Chapter 3: Mechanical Engineering

What is mechanical engineering?

Study of motion (or lack of motion) in an object composed of several component (parts, items)

↑ used on exam

In this chapter, we will study:

- Links
- Guiding controls
- Motion limitations and degrees of freedom
- Motion transmission systems
- Motion transformation systems

Links

Linking is mechanical function. It allows different components (parts) of a technical object to remain attached.

We always consider the links between 2 components at a time.

Characteristics of Links

Links can be:

- **Direct OR Indirect**

Direct: Two components are held because of their complementary shapes or similar size ↳ fit together

Indirect : Two components are held together by a third component, called a linking component

Examples of Linking Components:

glue, nail, screw, rivet

Examples: Direct: tupperware + lid

pen + cap

Indirect: • legs + tabletop (screwed together)

• top + side of picture frame (glue)

• bar + weight plates (clips)

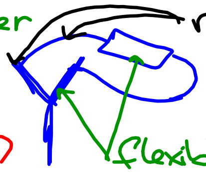
- **Rigid OR Flexible** (Elastic)

Rigid: no "return to shape/position" in link

rare → Flexible : linked parts can "return to their original shape/position" for object to function

Note: Flexible parts DOES NOT mean flexible link! The LINK must be flexible.

Examples:
- flexible linking component => flexible link
  - elastic, spring, rubber
- Example : Slingshot



* - **Removable OR Non-Removable** Separate?

Do not confuse partial and removable

Removable: parts can be separated without damage to parts or linking component

Non-Removable : separating the parts results in damage to parts/linking component

Examples:
- removable : screw
- non-removable : glue, rivets, nails
- removable : water bottle + cap

* - **Complete OR Partial** Motion (function)

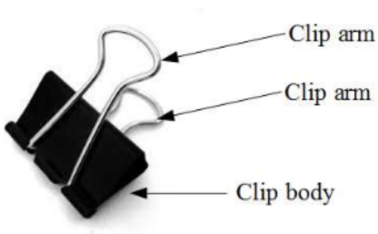
Complete: when the parts are linked (for object to function), there is no motion between parts

Partial: when the parts are linked (for function), there motion between the parts

Examples:
- complete: water bottle + cap (function)
- partial : 2 blades of scissors

Describing Links

1. Consider the paperclip illustrated below. What are the characteristics of the links described below?



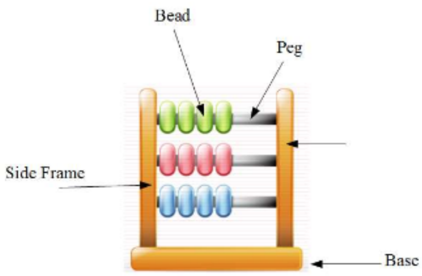
The link between the clip arm and the clip body is:

☒ direct	☐ indirect
☒ rigid	☐ flexible
☒ removeable	☐ non-removeable
☐ complete	☒ partial

The link between both clip arms is:

☐ direct	☒ indirect (clip body)
☐ rigid	☒ flexible
☒ removeable	☐ non-removeable
☐ complete	☒ partial

2. Consider the abacus illustrated below. What are the characteristics of the links described below? (Assume pegs and side frame are glued)



The link between an peg and a bead is:

☐ direct	☒ indirect (Side frame)
☒ rigid	☐ flexible
☐ removeable	☒ non-removeable (glue)
☐ complete	☒ partial

The one side frame and the base:
(Assume they are held together by a screw)

☐ direct	☒ indirect (screw)
☒ rigid	☐ flexible
☒ removeable	☐ non-removeable
☒ complete	☐ partial

Guiding Controls

Guiding is a mechanical function. A guiding control (or guiding component) is a component that guides or controls the motion of one or more moving parts.

We will consider 3 types of guiding controls

1. Translational guiding control: ensures the straight translational motion of a part

   always say translate (not slide)

   Examples:

   * window track (guides the window)

   window track → guiding component; window → guided component

2. Rotational guiding control: ensures the rotational motion of a part

   always say Rotate (not spin or turn)

   Examples:

   * wheel on axle

   wheel → guided; axle → guiding

3. Helical guiding control: ensures the translation motion of a part resulting from its rotational motion.

   rotation causes the translation

   Examples:

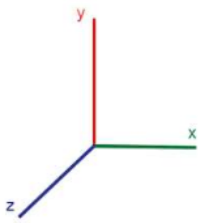
   * looks like a screw (threads)
   * bottle cap with bottle neck

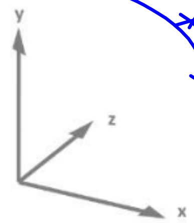
   bottle cap → guided; bottle neck → guiding

Degrees of Freedom

Direction of motion

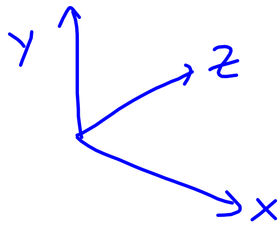
In order to represent the different direction of motion, we will use the x, y, z axes.





* use most of time
* use for 3d drawing + exam

There are 6 possible motions:



Translation along the x-axis T_x

Translation along the y-axis T_y

Translation along the z-axis T_z

Rotation about (around) the x-axis R_x

Rotation about (around) the y-axis R_y

Rotation about (around) the z-axis R_z

* look at the axle! ⟺ gives you the direction of rotation

We always consider the objects AS THEY ARE ILLUSTRATED.

Examples:

Describe the motion (type [T, R] and direction [x, y, z]) of:

1. The pendulum

R_x

2. The door.

R_y

3. The sliding window.

T_x

and

T_y

4. The "slider" on the toaster.

T_y

5. The engine start/stop button.

T_z

and

T_y

6. The faucet handle.

R_y

7. The kitty door

axle

R_z

8. The nut

nut

R_x, T_x

Degrees of Freedom

The number of degrees of freedom is the number of independent motions that can be performed by a component. (How many different motion?)

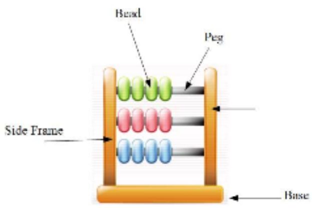
(T_x, T_y, T_z, R_x, R_y, R_z)

Examples:

1. How many degrees of freedom does the door have?

R_y → 1 degree of freedom

2. How many degrees of freedom do the beads of the abacus have?



Rotation, Translation ⇒ 2 degrees of freedom

3. Consider the soap pump below. How many degrees of freedom does the spout have?

? → axis

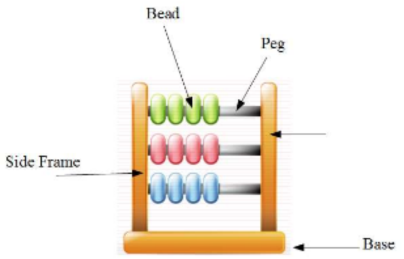
T_y, R_y → 2 degrees of freedom

Motion Limitations

In some objects, the function of some components is to limit the motion of another component.

↑ • prevent a part from translating too far (or rotation)

Example: What part limits the motion of the beads in the abacus?



* Side frame limits motion of beads

Friction and Adhesion

Friction is a force (can measure (in N)). It attempts to prevents two surface that are in contact from slipping. (opposes motion)

Adhesion is the phenomenon by which two surfaces tend to remain in contact, without slipping.

High friction = high adhesion

Low friction = Low adhesion

There are 5 factors that affect the strength of adhesion. by ❤

↳ or friction

1. **Nature of the surfaces** (what materials the surfaces are made of)

   Ex: smoother materials → less friction/adhesion
   rougher materials → more friction/adhesion

   * Rubber → large friction/adhesion
   * Ice → low friction/adhesion

2. **Presence of a lubricant (**a lubricant is a substance that is added to the surface)

   ↳ usually a liquid

   Ex:

   * grease, oil, wax, water, soap

   → lubricants ↓ friction/adhesion
   → adhesives are NOT lubricants

3. **Temperature**

   * colder : ↓ friction/adhesion
   * hotter : ↑ friction/adhesion

4. **State (condition) of the surface** (degree to which the surface is damaged, old, new, etc.)

   *same surface

   * sanding → makes surface smoother
     → ↓ friction/adhesion
   * carving grooves → makes surface rougher
     → ↑ friction/adhesion

5. **Perpendicular force between the surfaces** (how hard to two surfaces are pressed against each other.)

   * ↑ perpendicular force → ↑ friction/adhesion
   * ↓ perpendicular force → ↓ friction/adhesion

Motion Transmission Systems

A motion transmission system relays motion from one location to another

The nature of the motion does not change (rotation stays a rotation) always rotation

Components of a motion transmission system

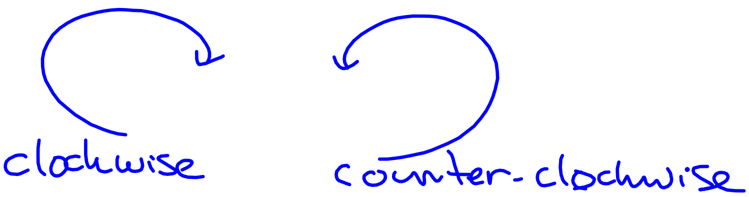
- Driver component
  → initiates motion
  → where force is applied (person, motor, engine)
- Driven component
  → "last" component, purpose of motion
- Intermediate component
  → between driver + driven

Reversibility of Motion Transmission System

reversible: you can apply force to the driven (instead of driver) and mechanism still work.

non-reversible: applying a force to the driven doesn't work (gets stuck)

Direction of Rotation

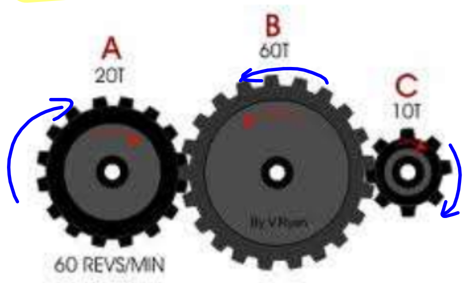


Types of motion transmission system

- Gear train
- Friction gear
- Chain and sprocket
- Belt and pulley
- Worm and worm gear

Looking at the different Motion Transmissions Systems

1. Gear train



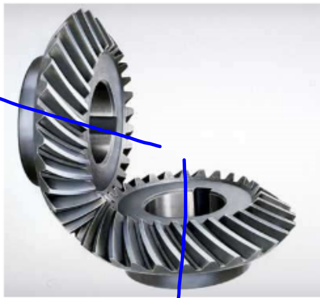
*Reversible

*adjacent gears rotate in opposite directions

*does not slip (heavy load)

*→maintenance required (lubricating)
→difficult to manufacture (must be perfect)

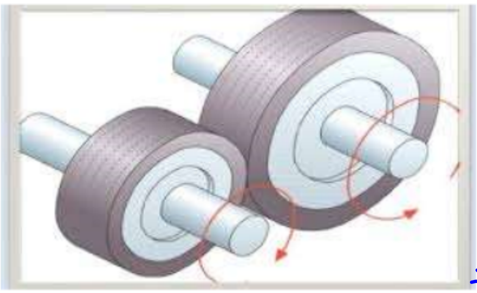
A note on bevel gears: Bevel gears are used to change the angle of the rotation.



change axis of rotation

Rx ⟷ Ry

2. Friction gears



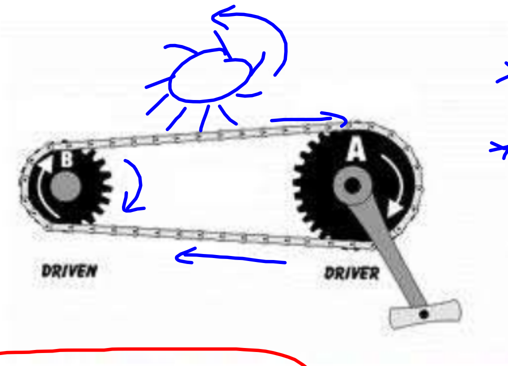
*Reversible

*Adjacent gears rotate in opposite directions

*→less maintenance
→easier to manufacture

*→can slip
→can wear down over time

3. Chain and sprocket



*Reversible

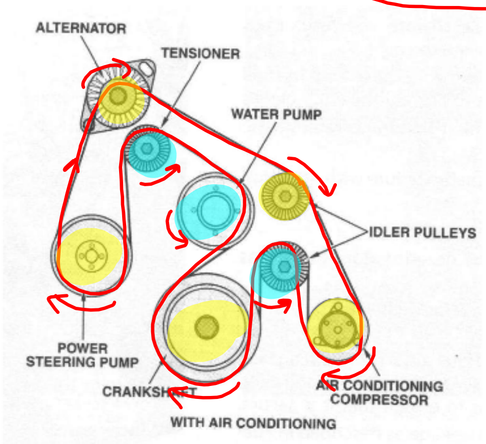
*Inside chain = one direction
Outside chain = other direction

*no slipping

*requires maintenance (oil)
difficult to manufacture

4. Belt and pulley

inside
outside



Drive belt installation schematics.

*reversible

*inside belt = one direction
outside belt = other direction

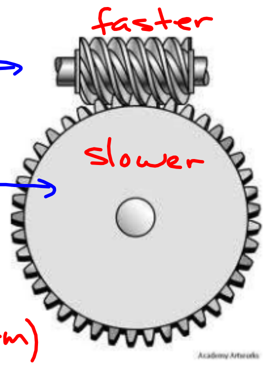
*easier to manufacture
less maintenance

*can slip

5. Worm and worm gear

worm →

worm gear →
(teeth on an angle to fit worm)



*not reversible
driver = worm
driven = worm gear

*1 full rotation of worm = rotation of worm gear by "1 tooth"

*doesn't slip
can be used for precision (small change)

*difficult to manufacture
maintenance!

Speed Change in Motion Transmission Systems

Rotational Speed

revolutions ↓

The units we use to measure the speed of rotation of a part is the rotation per minute (RPM).

1 RPM = one full rotation in one minute

100 RPM = 100 full rotation in one minute

Examples:

1. It takes a gear 1.5 s to make a full rotation. What is the rotational speed of this gear in RPMs?

$$\text{Speed} = \frac{1\ \text{rot}}{1.5\ \text{s}} \times \frac{60\ \text{s}}{1\ \text{min}} = 40\ \text{RPM}$$

2. The wheels on a bicycle have a radius of 32.0 cm. You ride the bicycle over a distance of 1.55 km. This takes 5.50 minutes. What is the rotational speed of the wheels in RPMs?

1 rotation → circumference

$$C = 2\pi r = 2\pi(32.0\ \text{cm}) = 201\ \text{cm} \rightarrow 2.01\ \text{m}$$

$$\frac{1.55\ \text{km}}{5.50\ \text{min}} \times \frac{1000\ \text{m}}{1\ \text{km}} \times \frac{1\ \text{rot}}{2.01\ \text{m}} = 140\ \text{RPM}$$

There is speed change in a motion transmission system when the driver gear and the driven gear don't rotate at the same speed.

Smaller gears rotate faster (fewer teeth)

Larger gears rotate slower (more teeth)

Speed ratio (S.R.)

The speed ratio is used to express by what factor the speed of the driven gear is increased/reduced compared to the speed of the driver gear.

$$S.R. = \frac{\text{Speed driven}}{\text{Speed driver}}$$

* S.R. has no units!

Examples:

1. If a motion transmission system has a speed ratio of 8, it means…

   driven rotates 8 times faster than driver

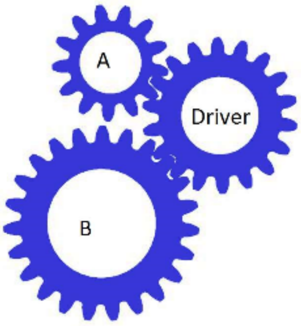
   ex: driver : 20 RPM
   driven : 160 RPM

2. If a motion transmission system has a speed ratio of 0.5, it means…

   driven is 2 times slower than driver

   ex: driver : 50 RPM
   driven : 25 RPM

3. Consider the gear train below.



The driver gear has a rotational speed of 250 RPM.
Gear A rotates at a speed of 346 RPM.
Gear B rotates at a speed of 196 RPM.

→ always compare to driver

a. What is the speed ratio of gear A?

$$S.R. = \frac{\text{Speed A}}{\text{Speed driver}} = \frac{346\text{ RPM}}{250\text{ RPM}} = 1.384$$

b. What is the speed ratio of gear B?

$$S.R. = \frac{\text{Speed B}}{\text{Speed driver}} = \frac{196\text{ RPM}}{250\text{ RPM}} = 0.784$$

We can also determine the speed ratio of a motion transmission system using the "size of the gears" (diameter, radius, number of teeth)

High
Faster gears are smaller. They have fewer teeth.

Slower gears are larger. They have more teeth.

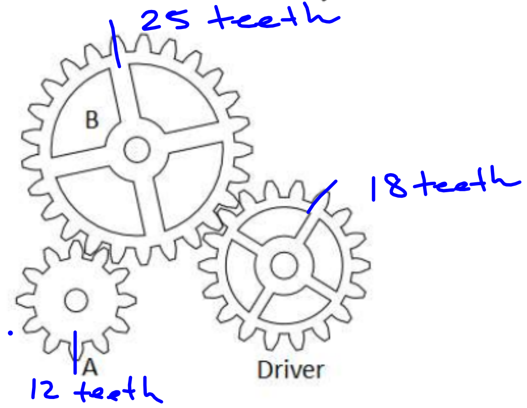
So the formulas for speed ratio using the size of the gears...

$$S.R. = \frac{\text{size driver}}{\text{size driven}}$$

$$S.R = \frac{\text{teeth driver}}{\text{teeth driven}}, \quad S.R. = \frac{\text{radius driver}}{\text{radius driven}}$$

Examples

1. Consider the motion transmission system below.



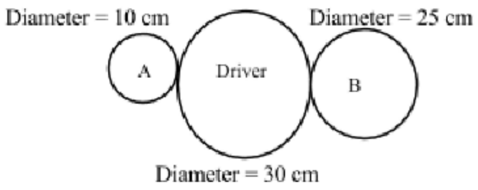
a. What is the speed ratio of gear A?

$$S.R. = \frac{\text{teeth driver}}{\text{teeth A}} = \frac{18}{12} = 1.5$$

b. What is the speed ratio of gear B?

$$S.R. = \frac{\text{teeth driver}}{\text{teeth B}} = \frac{18}{25} = 0.72$$

2. Consider the motion transmission system below.



a. What is the speed ratio of the gear A?

$$S.R. = \frac{\text{diameter driver}}{\text{diameter A}} = \frac{30\text{ cm}}{10\text{ cm}} = 3$$

b. What is the speed ratio of the gear B?

$$S.R. = \frac{\text{diameter driver}}{\text{diameter B}} = \frac{30\text{ cm}}{25\text{ cm}} = 1.2$$

Calculating the speed change

Since we have two formulas for the speed ratio…

$$\frac{\text{Speed driven}}{\text{Speed driver}} \leftarrow S.R. \rightarrow \frac{\text{size driver}}{\text{size driven}}$$

$$=$$

We can combine them to solve for an unknown (either the speed or number teeth (or size) of one of the components).

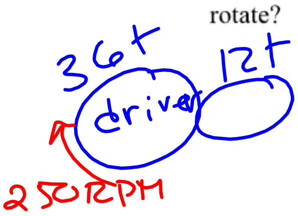
$$\frac{\text{Speed driven}}{\text{Speed driver}} = \frac{\text{size driver}}{\text{size driven}}$$

OR

$$\left(\text{Speed driver}\right)\left(\text{size driver}\right) = \left(\text{Speed driven}\right)\left(\text{size driven}\right)$$

Examples:

1. A 36-tooth driver gear turns at a rate of 250 RPM in the clockwise direction. It is connected to a 12-tooth gear. At what rate and in what direction does the 12-tooth gear rotate?



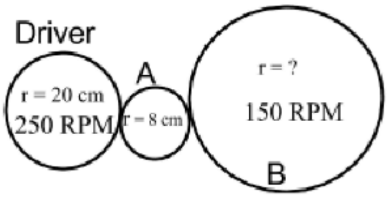
$$\frac{\text{Sp driven}}{\text{Sp driver}} = \frac{\text{teeth driver}}{\text{teeth driven}}$$

$$\text{Sp driven} = \frac{(\text{teeth driver})(\text{Sp driver})}{\text{teeth driven}}$$

$$= \frac{(36\,t)(250\,RPM)}{(12\,t)}$$

$$= 750\ RPM,\ \text{counter clockwise}$$

2. Consider the friction gears below.



a. What is the rotational speed of gear A?

① $S.R. = \frac{r\ \text{driver}}{r\ A} = \frac{20\ cm}{8\ cm} = 2.5$

② $\text{Speed } A = 2.5\,(250\,RPM) = 625\ RPM$

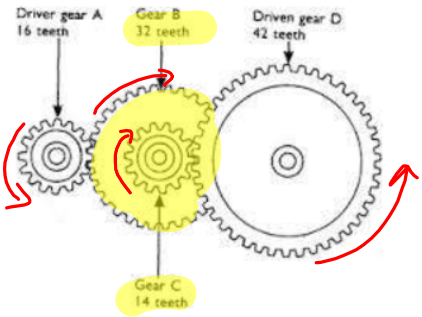
b. What is the radius of gear B?

① $S.R. = \frac{\text{Sp } B}{\text{Sp Driver}} = \frac{150\,RPM}{250\,RPM} = 0.6$

② $S.R. = \frac{r\ \text{driver}}{r\ B}$

$r\,B = \frac{r\ \text{driver}}{S.R.} = \frac{20\,cm}{0.6} = 33.3\ cm$

3. Consider the gear train below.



*Gear B and C are on the same axle → they rotate at the same speed (even though they are different sizes)

The driver gear has a rotational speed of 450 RPM in the counterclockwise direction.

What is the rotational speed and direction of gear D?

*can't do this in one step!

① A → B

$$\frac{\text{Speed B}}{\text{Speed A}} = \frac{\text{teeth A}}{\text{teeth B}}$$

(A ← driver)

$$\text{Speed B} = \frac{(t\ A)(\text{Speed A})}{(t\ B)} = \frac{(16)(450\text{RPM})}{32} = 225\text{ RPM}$$

② Speed C = 225 RPM (Same axle as B)

③ C → D (driver)

$$\frac{\text{Speed D}}{\text{Speed C}} = \frac{t\ C}{t\ D}$$

$$\text{Speed D} = \frac{(t\ C)(\text{Speed C})}{t\ D} = \frac{(14)(225\text{RPM})}{42} = 75\text{ RPM}$$

(Counterclockwise

Motion Transformation Systems

A motion transformation system relays the motion from one location to another. It also transforms the motion from one form to another.

The two types of motion are: rotation and translation.

Σ motion transformation

So a motion transformation system will do one of the following:

Rotation (driver) → Translation (driven)

Translation (driver) → Rotation (driven)

Note: Just like motion transmission systems, motion transformation systems may or may not be reversible .

Five (5) Types of Motion Transformation Systems

1. ***Rack and pinion***

pinion – rotation

rack – translation

* Reversible

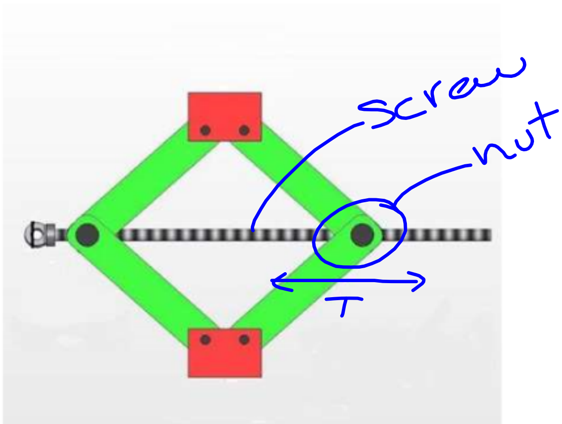
→ rack = driver
T causes R

→ pinion = driver
R causes T

2. *Screw gear - type 1*

The screw is the driver (it rotates)

The nut does a translation



*Not reversible

Screw = driver

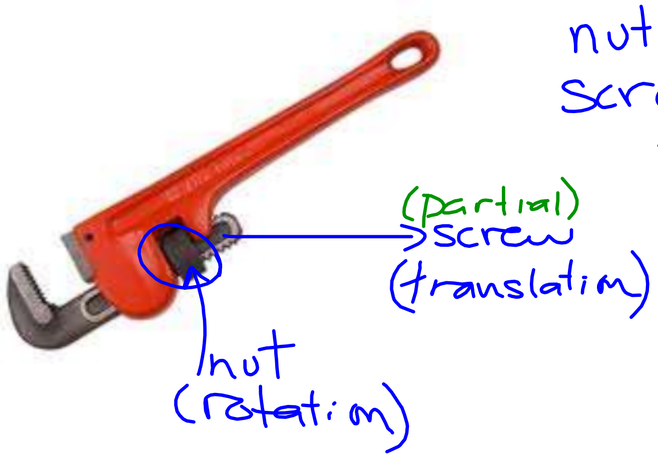
Nut = driven

R causes T

3. *Screw gear - type 2*

The nut is the driver (it rotates)

The screw does a translation



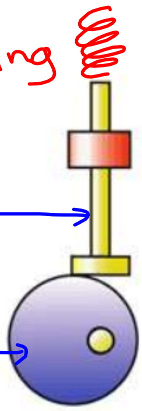
*Not reversible

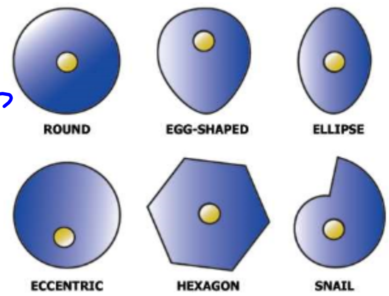
nut = driver

screw = driven

R causes T

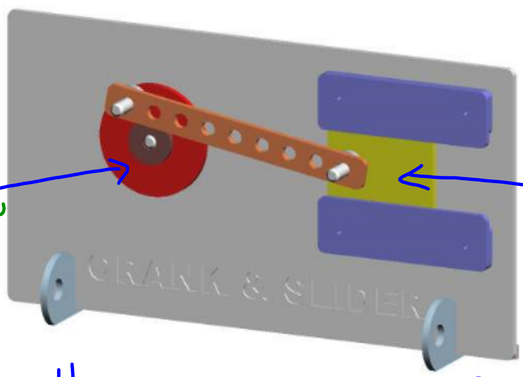
4. Cam and follower





*not reversible
cam = driver
follower = driven
R causes T

5. Slider-crank



Usually
crank = driver
slider = driven
R causes T

Can be reversible
(depends on object)
slider = driver
crank = driven
T causes R