Unit 4: Structures and mechanisms

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Contents

Textos Marea Verde

Prior knowledge

Activity: Summarize your general knowledge on this topic.

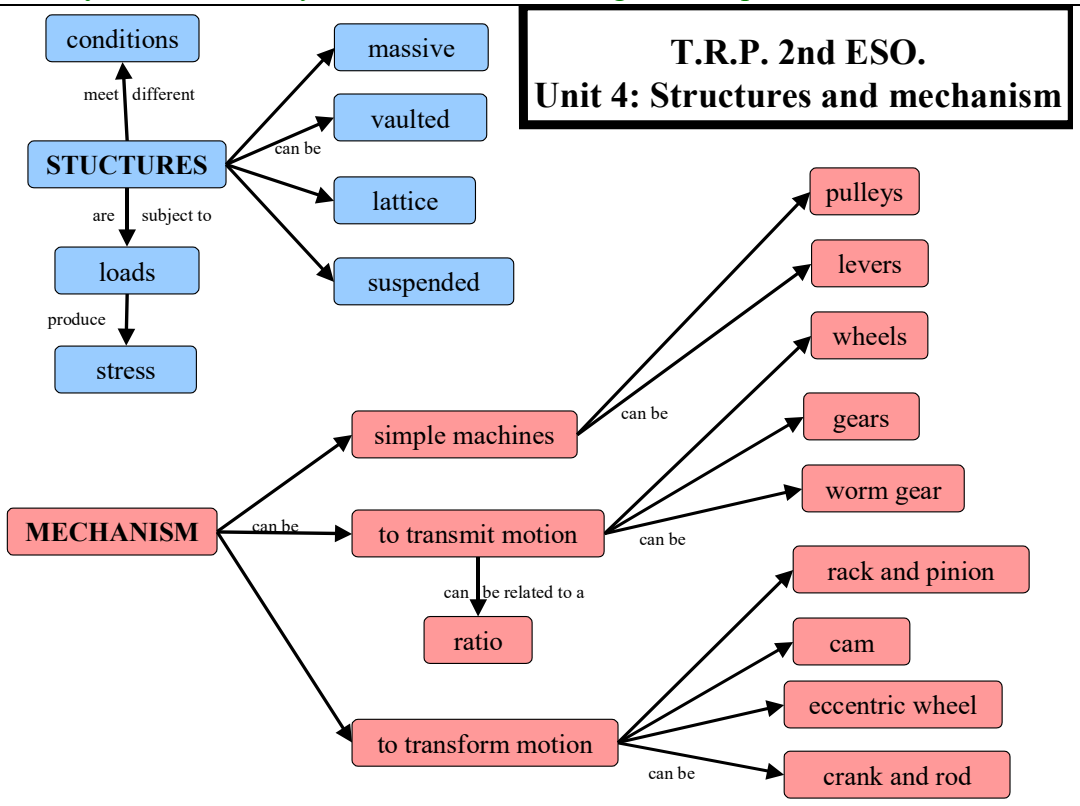
Keywords

Activity: Copy following keywords, understand their meaning and translate them into English.

Force	fulfill	Pulley
Load	Brace	Groove
Structure	Stay cables	Axle
Skyscraper	Column	Hoist
Dam	Pillar	Mechanism
Stress	Beam	Driven element
Strength	Sections	Driver element
Compression	Truss	Transmission ratio
Tension	Framework	Friction wheels
Bending	Node	Slippage
Torsion	Machine	Belt
Shear	Lever	Gears
Stretch	Fulcrum	even-/odd-numbered
Twist	Effort	Rack
Centre of gravity	Resistance	Connecting rod
Stable	balanced	Cam

Mindmap of the unit

Activity: Analize and try to understand following mindmap



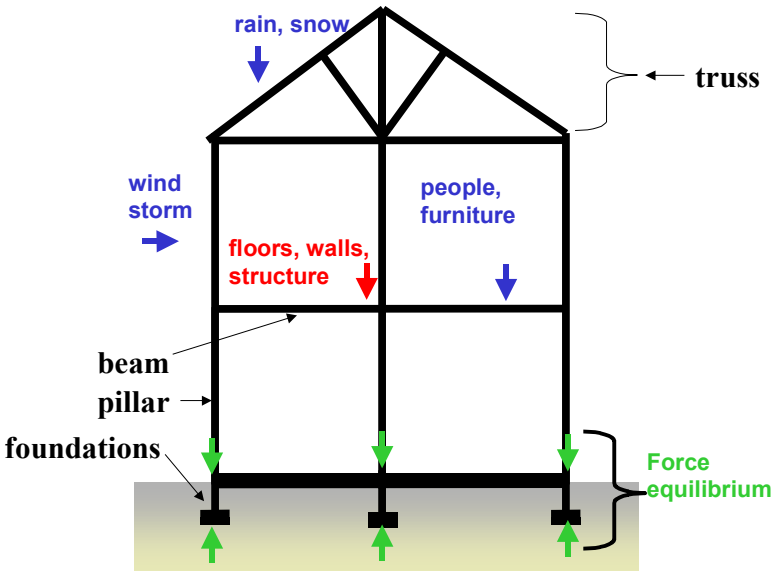
4.1. Structures

Definition:
A structure is the set of elements in a body that resist the forces that act on it (loads), fulfilling three conditions:

- ✓ remaining upright (stability)
- ✓ without breaking (resistance)
- ✓ without deforming too much (rigidity).

The forces that act on a structure are called loads. Loads can be permanent (e.g. own weight) or variable (e.g. weight of snow).

Structure elements, permanent loads, variable loads



4.1.1. Types of structures

Birds' nest, bones, shells, etc are natural structures. Chairs, skyscraper, electrical towers, etc are artificial structures.

The main types of structures used throughout the history of construction are:

- ✓ Massive (e.g., pyramid, stone bench, etc)
- ✓ Vaulted (e.g., stone bridges, cathedrals, arches, etc.)
- ✓ Frame or Lattice (*entramadas*; e.g., modern blocks of flats); the elements are:
  - Truss (cerchas)
  - Joists (viguetas)
  - Beams (vigas)
  - Pillars (pilares); columns (columnas)
  - Foundations (cimientos)
- ✓ Suspended (*colgantes*; e.g. suspended bridges)

Activities: Copy following exercises and solve them in your notebook

1) Complete with: *counteracts, responds, applied, held*
A tree doesn't normally move if we push it because its roots are_____ by the earth. The force of the earth _____ our force. When we push the tree, it _____ with an identical force_____ against us.

2) Match the parts of the sentences:

The structure of a pen includes...	... the legs and the board
The structure of a plastic cup includes...	...the outer case that holds its different components
The structure of a camera includes...	... the cylinder or prism that holds the tube of ink
The strucutre of a table includes...	... the whole object including the ridges (*crestas*) and the edge

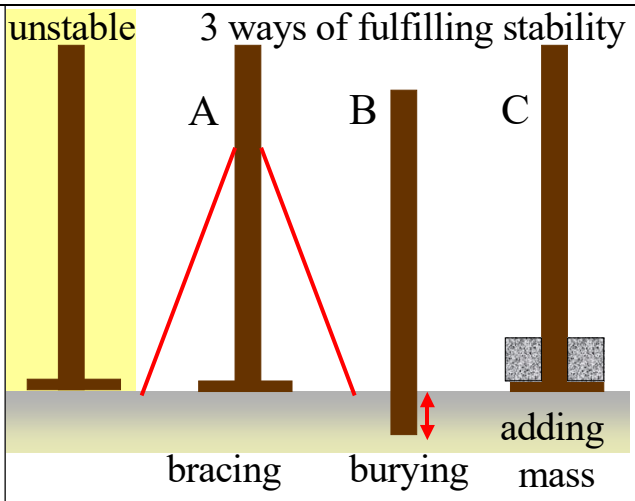
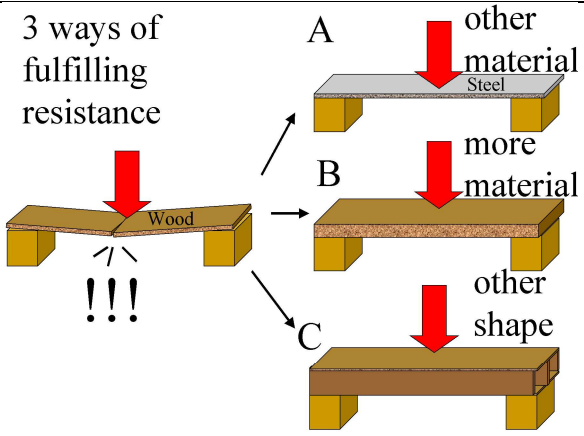
3) Draw in half a page the structure of a dam with all the forces acting on it.

4) Write five examples of natural structures and five examples of artificial structures.

5) Fill in the table with the examples and add one more: *Lisboa's bridge, Debod temple, Segovia's acueduct, school building*.

Massive structure	Vaulted structure	Lattice structure	Suspended structure

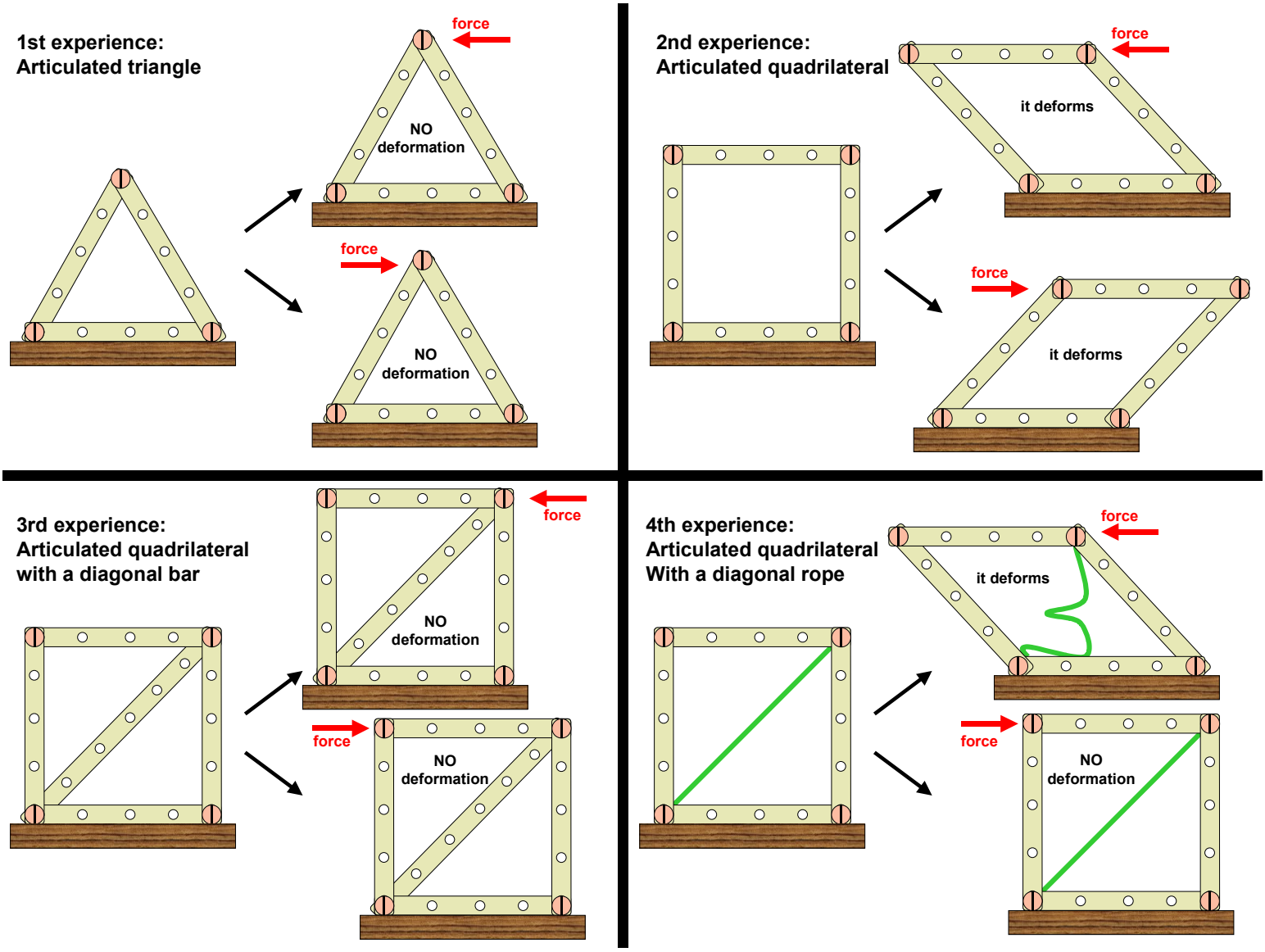
4.1.2. Structural conditions. Triangulation.

Structural condition	**Meaning**	**How to fulfill the condition**	
Stability	To remain upright and not tip over	The centre of gravity (=CG; = point of application of the weight) should be centred over the base and close to the ground: ✓ widening the base by **bracing** ✓ widening the base by **burying** ✓ CG closer to the ground by **adding mass** to the base	
Resistance	To bear loads without breaking	Using for the structure: ✓ resistant materials ✓ enough quantity of material ✓ appropiate shape	
Rigidity	To deform as less as possible	Using for the structure: ✓ welding joints ✓ appropiate shape ✓ triangulation	See activity

Activities: Pay attention to following experiences:

1st Rigidity of 3 articulated bars forming a triangle.
2nd Rigidity of 4 articulated bars forming a frame.
4th As 2nd but with a diagonal rope.
5th As 2nd but with two diagonals ropes.

3rd As 2nd but with a diagonal.
Make a drawing for each experience and write your conclusions;



Polygon structures with four or more sides made of bars (articulated structures) get deformed when applying a force; this doesn't occur with triangles, which are rigid structures.

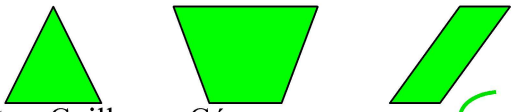
To avoid deformation of articulated structures we use triangulation:

- ✓ one diagonal bar (supports traction and compression) = bracing
- ✓ two diagonal ropes (supports only traction) = cross bracing

Activities: Copy following exercises and solve them in your notebook

6) How is stability fulfilled in following structures? A) pyramid ; B) Radio antena; C) Telegraph pole; D) Tower crane; E) Kio Towers

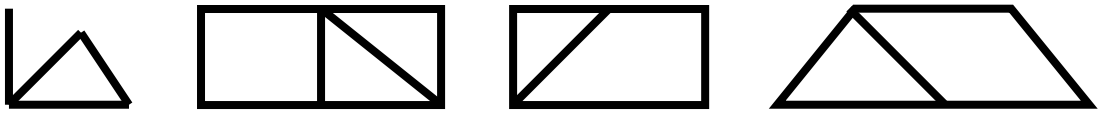
7) Which of the following bodies seems the most / least stable ? Why?



8) Which of the two board positions has better resistance to bending?

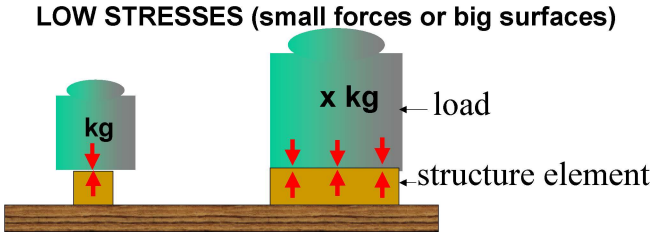
9) Imagine a structure made from four ice cream sticks connected with corner clips:
   - ✓ What would happen if you pressed on two of the corners?
   - ✓ And if we reinforce the square structure with a diagonal stick?
   - ✓ And if we reinforce the square structure with a diagonal wire?

10) Add bars to following structures to avoid deformation.



11) Choose the correct option:

- ✓ The self is curved because it *couldn't bear / act on* the weight of those heavy books.
- ✓ The resistance of a structure is *determined / exerted by* the material it's made from.
- ✓ That construction site doesn't *prevent / fulfill* the safety regulations.
- ✓ The pressure of the water in the tank *has deformed / resisted* the sides. They weren't made of strong plastic.



4.1.3. Stresses

Definition: Each element of a structure is subjected to stress (internal tension). The stress is proportional to the force applied and inversely proportional to the element section surface.

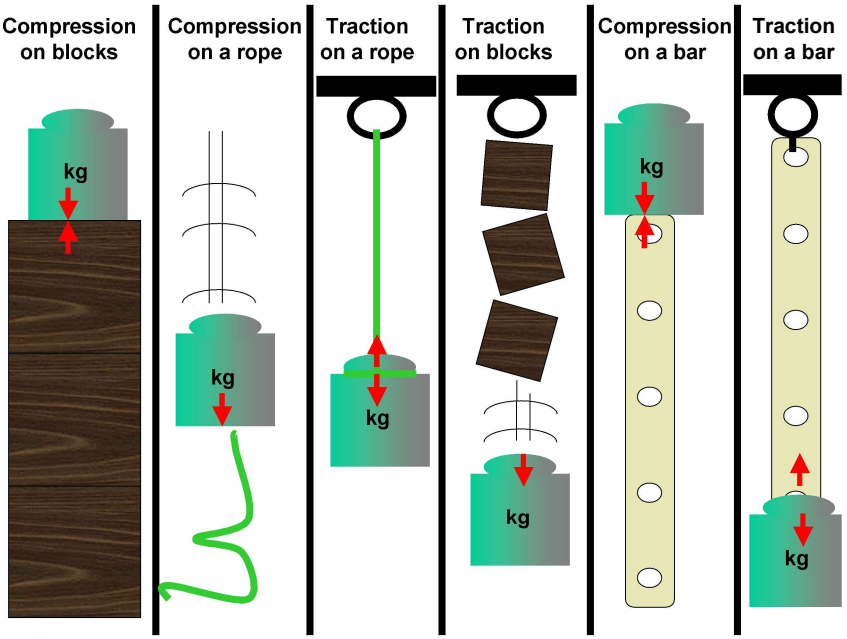
$$\text{Stress} = \frac{\text{Force}}{\text{Surface area}}$$

Types of stresses:

Traction and compression.

If a force acts perpendicularly on an element it causes a traction (stretch) or compression.

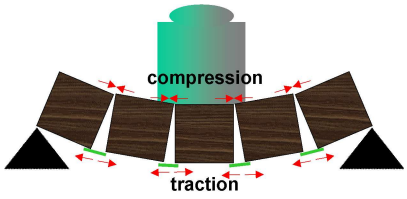
- ✓ The wires and ropes are deformable and can only support traction.
- ✓ Blocks without addition of binders show a stable form and only support compression.
- ✓ Bars support both, traction and compression.



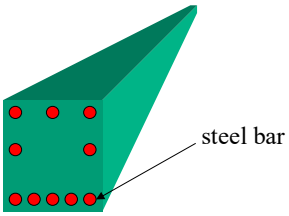
Some materials support traction better than compression; e.g. wood supports traction 5 times better than compression. On the opposite, concrete and stone support compression 5 times better than traction.

Bending.
If a beam supports a load it deforms (bends). The material supports compression on the upper part and traction on the lower part.
Concrete withstands well compression but poorly traction. Therefore in reinforced concrete beams (viga de hormigón armado) traction is supported by the steel bars that are mainly located in the bottom.

Bending experiment of a beam of blocks joined with tape



Disposition of steel bars in a reinforced concrete beam



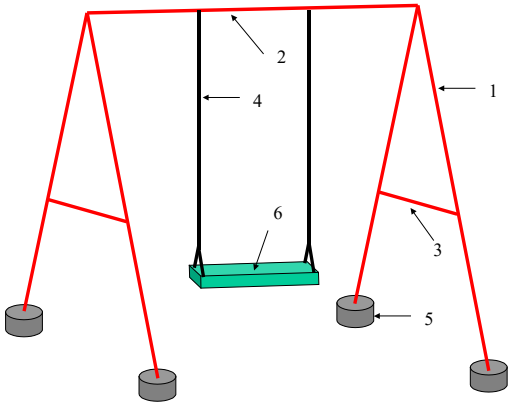
Torsion
Forces try to twist the structure element.

Shear or cutting
The forces act like two scissor blades.

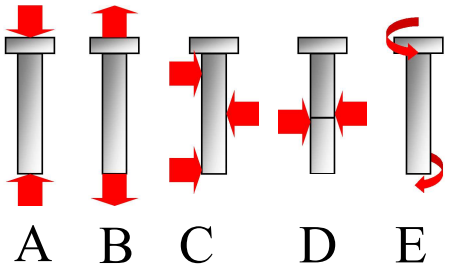
Activities: Copy following exercises and solve them in your notebook

12) Write 3 examples of everyday objects subjected to traction and compression.

13) Draw a swing and label the stresses each element bears:*compression, bending, traction, bending, traction, compression*



14) What stresses are the bolts A, B, C, D and E subjected to?



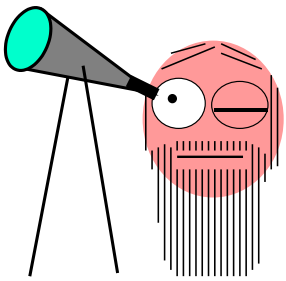
15) Complete the table with other situationa in which the different types of stress may occur.

Traction	Compression	Bending	Torsion	Shear
Chain with a pendant	Table legs	Bookshelf	Pencil being sharpened	Guillotine

16) What is subjected to a greater stress: a hair (∅ = 0,1 mm) with an apple hanging (1 N) or a cable (∅ = 10 mm) with a 1 t car hanging?

4.2. Mechanisms

Definition: A machine is a device that enables us to perform work with greater comfort and less effort. Mechanism are elements of the machines that perform specific task like transmiting or transforming forces and motions.



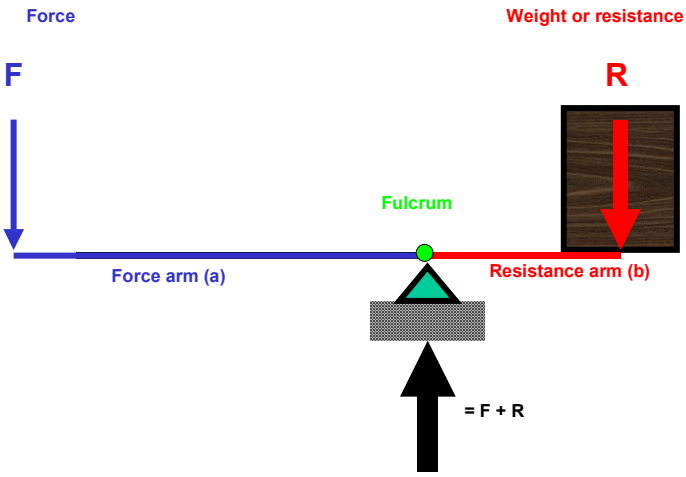
Golden Rule of Mechanics *(Galileo Galilei, 1594):*

" What you save in force, you have to put in track" .

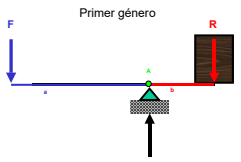
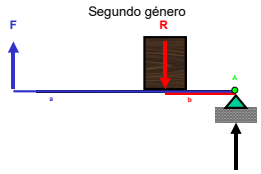
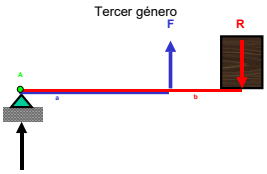
4.2.1. Simple machines

Simples machines are e.g. the lever and the pulley.

Lever.
A lever consist of a rigid bar that rotates around a fulcrum and enables as to move heavy loads.



The lever is balanced when the force multiplied by the force arm is equal to resistance multiplied by the resistance arm. $F \cdot a = R \cdot b$

Types of levers			
Class	Description	Example	Diagram
Class 1	The **fulcrum is between** the force and the resistance 1) $a > b \Rightarrow F < R$ (Golden Rule!) 2) $a = b \Rightarrow F = R$ (Golden Rule!) 3) $a < b \Rightarrow F > R$ (Golden Rule!)	1) Pliers, Crowbar 2) Seesaws in parks 3) Scissors, oar	
Class 2	The **resistance is between** the force and the fulcrum $a > b \Rightarrow F < R$ (Golden Rule!)	Wheelbarrow, nutcracker, paper punch	
Class 3	The **force is between** the fulcrum and the resistance $a < b \Rightarrow F > R$ (Golden Rule!)	Fishing rod, tweezers, staple removers	

Solved exercise: A nutcracker (20 cm long) cracks a walnut (located 5 cm from the fulcrum) with a force of 3N. What is the resistance of the walnut?
$F \cdot a = R \cdot b \Leftrightarrow R = F \cdot a/b \Rightarrow R = 3N \cdot 20cm/5cm = 12\ N$

Fixed pulley.

A fixed pulley is a wheel that have a groove for a rope to go round it; it rotates around an axle fixed on an immobile support.

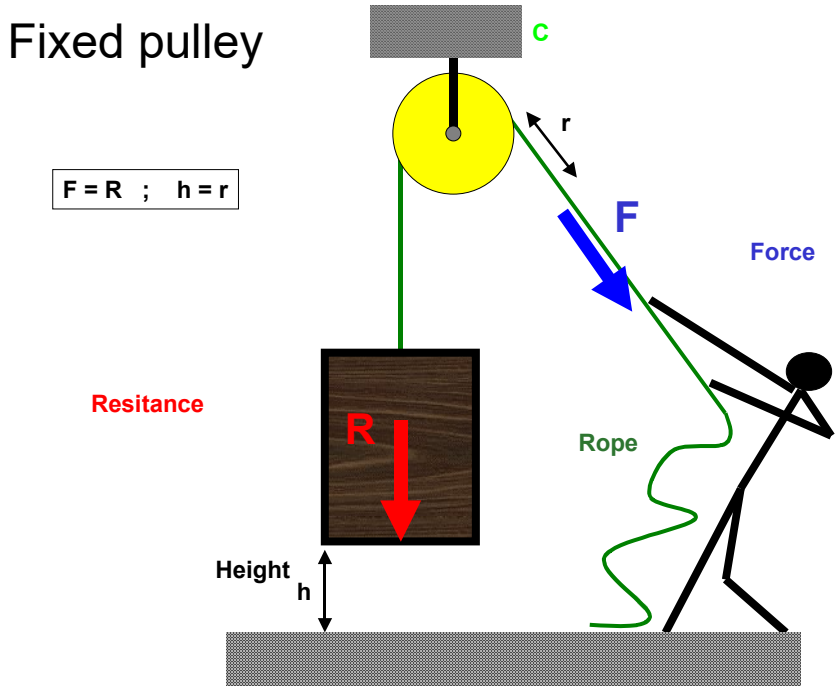
It saves us effort because our weight helps us to pull.

A fixed pulley is balanced when the force is equal to the load.

F = R

The height h is equal to the rope lenght r. (Golden Rule!)

h = r



Moveable pulley. Hoist (= polipasto).

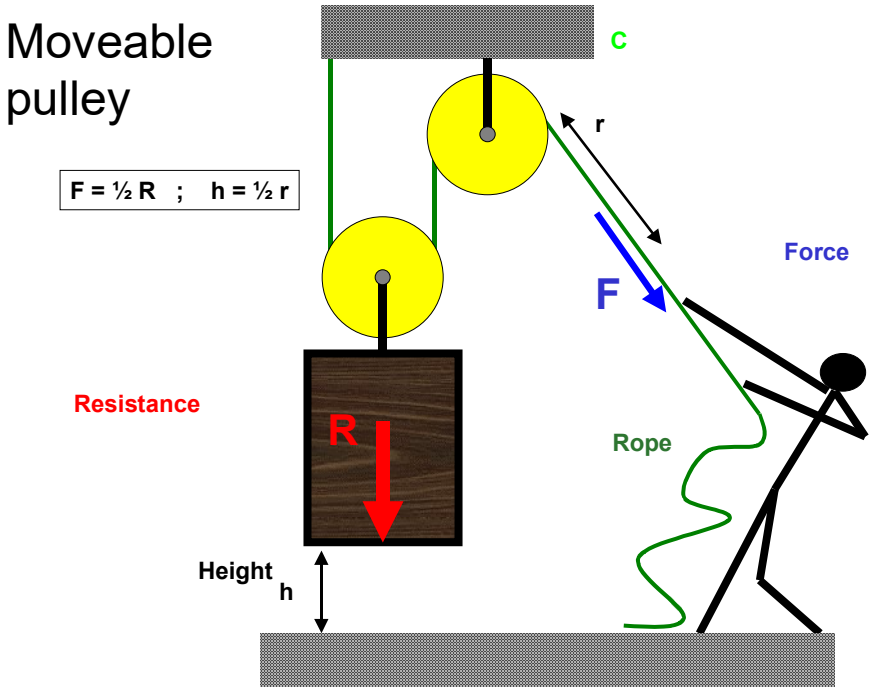
A moveable pulley has two or more pulleys: some fixed while the others can move.

A moveable pulley with only two pulleys (one fixed and one not) is balanced when it fulfills:

F = ½ R

The height h is only equal to half the rope lenght r. (Golden Rule!)

h = ½ r



Other simple machines

The wedges (cuñas) and the ramp (rampa) are simple machines used since ancient times.

Activities: Copy following exercises and solve them in your notebook

17) Fill in the following table

Type of lever			
Instrument	**Draft**	**Lever class**	**Explanation**
Tweezers			
Wheelbarrow			
Scissors			
Hammer (pulling out a nail)			
Nutcracker			
Shovel			

18) What effort do you need to lift a load of 100 kg with a fixed pulley? And with a moveable pulley? How much rope do you have to pull if you want to lift the load 1 meter? Golden Rule!

19) Complete the sentences with following words: a wheelbarrow, more, less, a seesaw, the same, tweezers.

- ✓ A class 1 lever with a fulcrum in the centre needs _____ effort to move the load, for example_____.
- ✓ A class 2 lever needs _____ effort to move the load, for example_____.
- ✓ A class 3 lever needs _____ effort to move the load, for example_____.

20) Calculate and answer if your friends (total weight 200 kg) will be able to lift a load of 1 t with a lever, in which the force arm is 1 m and the resistance arm 30 cm long. If not, what do you have to do, to lift the load? Golden Rule!

21) Calculate and answer if your friends (total weight 200 kg) will be able to lift a load of 1 t with a hoist of two pulleys (one fixed and one not). If not, how many pulleys (fixed and not) do you have to add to lift the load? Make a sketch of the resulting hoist. Golden Rule!

4.2.2. Motion transmission

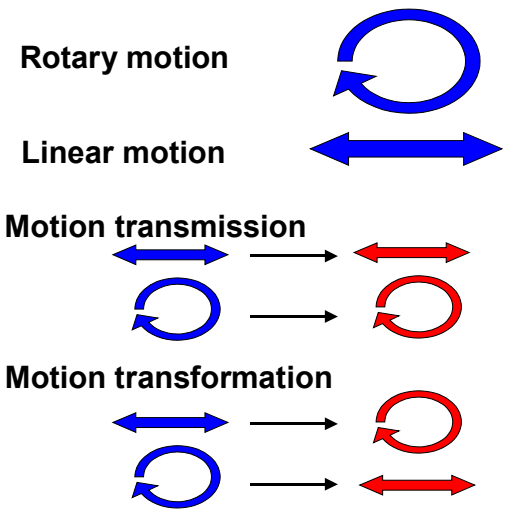
Motion can be classified in two types: rotary and linear.

We speak about motion transmission when a mechanism converts:

- ✓ a linear into a linear motion
- ✓ a rotary into a rotary motion.

We speak about motion transformation (or conversion) when a mechanism converts:

- ✓ a linear into a rotary motion
- ✓ a rotary into a linear motion.



Machines often have an engine. In the engine starts a rotary motion and is transmitted to the rest of the machine.

Pulleys and levers transmit linear motion. Thereby the linear speed is often modified.

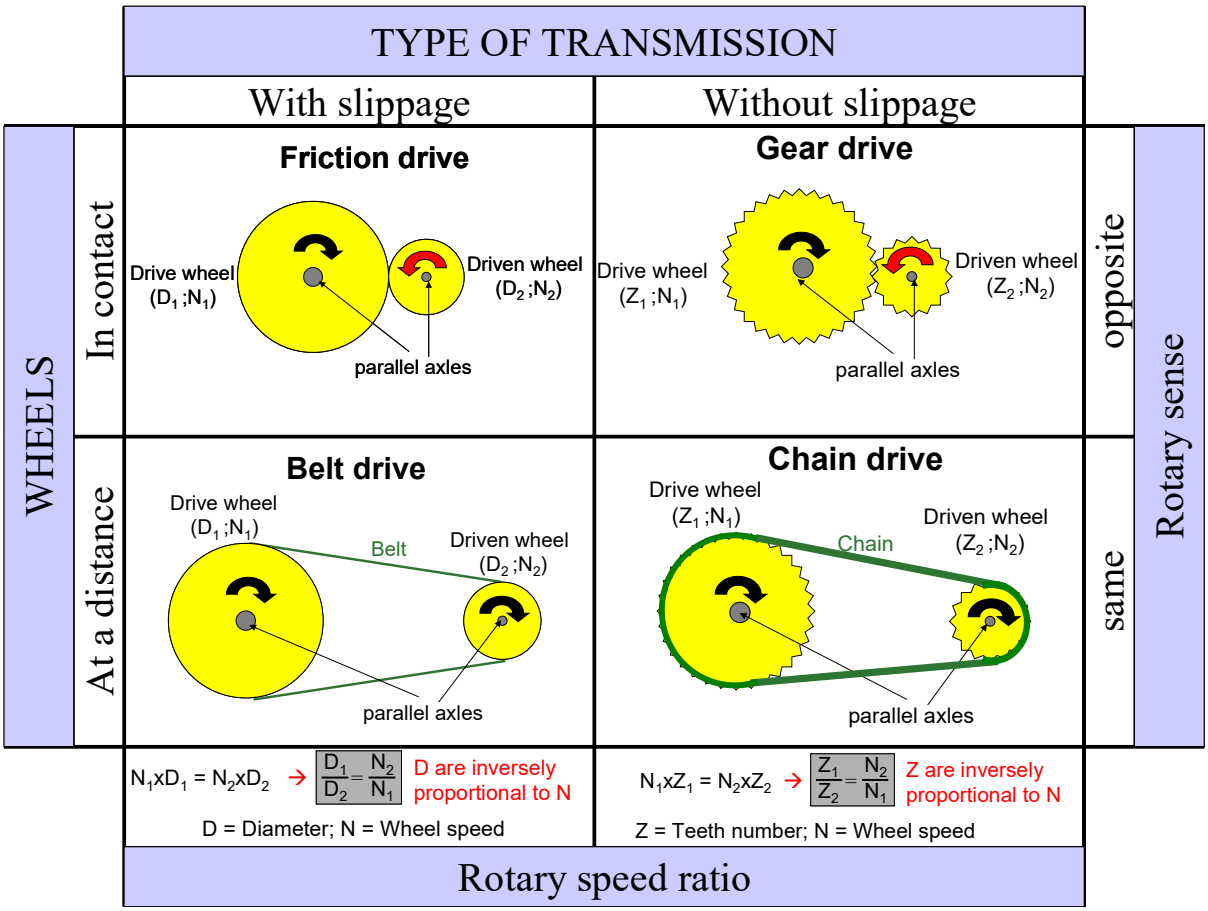
Friction drive, Belt drive, Gear drive, Chain drive and Worm gear transmit rotary motion. Thereby the rotary speed is often modified.

A friction drive is made up of wheels that are in contact. The driven wheel rotates in the opposite sense as the drive wheel. **Uses**: e.g. formerly drying laundry.

A belt drive is made up of pulleys at a certain distance and a belt. The rotary sense is the same in both wheels. As in the friction drive, slippage may appear and the wheel speed are inversely proportional to their diameters. **Uses**: e.g. sewing and washing machines.

A gear drive is made of cogwheels that are in contact. The rotary sense of the wheels is the opposite. **Uses:** e.g. mechanical clocks.

A chain drive is made of cogwheels at a certain distance and a chain. The rotary sense is the same in both wheels. As in the gear drive, slippage doesn't appear and the wheel speed are inversely proportional to the number of teeth (cogs or sprockets; piñones). **Uses**: e.g. bicycles.



In the friction drive or in the gear drive, if we want the rotary sense of both wheels to stay the same, we have to insert a third wheel between them. This wheel is called idler (rueda loca) and its size doesn´t affect the output speed (N_2).

Activities: Copy following exercises and solve them in your notebook

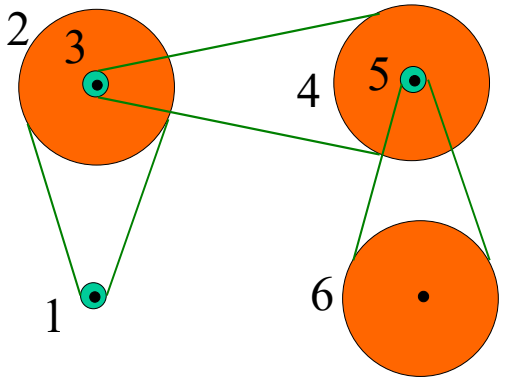
22) Calculate the gear ratio in this friction system: D_1=10, D_2 = 30. What is the rotation speed of the driven wheel (N_2) if the N_1 = 30 rpm? Which way does the driven wheel rotate?

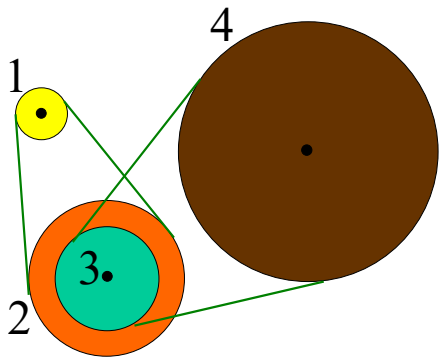
23) How can a pulley system be reversed so that the pulleys rotate in the opposite directions?

24) The front gear of a bicycle have 44 and 56 teeth respectively. The smallest back gear has 14 teeth and each of the other back gears has two teeth more than the previous one. The gear wheel has 5 gears. The back tire has an diameter of 60 cm and N1 is equal to 60 rpm. Complete following table:

Front gear	**Back gear**	**N_1**	**N_2**	**Speed (km/h)**
Smaller: Z_1=	Smallest: Z_2=	60 rpm		
Bigger: Z_1=	Smallest: Z_2=	60 rpm		
Bigger: Z_1=	2nd Smallest: Z_2=	60 rpm		

25) Given a pulley train with these diameters: D1 = 10 mm, D2 = 30 mm, D3 = 20 mm, D4 = 50 mm, calculate N4 if wheel 1 rotates at 20 rpm.

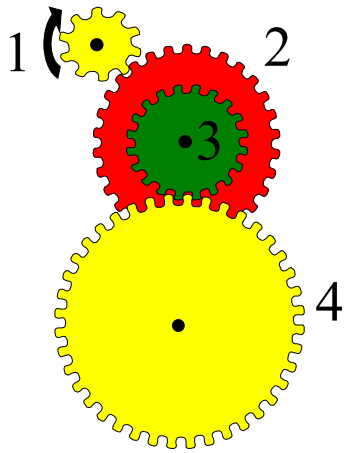




26) Look at this pulley train. The diameters of the big pulleys are 30 cm and the diameters of the small pulleys are 5 cm. Pulley 1 rotates at a velocity of 150 rpm. Fill following table:

Pulley	1	2	3	4	5	6
Diameter (D)						
Velocity (N)						

27) Indicate with arrows the rotation direction of this gear system (wheel 1 rotates clockwise) and fill following table. Is this a speed reducing or multiplying system?



Wheel	1	2	3	4
Number of teeth (Z)				
Speed (N)	240 rpm			

4.2.3. Motion transformation

The rack and pinion (cremallera y piñon), the nut and bolt, the crank and connecting rod (manivela y biela), the cam (leva) and the eccentric wheel are examples of mechanism that transform the **rotary into linear** motion.

Some of them are **reversible**, that means, they transform also the **linear into rotary** motion. The linear motion can be of two types: linear or **reciprocating** (alternativo).

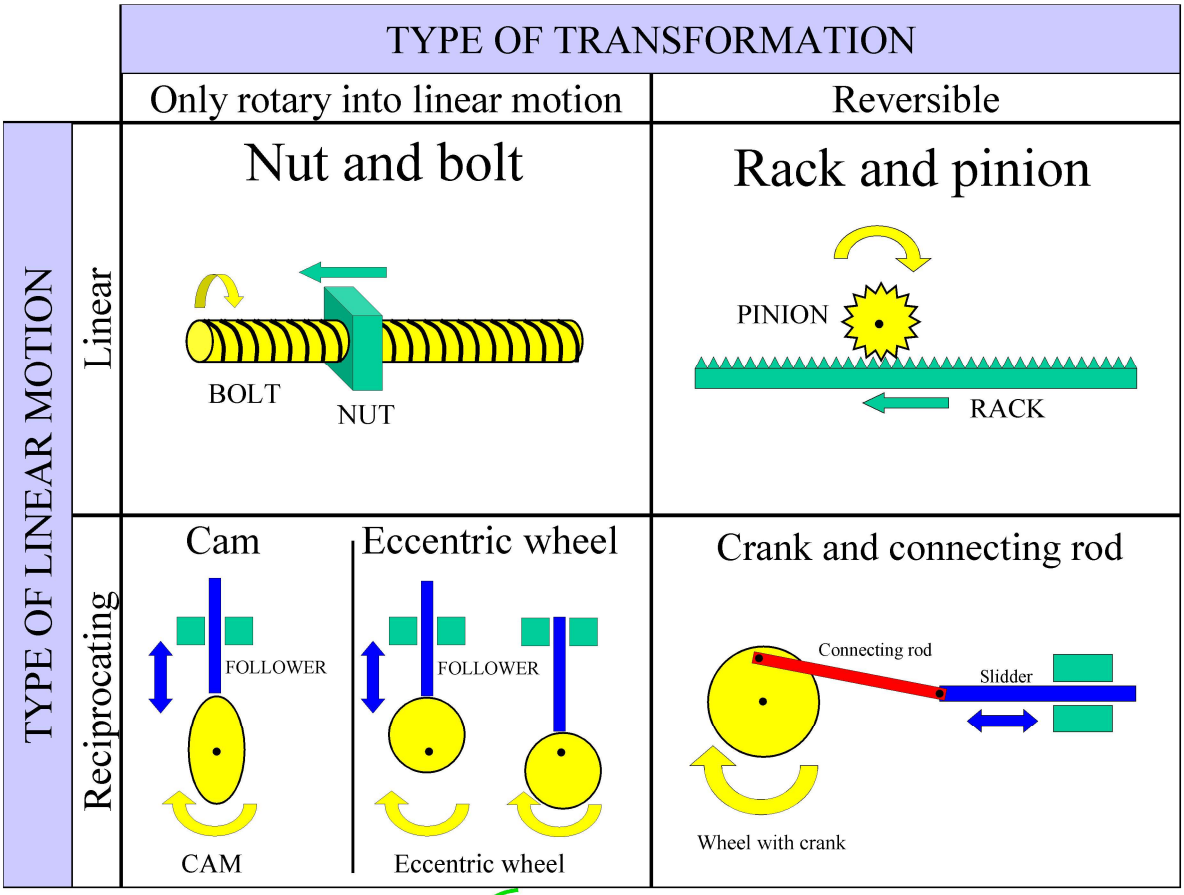
Nut and bolt : when the bolt rotates the nut moves in a **linear** motion along the bolt. It is usually **not reversible**. **Uses**: e.g. taps, car jack, bench vice, bar clamp, lips pencils, etc.

Rack and pinion : when the pinion rotates the rack moves in a **linear** motion. It is **reversible** (moving the rack, the pinion rotates). **Uses**: e.g. Corkscrews, funicular, automovil steering, garage doors, etc.

Cam : when the cam rotates its edge pushes a 'follower' (seguidor) and we get an **reciprocating** motion. It is **not reversible**. **Uses**: e.g. music boxes, opening of valves of combustion engines.

Eccentric wheel : when the wheel rotates around its off-centre axle its edge pushes a 'follower' (seguidor) and we get an **reciprocating** motion. It is **not reversible**. **Uses**: e.g. like the cam.

Crank and connecting rod : when the crank rotates the connecting rod moves in a oscilating motion and the slider in a **reciprocating** motion. It is **reversible** (moving the slider, the crank rotates). **Uses**: e.g. sewing machines, steam engine, windscreen wipers.



Activities: Copy following exercises and solve them in your notebook

28) Fill the table regarding two different rack and pinion mechanism:

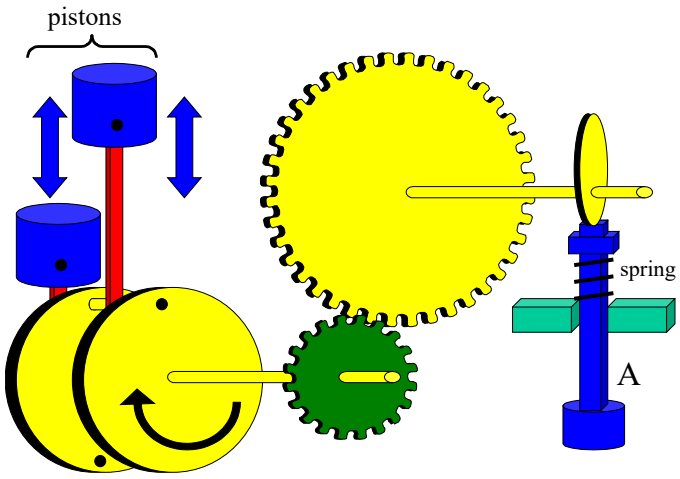
Case	Number of teeth in the pinion	Distance between the teeth	Rotation speed	Rack speed (mm / minute)
1	20	2 mm	90 rpm	V = 90 * 20 * 2 = _____
2	20	3 mm	30 rpm	

29) Match the parts and the functions of a cranck and connecting rod system:

- Crank
- Connecting rod
- Slider (or piston)

- This uses oscillating motion to transmit motion to the piston
- This uses reciprocating motion
- This transmits the rotary motion of the wheel to the connecting rod

30) This is a diagram of an important part of a combustion engine. It is a crankshaft (cigüeñal = varios sistemas biela-manivela unidos por un mismo eje) connected to another mechanical system. The combustion of the fuel moves the pistons up an down:



a) What type of motion does the axle of the crankshaft transmit?

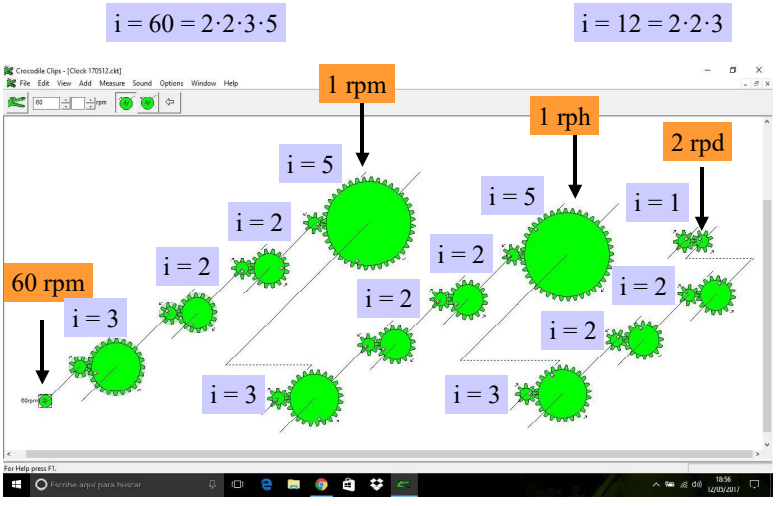
b) What is the function of the gear system?

c) What is the motion of the piece A?

Besides transmision and transformation (conversion) of motion, mechanism can also control motion as for example the ratchet (trinquete).

A.Espinosa (CC)

Gear system for a clock



31) Design in the computer room the gear system for a clock with three clock hands: one for seconds (1 rpm), a second one for minutes (1 revolution per hour; 1 "rph") and a third one for hours (2 revolution per day; 2 "rpd"). The first wheel rotates at 1 revolution per second (60 rpm). You can use the program "crocodile-clip".