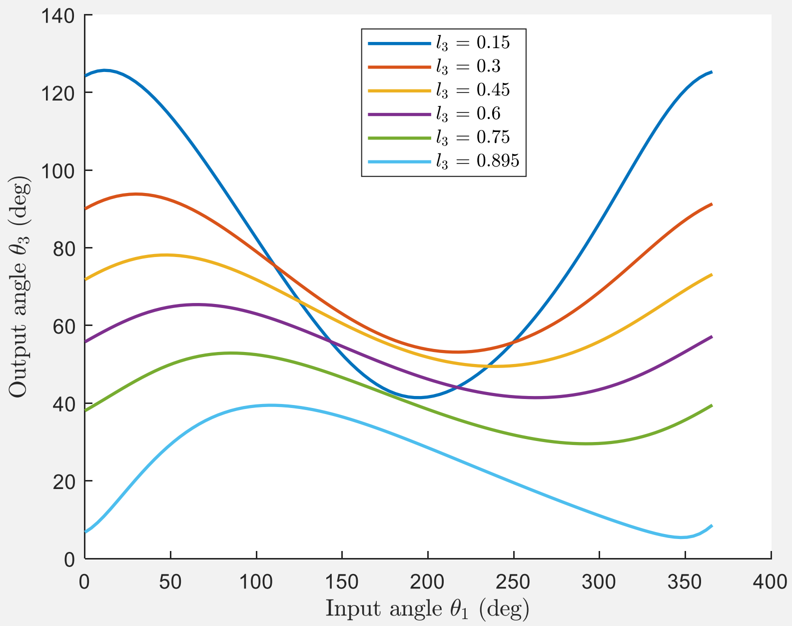


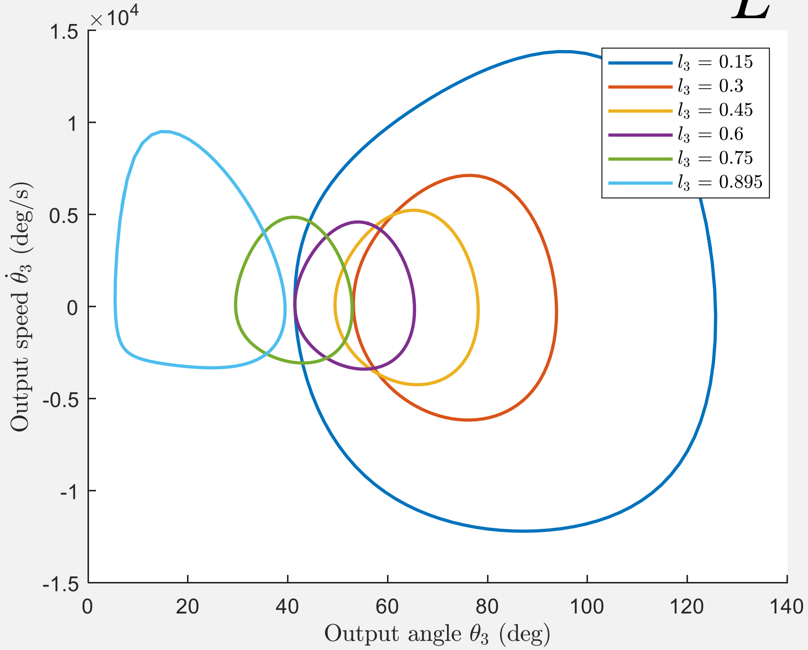
Crank-Rocker Mechanism (2)

The resulting motion profiles are **easily customizable**.

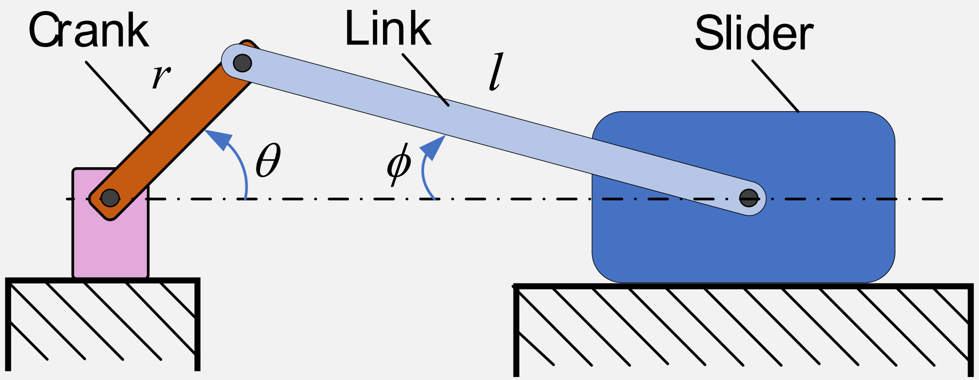
For instance, if we set $l_1 = 0.1, l_2 = 0.5, L = 0.5$ and picks different values of l_3, we obtain the following profiles:







Slider-Crank Mechanism (1)



Slider-crank mechanism converts rotary to linear motion and vice versa.

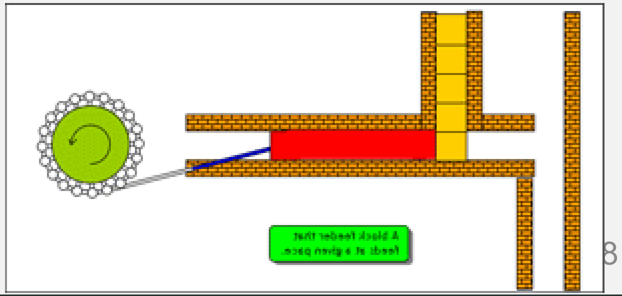
Assuming slider's position is denoted by x and the axis of its motion going through the crank's axis of rotation, one can write the equations as

$$x = r\cos\theta + l\cos\phi$$

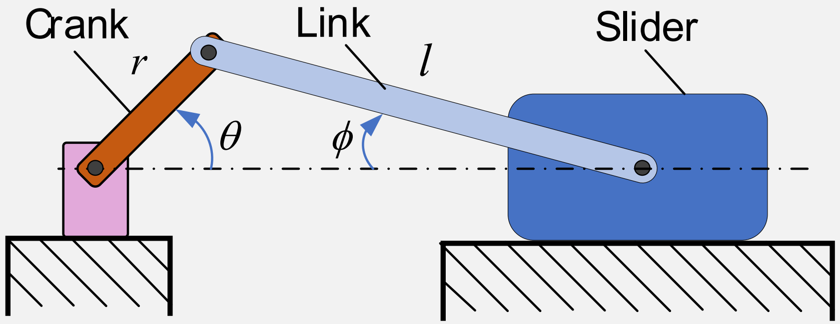
$$r\sin\theta = l\sin\phi$$

From here on, one can find the position of the slider as

$$x = r\cos\theta + \sqrt{l^2 - r^2\sin^2\theta}$$

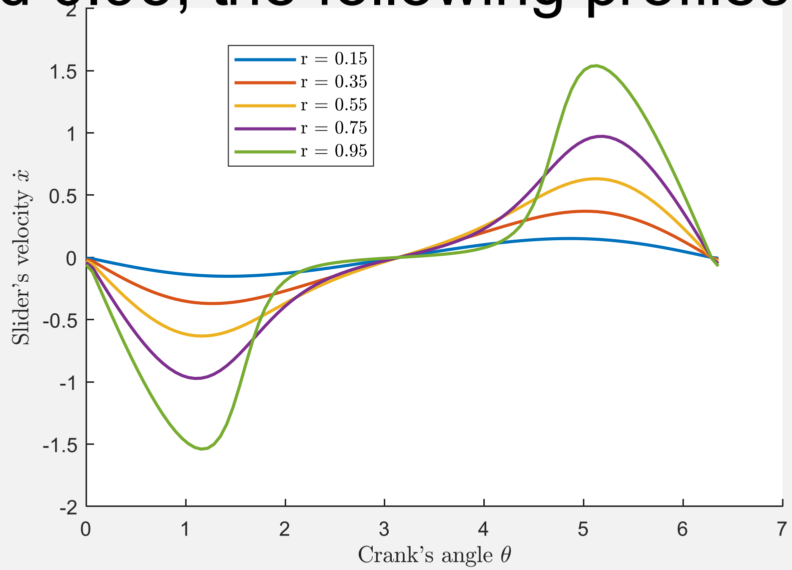


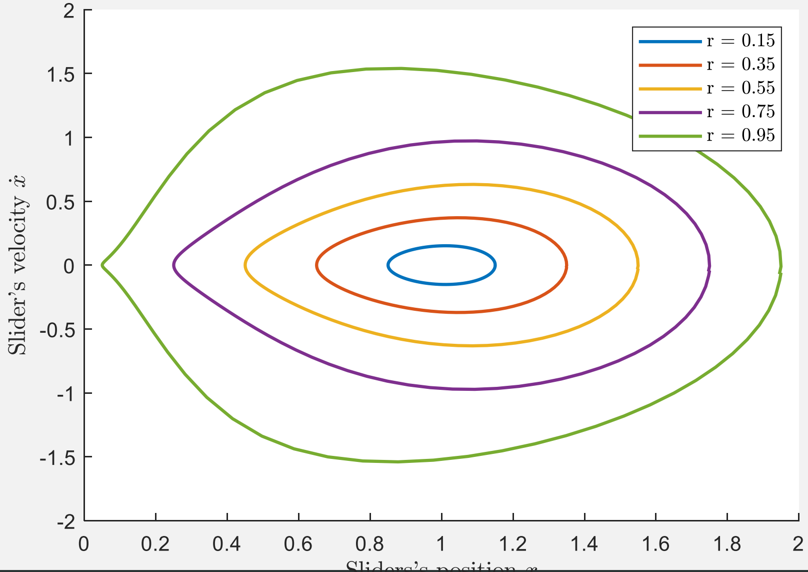
Slider-Crank Mechanism (2)



By changing the ratio between the crank's and the link's lengths, one can generate a variety of **position-velocity profiles** of the slider.

For instance, if $l = 1$ unit and the value of r is between 0.15 and 0.95, the following profiles arise:



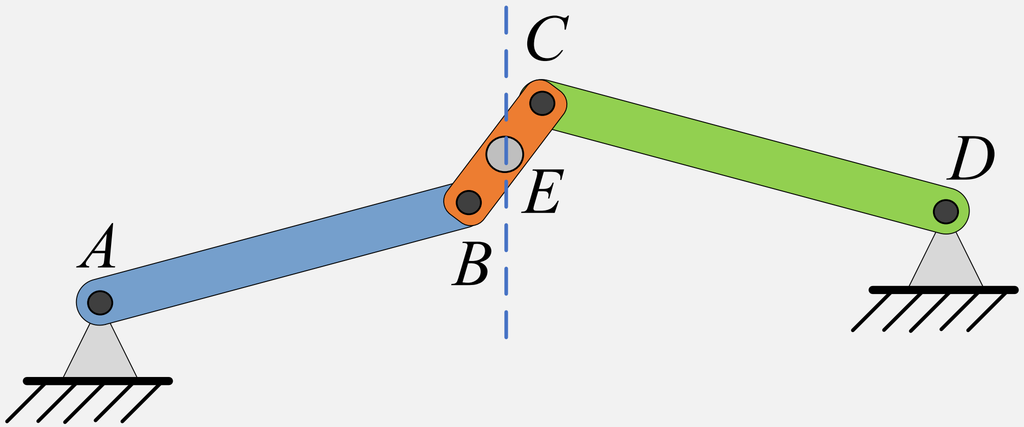


Slider-Crank Mechanism (2)

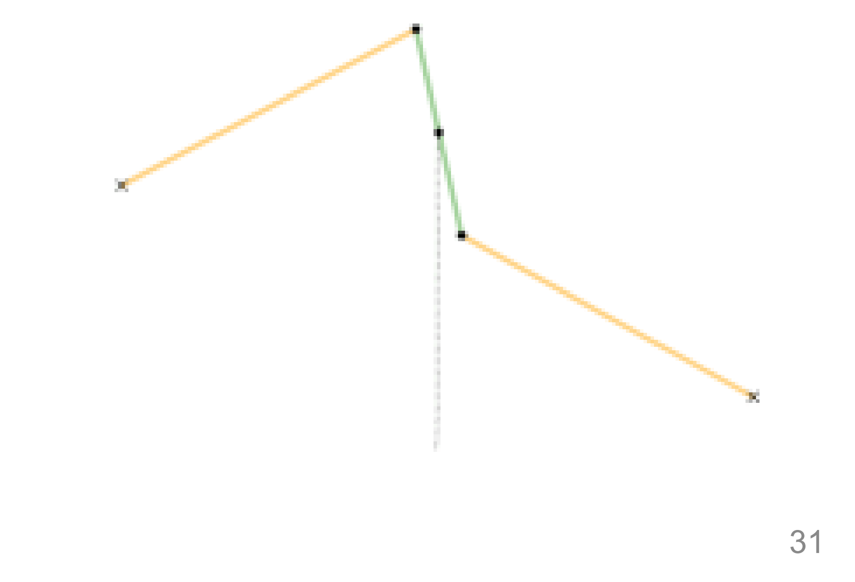
Using, $\theta = \omega t$, we have

- Position $$x = r\cos(\omega t) + \sqrt{l^2 - r^2\sin^2(\omega t)}$$
- Velocity $$\dot{x} = -\omega r\left(sin(\omega t) + \frac{r}{2l}sin(2\omega t)\right);$$
- Acceleration $$\ddot{x} = -\omega^2 r\left(\cos(\omega t) + \frac{r}{l}\cos(2\omega t)\right).$$

Straight-Line Generators (1)



Linkages are capable of describing **straight lines**, a function useful in many different kinds of machines, particularly machine tools. The **dimensions** of the rigid links are important for the proper functioning of these mechanisms.

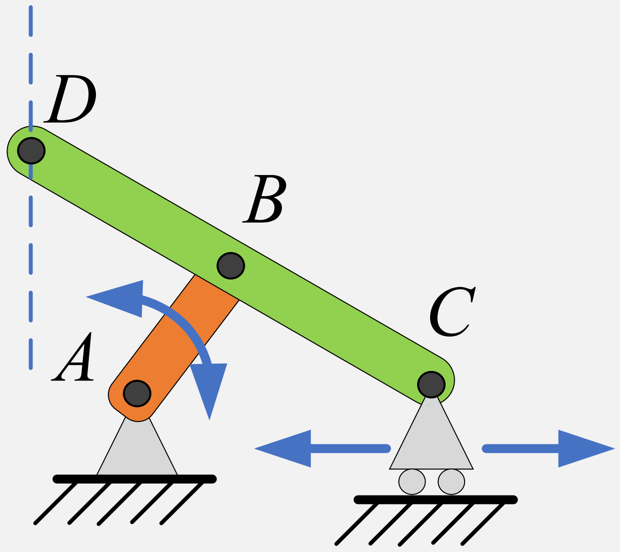


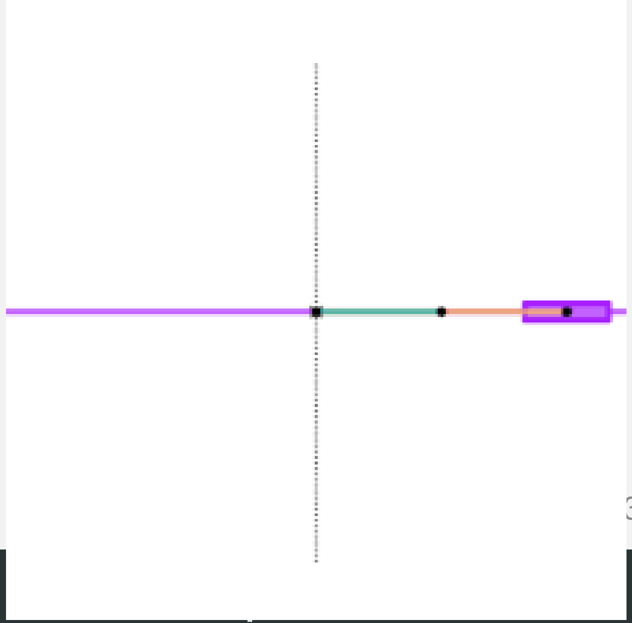
Watt's straight-line generator can describe a short vertical straight line. Equal length links AB and CD are hinged at A and D, respectively. This linkage was used by Scottish instrument maker, James Watt, in a steam-driven beam pump in about 1769, and it was a prominent mechanism in early steam-powered machines.

Straight-Line Generators (2)

Scott Russell straight-line generator can also describe a straight line.

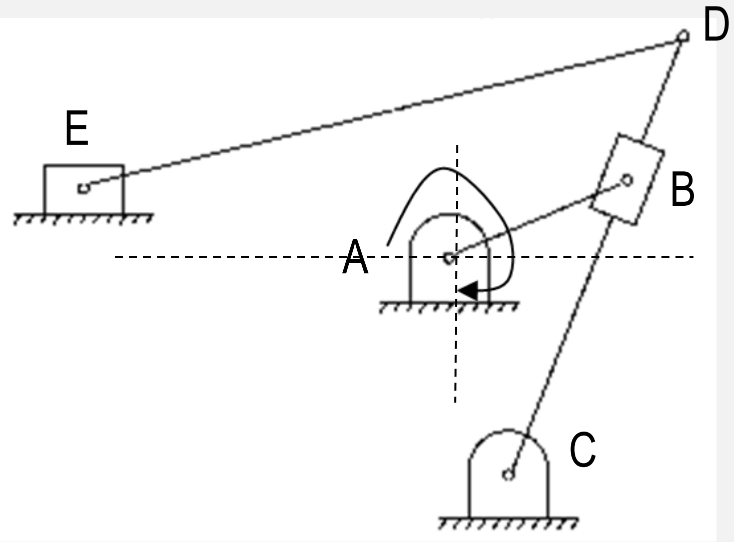
- Link AB is hinged at point A and pinned to link CD at point B. Link CD is hinged to a roller at point C which restricts it to horizontal oscillating movement.
- This configuration confines point D to a motion that traces a vertical straight line.



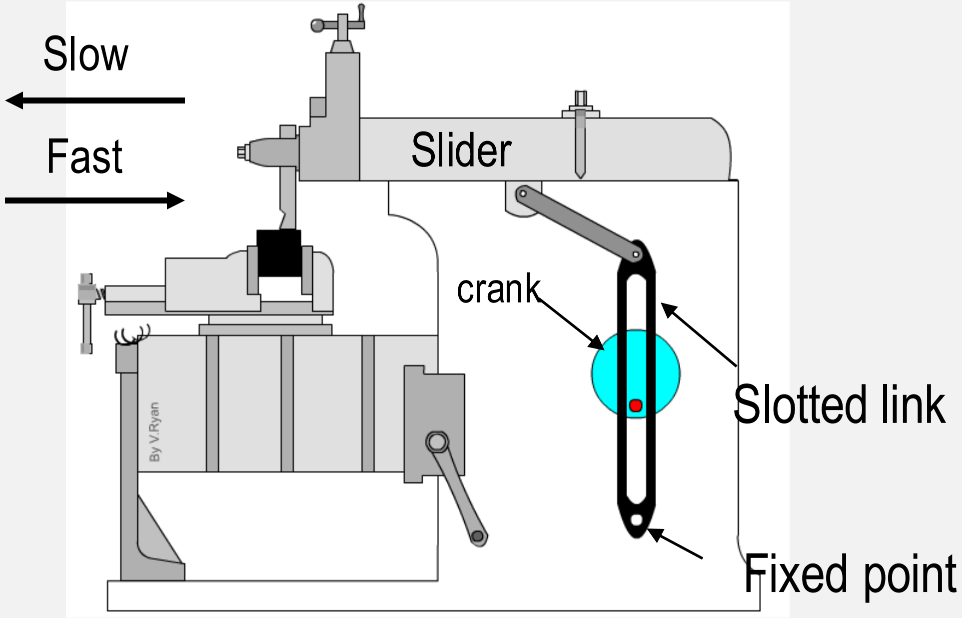


Additional Mechanisms (1)

- Quick Return mechanisms



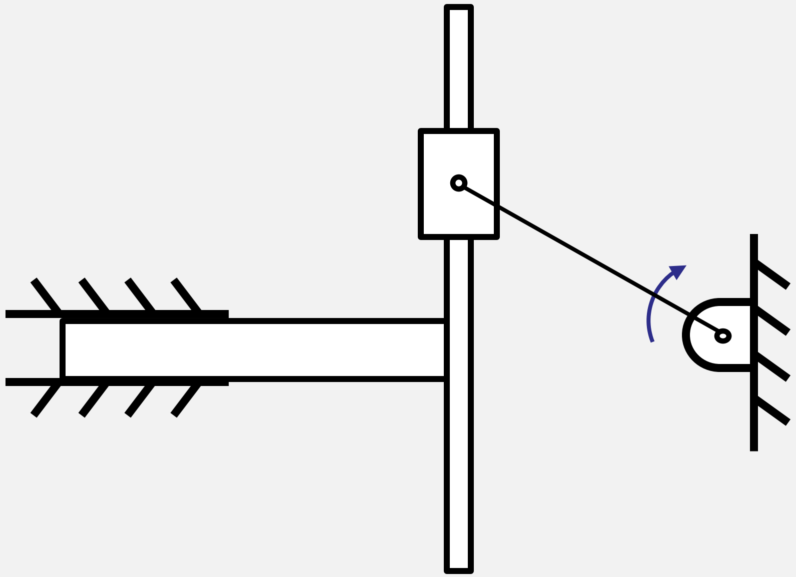
Velocity of E is fastest when input link AB is vertically downwards

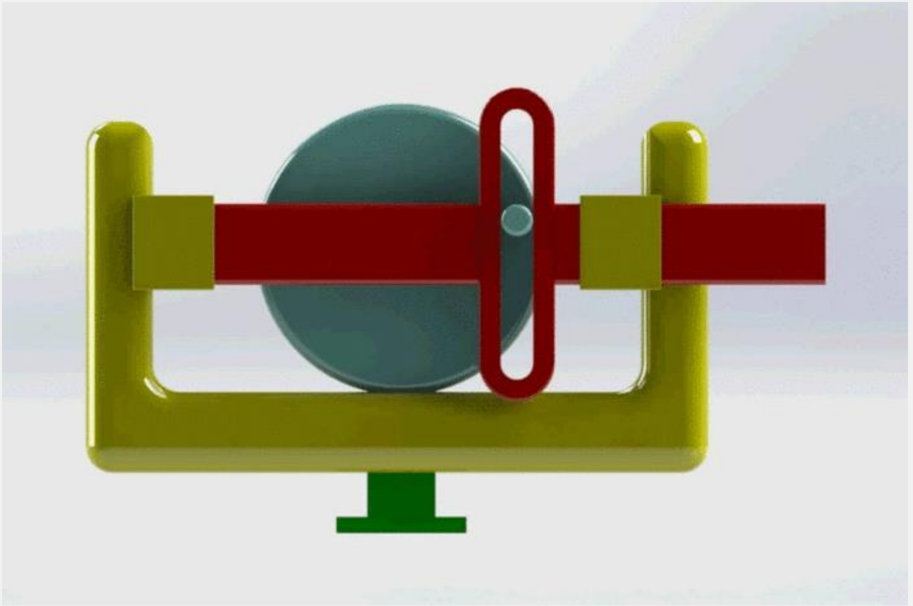


THE SHAPING MACHINE

Additional Mechanisms (2)

- Scotch Yoke mechanisms





Additional Mechanisms (3)

- Geneva Wheel mechanisms