

## **THE CENTRIPETAL FORCE**

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## I. THE LAWS OF NEWTON

The general laws of movement were discovered and formulated by the English mathematician and physicist Isaac Newton (1642 - 1727).

These laws are universal and allow you to describe any form of movement.

These laws read as follows:

### **Principle of inertia**

*'A mass on which no force is acting, remains motionless if motionless, or keeps a constant speed if in motion.'*

*'A mass in motion on which no force is acting, describes a perfect rectilinear path.'*

The concept of force stems from this principle.

### **Force concept**

*'A force refers at any cause acting on the speed or on the trajectory of a mass.'*

### **Principle of reciprocity**

*'Any mass subjected to a force, responds by a reciprocal action of equal intensity, but of opposite direction.'*

How can we define the concept of centripetal force and how can we apply these laws in the case of a land vehicle?

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## II. CENTRIPETAL FORCE: THE TRUE DEFINITION

A frequent mistake is to associate guiding force to centripetal force although they have nothing in common. Therefore they should not be confused.

### Reminder

Isaac Newton's *principle of inertia* states that straight-line motion is the rule, a rectilinear trajectory of a moving mass being able to be deviated only by a force.

The concept of force derives from this principle and can be defined as follows: '*A force refers to any cause able to deflect the trajectory of a mass.*'

Centripetal means '*that brings closer to a center.*' Where to locate this center? This term may have two different meanings.

### Two centers...

1. When a mass describes a circular trajectory, this center is obviously the one of the circle this mass describes.

In the case of a bend taken by a car, the action of a centripetal force should lead to a steady decrease of the radius' length until it reaches zero. The car would then describe a spiral-shaped trajectory ending at this center. Obviously, this is never the case.

2. In the second meaning, which goes beyond circular movement, this center is that of a mass, which in physics means a virtual point useful for describing some phenomena. Synonym: center of gravity, center of balance. For instance, the phenomenon of universal attraction can be described as an attraction between two centers of mass, which supposes the existence of a distant cause.

In the case of a bend taken by a car, a centripetal force should act on the center of the mass of the car. Obviously, this is not the case: no force is acting on the center of the mass of the car, except the weight.

### Centripetal force: the true definition

*'Centripetal force is a force acting at a distance to bring closer two centers of mass.'*

Amongst an infinity of physical forces, only two meet this criterion:

- *Electromagnetic force.*
- *Gravitational force.*

## Two centripetal forces...

1. Electromagnetic force operates at a distance during a chemical reaction. It allows a heavy atom to capture one or several lighter atoms to form a molecule. Its action can therefore be described as centripetal.

For instance, when oxygen atoms come into contact with hydrogen atoms, each oxygen atom attracts and captures two hydrogen atoms to form a molecule of water.

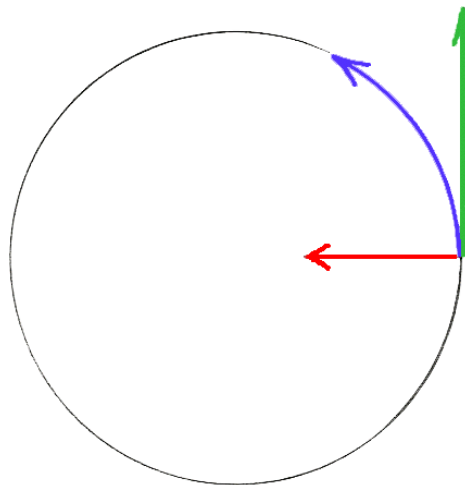
2. Gravitational force is the other force that operates at a distance.

It can be verified by throwing an object in the air. Once delivered to itself, the object is subjected to a force that brings it closer to the center of the Earth that attracts it. That is the weight.

The same kind of attraction maintains Earth in orbit around the Sun: the mass of the Sun gives off a force that diverts Earth's trajectory. That is the centripetal force.

If this force did not exist, Earth would leave the Solar system.

If Earth's speed was zero, it would immediately head off to the Sun.



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### Diagrammatic representation of the Earth's rotation around the Sun

Earth describes a circular trajectory (blue arrow) because a the force generated by the Sun's mass (red arrow). That is centripetal force. If it did not exist, Earth's trajectory would be a straight line (green arrow). Be careful not to add force, speed and trajectory!

## Expressing centripetal force...

Centripetal force is expressed thanks to the relation discovered by Isaac Newton to explain the Moon's rotation around Earth, then that of Earth around the Sun:

$$F = M V^2 / R$$

Note: this relation expresses only centripetal force or, by analogy of reasoning, *guiding force*, but certainly not centrifugal one (see ADILCA files '*centrifugal force*' and '*guiding force*').

### Centrifugal force and Centripetal force...

Centrifugal and centripetal force are often presented as inseparable. This simplistic reasoning rests on the two following confusions.

1. First confusion stems from poor understanding of the concept of centrifugal force.

Centrifugal force being an imaginary force, it only appears in partial descriptions that leave out any mention of real movement. What is it all about?

In this description, entirely different from the former, one must assume that Earth ceases to orbit around the Sun and remains motionless in space. Driven by gravitational force, Earth would immediately head off to the Sun until it reaches it, unless an imaginary force equal in magnitude and opposite in direction came to prevent it!

That imaginary force is centrifugal force! But this description is truncated because it implies that Earth stops orbiting around the Sun<sup>(1)</sup>.

In a nutshell, centrifugal force and centripetal force are not part of same reasoning!

2. Second confusion stems from a poor understanding of Isaac Newton's third law which goes<sup>(2)</sup>:

*'To every action there is always an equal but opposite reciprocal action.'*

Indeed this reciprocal action exists, but how and where does it manifest itself?

Consider again the description of movement within the Solar system and the relation between the Sun and Earth: the Sun generates a force that acts from a distance and keeps Earth on a circular orbit. This is centripetal force.

The Law of reciprocal action as set out by Newton allows us to deduce that Earth attracts the Sun with a force of equal intensity but in opposite direction.

Why is it that only Earth changes its trajectory, leaving the Sun entirely insensitive to this force? The explanation lies in the Sun's mass being over 333,000 times greater than Earth's. Taking advantage of this imbalance, the Sun lays down the law which Earth can only comply with<sup>(3)</sup>.

In a nutshell, don't confuse centrifugal force with reciprocal action!

### Three fundamental differences...

Let us get back to Earth: is the guiding force (that is requested by a car driver to negotiate a bend) a centripetal force?

Let us examine step by step the characteristics of guiding force:

1. The car never gets closer to the center of its trajectory: it is only diverted from a straight line trajectory.
2. This force does not act at a distance, it is a contact force.
3. This force does not impact the center of the mass of the car but acts at the circumference of the tires of the steering wheels.

Those three fundamental reasons enable us to conclude quite definitely that guiding force is in no way centripetal.

*Quod erat demonstrandum!*

### Conclusion

One must face the facts: when it comes to cars, there are no such things as centrifugal or centripetal forces!

(1) *This truncated description is said to be 'static' as opposed to the actual description, said to be 'dynamic'. Beware of the strict application of this way of thinking: it would imply that there are more seasons!*

(2) *Beware of instruction manuals! This law can only be applied to real forces, never to fictional ones. This means that in an imaginary description, there is no reciprocal action.*

(3) *Mass of the Sun (S):  $2 \times 10^{30}$  kg; mass of Earth (E):  $6 \times 10^{24}$  kg; ratio S/E =  $1/3 \times 10^6$ .*

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### III. CENTRIPETAL FORCE: THE CALCULATION MODE

#### 1. Centripetal force

$$F = M \cdot V^2 / R$$

**F**: centripetal force, expressed in **N**

**M**: mass, expressed in **kg**

**V**: orbital speed, expressed in **m.s<sup>-1</sup>**

**R**: orbital radius, expressed in **m**

Consistency of the units:  $F = \text{kg} \cdot (\text{m} \cdot \text{s}^{-1})^2 \cdot \text{m}^{-1} = \text{kg} \cdot (\text{m}^2 \cdot \text{s}^{-2} \cdot \text{m}^{-1}) = \text{kg} \cdot \text{m} \cdot \text{s}^{-2} = \text{N}$

Example: calculate the centripetal force that keeps the Earth in orbit around the Sun. Characteristics of the Earth and its movement: mass  $6 \times 10^{24}$  kg; orbital speed  $30 \times 10^3$  m.s<sup>-1</sup>; orbital radius  $150 \times 10^9$  m.

$$F = 6 \times 10^{24} \times (30 \times 10^3)^2 / (150 \times 10^9)$$

$$F = 6 \times 10^{24} \times 900 \times 10^6 / (150 \times 10^9)$$

$$F = 6 \times 900 \times 150^{-1} \times 10^{+24} \times 10^{+6} \times 10^{-9}$$

$$F = 36 \times 10^{21} \text{ N} = 36 \text{ ZN}$$

Note: only one force explains the movement of the Earth around the Sun, that is the centripetal force. This force acts alone, it attracts the globe towards the center of the Sun. There is no other force acting in the system.

#### 2. Reciprocal action

According to Isaac Newton's principle of reciprocity, the globe exerts a force on the Sun, of the same intensity but of opposite direction. This action is easily calculated from the following equation:

$$A = - F$$

**A**: reciprocal action, expressed in **N**

**F**: centripetal force, expressed in **N**

Example : calculate the reciprocal action that the globe exerts on the Sun, the centripetal force that keeps the Earth in orbit around the Sun being 36 ZN:

$$A = - 36 \text{ ZN}$$

The Sun is not affected by this attraction because of its mass.

### 3. Transverse acceleration

$$Y = F / M$$

**Y**: transverse acceleration, expressed in **m.s<sup>-2</sup>**

**F**: centripetal force, expressed in **N**

**M**: mass, expressed in **kg**

Consistency of the units:  $Y = \text{kg} \cdot \text{m} \cdot \text{s}^{-2} \cdot \text{kg}^{-1} = \text{m} \cdot \text{s}^{-2}$

Example 1: calculate the transverse acceleration that the Earth undergoes to keep it in orbit around the Sun. Characteristics of the Earth and its movement: mass  $6 \times 10^{24}$  kg; centripetal force  $36 \times 10^{21}$  N.

$$Y = 36 \times 10^{21} / (6 \times 10^{24})$$

$$Y = 36 \times 6^{-1} \times 10^{+21} \times 10^{-24}$$

$$Y = 6 \times 10^{-3} = 0.006 \text{ m} \cdot \text{s}^{-2}$$

Example 2: calculate the acceleration that the Sun undergoes because of the Earth's attraction. Mass of the Sun:  $2 \times 10^{30}$  kg; reciprocal action –  $36 \times 10^{21}$  N.

$$Y = - 36 \times 10^{21} / (2 \times 10^{30})$$

$$Y = - 36 \times 10^{+21} \times 2^{-1} \times 10^{-30}$$

$$Y = - 18 \times 10^{(+21-30)}$$

$$Y = - 18 \times 10^{-9} = - 0.000\ 000\ 018 \text{ m} \cdot \text{s}^{-2}$$

### 4. Centrifugal force

$$F' = - M \cdot Y$$

**F'**: centrifugal force, expressed in **N**

**M**: mass, expressed in **kg**

**Y**: transverse acceleration, expressed in **m.s<sup>-2</sup>**

Consistency of the units:  $F' = \text{kg} \cdot \text{m} \cdot \text{s}^{-2} = \text{N}$

Exemple: calculate the force that would have to be exerted on the center of mass of the Earth, if it was motionless (zero orbital speed), to maintain it in equilibrium in space and prevent it from falling towards the Sun:

$$F' = - 6 \times 10^{24} \times 6 \times 10^{-3}$$

$$F' = - 6 \times 6 \times 10^{+24} \times 10^{-3}$$

$$F' = - 36 \times 10^{21} \text{ N} = - 36 \text{ ZN}$$



Note 1: this force is commonly referred to as '*centrifugal force*' which is an incorrect name since there is neither trajectory nor center (the Earth is motionless). The scientific name of this force is: imaginary force, fictional force, or pseudo-force.

Note 2: the sign [-] is required, it specifies that the spatial orientation of the centrifugal force conflicts the logic of the Solar system.

Note 3: beware to misinterpretation, the numerical equality of results does not allow the interchangeability of descriptions, concepts or reasoning. The most common mistake is to confuse the centrifugal force with the reciprocal action that the Earth exerts on the Sun. Indeed, although these two forces have the same intensity (- 36 ZN), they have nothing in common:

- the centrifugal force acts on the center of gravity of the Earth, but it is an imaginary force, it is a static description.
- the reciprocal action acts on the center of gravity of the Sun, it is a real force, it is a dynamic description.

Note 4: the different calculations must be done in the order indicated. It is indeed impossible to directly calculate the centrifugal force without performing the intermediate calculations detailed above.

Note 5: any scientific approach is based on the same principle: from *experiment* and *measurements* to *calculations* that finally lead to *reasoning* (here: the concept of centrifugal force). This passage from concrete to abstract reasoning, from the real to the imaginary has often been short-circuited, hence the confusion or misunderstanding about the centrifugal force.

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