

The Importance of Centrifugal Force

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Abstract. University physics courses teach that centrifugal force doesn't exist, while university applied maths courses teach that centrifugal force is merely a fictitious force that arises when making observations from a rotating frame of reference. Meanwhile, Sir Isaac Newton claimed that a centrifugal force is the equal and opposite reaction to a centripetal force.

We also read in the literature that the centrifugal force acting on a body relative to a centre of rotation is merely an effect of inertia, owing to the tendency for the body to move in a straight-line path, and so it draws away from the centre. This article attempts to ascertain which, if any, of these positions is correct, and why the matter is important.

The Inertial Frame of Reference

I. It would be generally agreed that in an inertial frame of reference in a terrestrial context, and in a non-rotating system, that *centrifugal force* is a quantity which is not noticed to exist. In such a context, a body continues in its state of rest or uniform straight-line motion unless acted upon by a Newtonian force, and while we can geometrically identify a centrifugal force acting outwards on a moving body, from every point in space, these *centre-fleeing* centrifugal forces all cancel to zero. In a rotating system however, if a body is forced to co-rotate with the system, then the specific centrifugal force from the centre of rotation will become an isolated physical reality within the rotating system, and an externally applied inward acting *centripetal force* will be required to cancel it.

When physics students are taught that centrifugal force doesn't exist, the demonstration invariably takes place in the restricted context of circular motion where the students are correctly shown how a *centre-seeking* centripetal force deflects an object off its straight-line inertial path. Unfortunately, however, the restricted context of circular motion masks the involvement of a centrifugal force by virtue of the fact that this has the same magnitude as the centripetal force, and this makes it superficially appear as though no centrifugal force is involved. In order to expose the centrifugal force, we need to look at curved path motion more generally, and we should ideally avoid circular motion

examples for the reasons stated in the previous sentence. Elliptical planetary orbits serve this purpose very well.

The Gravitational Field

II. No physical explanation was given in the section above for an inertial frame of reference, just as no physical explanation has ever been given for gravity. We do however know that a gravitational field distorts an inertial frame of reference and that the centrifugal force to the gravitational centre acts in opposition to gravity. Both gravity and centrifugal force are radial forces in that they relate to the second time derivative of the radial distance to a point origin. In the case of gravity, this point origin is clearly defined by the location of the gravitational mass of the attracting body, whereas in the case of centrifugal force, all points in space are legitimate point origins. When doing orbital mechanics, we are of course only interested in the centrifugal force to the gravitational centre or to the focus of the orbit. These orbits are conic sections which can be ellipses, circles, parabolas, or hyperbolas.

Gravity is accepted to be a real Newtonian force since it causes a body to deviate from its state of rest or its uniform straight line inertial path. Centrifugal force, on the other hand, is merely a consequence of the tendency of a moving body to travel in a straight-line path in the absence of a centripetal force acting on it. As such, centrifugal force is said to be an inertial force rather than a Newtonian force.

Centrifugal force is nevertheless every bit as real as gravity. We have known since the time of Leibniz that the radial planetary orbital equation takes the form [1], [2], [3],

$$m\ddot{r}\hat{\mathbf{r}} = m(g + r\dot{\theta}^2)\hat{\mathbf{r}} \tag{1}$$

where $mg\hat{\mathbf{r}}$ is gravity and $mr\dot{\theta}^2\hat{\mathbf{r}}$ is centrifugal force. Equation (1) can be rearranged as,

$$m\mathbf{g} = m(\ddot{r} - r\dot{\theta}^2)\hat{\mathbf{r}} \tag{2}$$

and due to conservation of angular momentum (Kepler's second law), equation (2) can be simplified to,

$$m\mathbf{g} = m\ddot{\mathbf{r}} \tag{3}$$

In modern applied maths textbooks, equation (3) is a popular starting point in planetary orbital analysis, but it masks the involvement of centrifugal force

and leads to the false claim that gravity is the only real force acting in the planetary system. The argument is that the $m\ddot{\mathbf{r}}$ term represents the total force in the inertial frame of reference, and that this equates to gravity, and that therefore no centrifugal force is involved. While it can be seen from equations (1) and (2) that this argument is false, the argument is often reinforced by denying the name '*centrifugal force*' to the $mr\dot{\theta}^2\hat{\mathbf{r}}$ term. But it is centrifugal force, and it is very much involved in a planetary orbit. Gravity and centrifugal force are both radial forces acting in opposition to each other, and the latter is implicit within the second time derivative of the radial position vector. Equation (3) is not an actual equation for gravity, but rather it is telling us that gravity is the difference between the net radial force and the centrifugal force.

Newton's Rotating Bucket

III. Centrifugal force is physically encountered as a real force in Newton's rotating bucket. There is no doubt about its existence, and it is not, as Newton claimed, a reaction to a centripetal force, [4], [5]. The centrifugal force acting outwards against the inside of the bucket's wall is the primary active agent, while the inward acting centripetal force exerted by the wall is a reactive constraint. The centrifugal force is quite definitely not a reaction. Centrifugal force is an action, just as we already saw in the section above in connection with planetary orbits where it is totally independent of gravity. Centrifugal force is tied up with a body's momentum and kinetic energy and it is as real as those.

Some say that centrifugal force is merely the inertial resistance to attempts by a centripetal force to deviate a body off its straight-line inertial path. It's true that centripetal force curved path motion and it's true that centrifugal force opposes this centripetal force. However, the centripetal force does not actually induce the centrifugal force, and in many cases, such as described in the paragraph above, it's the centripetal force that is induced by the centrifugal force. The centrifugal force is there already, built into the momentum of the moving body. It's the body's momentum that decides the magnitude of the centrifugal force. This magnitude is not decided by the magnitude of any applied or induced centripetal forces. Centrifugal force is not, as Newton said, part of an action-reaction pair with the centripetal force, [6], and besides, the two forces are acting on the same body, whereas an action-reaction pair can only act across two bodies. When a centrifugal force forms part of an action-reaction pair, it is with another centrifugal force.

Neither is centrifugal force merely a fictitious force arising due to making observations from a rotating frame of reference. We don't need a rotating frame of reference to observe a real centrifugal force, although in the case of a body that is being forced to co-rotate, an actual physically rotating system can directly expose the centrifugal force relative to the centre of rotation. A

centrifuge device is a prime illustration of this syndrome, and we can observe a centrifuge in action while sitting in a chair in the corner of the room. We don't need to be rotating with the centrifuge in order to observe the centrifugal force in action.

Conclusion

IV. The importance of centrifugal force lies principally in the context of a vortex, as illustrated by Newton's rotating bucket. The outward pressure which the rotating water exerts on the inside wall of the bucket is due to a very real centrifugal force, which is in turn due to the inertial effect of each element of the water as it endeavours to move in a straight-line path. The reason why this context is so important is because it lies at the root of the principle upon which James Clerk Maxwell established his famous equations of electromagnetism. Maxwell's equations were established on the basis that space is densely packed with tiny molecular vortices that press against each other with centrifugal force while striving to dilate, [7], [8], [9], [10], [11]. These vortices self-align along their mutual rotation axes hence tracing out the local magnetic field.

When a charged particle moves through a magnetic field, it experiences a magnetic force, $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$, which is actually a centrifugal force, or more accurately, the difference between two centrifugal forces acting oppositely to each other on either side of the particle, at right angles to its direction of motion. This sea of molecular vortices serves as the physical basis for an inertial frame of reference, [12], as well as serving as the medium for the propagation of light waves, and the magnetic flux density \mathbf{B} is related to the fine-grained vorticity in the sea.

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“All space, according to the younger Bernoulli, is permeated by a fluid aether, containing an immense number of excessively small whirlpools. The elasticity which the aether appears to possess, and in virtue of which it is able to transmit vibrations, is really due to the presence of these whirlpools; for, owing to centrifugal force, each whirlpool is continually striving to dilate, and so presses against the neighbouring whirlpools.”
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“Long ago he (mankind) recognized that all perceptible matter comes from a primary substance, of a tenuity beyond conception and filling all space - the Akasha or luminiferous ether - which is acted upon by the life-giving Prana or creative force, calling into existence, in never ending cycles, all things and phenomena. The primary substance, thrown into infinitesimal whirls of prodigious velocity, becomes gross matter; the force subsiding, the motion ceases and matter disappears, reverting to the primary substance”.
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 In relation to the speed of light, *“The most probable surmise or guess at present is that the ether is a perfectly incompressible continuous fluid, in a state of fine-grained vortex motion, circulating with that same enormous speed. For it has been partly, though as yet incompletely, shown that such a vortex fluid would transmit waves of the same general nature as light waves— i.e., periodic disturbances across the line of propagation—and would transmit them at a rate of the same order of magnitude as the vortex or circulation speed”*
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