THE CENTRIPETAL FORCE

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I. WHAT YOU NEED TO KNOW ABOUT CENTRIPETAL FORCE

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

What then defines a centripetal force?

Definition

Force means «*any cause that curves the trajectory of a mass*».

Centripetal means «*that brings closer to a center*».

So, a force is said to be centripetal when it brings a mass closer to a center. Where to locate this center? In physics, this term may have two different meanings.

Finding the center…

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 definition, which goes beyond circular movement, this center is a *center of mass*, which in physics means a virtual point useful for describing some phenomena.

For instance, the phenomenon of gravitation can be described as an attraction between two centers of mass. This definition supposes a force operating at a distance.

Amongst the four fundamental physical forces that guide the Universe, only two meet this criterion, namely *electromagnetic force* and *gravitational force*. So their actions can be qualified as centripetal – but they are the only ones.

Only two kinds of centripetal force…

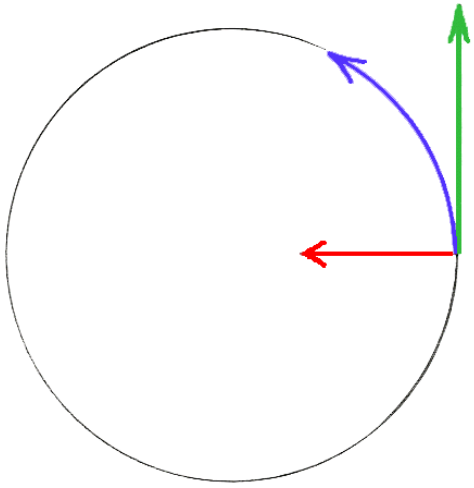
1. *Electromagnetic force* operates at a distance during a chemical reaction. It allows a heavy atom to capture one or several lighter atoms to form a molecule. Its action can therefore be described as centripetal.

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. Its action is also centripetal hence its name.

This can be verified by dropping an object on the ground. In its fall, the object gets closer to the center of mass of Earth which attracts it.

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. If this force did not exist, Earth would leave the Solar system. And if Earth's speed was zero, it would immediately head off to the Sun.



Diagrammatic representation of the Earth's rotation around the Sun

Earth describes a circular trajectory (blue arrow) because of the force generated by the Sun's mass (red arrow). This is centripetal force. If it did not exist, Earth's trajectory would be a straight line (green arrow).

Expressing centripetal force…

How to express 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:

$$\mathbf{F = M\ V^2 / R}\ ^{(1)}$$

Note: this relation can not express centrifugal force but only centripetal force and, by analogy, *guiding force* (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. Subject to 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 [(2)].

2. Second confusion stems from a poor understanding of Isaac Newton's third law which goes: «*To every action there is always an equal and opposite reaction*» [(3)]. Indeed this reaction 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 reciprocity as set out by Newton allows us to deduce that Earth attracts the Sun with a force of equal intensity as the one keeping it on its orbit, but in opposite direction. This real force exerts on the center of mass of the Sun, but has nothing to do with centrifugal force, which indeed shouldn't even be brought up in this description!

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 300,000 times greater than Earth's. Taking advantage of this imbalance, the Sun lays down the law which Earth can only comply with [(4)].

In a word, it is essential to dissociate the two descriptions, and thus the two forces: one is very real whereas the other is fictitious and appears only in the case of an imaginary description (see ADILCA file ''*centrifugal force*'')!

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) *According to the International System of Units (**SI**) compulsory in United States since 1964, in United Kingdom since 2004, the mass should be expressed in kilograms (symbol **kg**), speed in meters per second (**m.s^{-1}**) and radius of the trajectory in meters (**m**). Dimension obtained is kilograms-meters per square second (**kg.m.s^{-2}**) which characterizes the force unit, newton (**N**).*

(2) *This truncated description is said to be "static" as opposed to the actual description, said to be "dynamic". About hazards in applying too loosely this way of thinking (here this would imply there were no more seasons!), see ADILCA file "Cessac & Tréherne".*

(3) *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 reaction.*

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

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II. 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^{-1}**
R: orbital radius, expressed in **m**

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

Example: calculate the centripetal force that keeps the Earth in orbit around the Sun. Characteristics of the Earth and its movement: mass 6 x 10^{24} kg; orbital speed 30 x 10^3 $m.s^{-1}$; orbital radius 150 x 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 x 10^{21} **N** = 36 **ZN**

Note 1: only one force to explain the movement of the Earth around the Sun, that is the centripetal force. This force acts alone, it is exerted on the center of mass of the Earth, it is directed towards the center of the Sun. There is no other force to act in the solar system.

Note 2: according to Isaac Newton's principle of action reaction, a force of the same intensity but of opposite direction is exerted on the center of mass of the Sun, but without consequence as to its own movement, because of its mass.

2. Transverse acceleration

$$\Upsilon = F / M$$

Υ: transverse acceleration, expressed in **$m.s^{-2}$**
F: centripetal force, expressed in **N**
M: mass, expressed in **kg**

Consistency of the units: **Υ** = $kg.m.s^{-2}$. kg^{-1} = **$m.s^{-2}$**

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

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

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

$$\mathbf{\Upsilon} = 6 \times 10^{-3} = 0.006 \ \mathbf{m.s^{-2}}$$

3. Centrifugal force

$$\mathbf{F' = - M \, . \, \Upsilon}$$

F': centrifugal force, expressed in **N**
M: mass, expressed in **kg**
Υ: transverse acceleration, expressed in **$m.s^{-2}$**

Consistency of the units: **F'** = kg . $m.s^{-2}$ = **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:

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

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

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

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.

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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