When Joseph Bertrand accused Coriolis of plagiarism

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The documents we normally analyse on this site are well-written, correct and pedagogical. However, one might also learn from the exceptions. The current document "Théorie des mouvements relatifs" published 1848 in *Journal de l'École Polytechnique*, **19**, 149-154 [1] by the young mathematician Joseph Bertrand (1822-1900) is scientifically not quite correct, difficult to understand and coloured by personal prejuries. It is, however, still worth having a look at because the errors or weaknesses might encourage us to explain the matters in a more clear way and address his scientific misunderstandings in so far they are still with us today.

In spite of all its weaknessess the main importance of Bertrand's mémoire might not have been scientific, but political; it arose the interest in relative motion in rotating system, that some years later resulted in the famous pendulum experiment by Léon Foucault (1819-1868).

The most eye-catching aspect of Bertrand's paper is his urge to discredit a colleague, accusing the late Gaspard-Gustave Coriolis (1794-1843) of quasi-plagiarism. Bertrand insinuated that Coriolis, when developing his theory of deflection of relative motion (the "Coriolis Effect"), borrowed ideas from the renowned Alexis Claude Clairaut (1713–1765) without giving him proper credit.

1. A summary of the mémoire,"Mémoire sur la théorie des mouvements relatifs", was presented by Bertrand to the Academy 21 June 1847 and published in *Comptes-Rendus*, 1847, 24, p. 141-42.

Figure 1: Joseph Bertrand (1822-1900) was in the late 1840's a rising star in the academic community. *At the age of 17 he had been admitted to École Polytechnique. He continued at École des Mines which he left by distinction in 1846 to concentrate in mathematics and the reviewing the progress of general physics (image Wikipedia).*

1. Coriolis's 1835 mémoire

Coriolis had in his 1835 mémoire *"Sur les équations du mouvement relatif des systèmes de corps"* in *Journal de l'École polytechnique*, 24° cahier, XV, p. 142-154 reasoned that if a body within a rotating system at distance R from the centre of rotation was moving with velocity V_r relative to the rotation Ω and the ordinary centrifugal force Ω^2R (or in vector notation $-\mathbf{\Omega}\times(\mathbf{\Omega}\times\mathbf{R})$) had to be supplemented with an additional force $2\Omega V_r$ (or in vector notation $-2\mathbf{\Omega}\times\mathbf{V_r}$) what Coriolis called "the composed centrifugal force" and we call the "Coriolis force".

$$\left(\frac{d\boldsymbol{V}_r}{dt}\right)_r = -\boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \boldsymbol{R}) - 2\boldsymbol{\Omega} \times \boldsymbol{V}_r \qquad (1)$$

This "extension" to the centrifugal force is directed perpendicular to the relative motion $\mathbf{V_r}$, to the right in a counter-clockwise rotation (to the left in a clockwise). Because of the perpendicular direction to the motion it cannot change its speed (kinetic energy), only the direction[2].

Although both the Coriolis force and the centrifugal force are fictitious forces; they do not have any physical origin like gravitation, magnetic or electric forces, their mathematical structure is quite different. Both depend on rotation Ω, but the centrifugal force also depends on position R and the Coriolis force on relative velocity V_r. This might be the reason why they have been seen as two forces of independent origin. The fact that inertial, frictionless motion over the surface of a rotating planet can be described by the Coriolis force alone, may have supported this view.

Coriolis's 1835 mémoire might be one of the few texts that make clear that the centrifugal force and the Coriolis force are intrinsically coupled to each other. Eq. (1) does therefore not only express a mathematical affinity between the two forces, but also a physical.

2. Coriolis disregarded

Coriolis 1835 mémoire does not seem to have attracted much immediate attention among contemporary scientists. One reason might have been that his "composed centrifugal force" $2\Omega V_r$ did not appear crucially important. For most applications it amounts to a fraction of the centrifugal force $\Omega^2 R$. More generally, they are equal when

$$\Omega^2 R = 2\Omega V_r \rightarrow \Omega R \equiv U = 2V_r \qquad (2)$$

i.e. when the relative velocity V_r is twice the rotational velocity U. On a carousel with Ω = 2 rad/sec (one orbit in 3.14 second) the Coriolis force is, for a 0.5 m/s moving object, stronger than the centrifugal force only within 50 centimeters from the centre of rotation.

When Coriolis published his mémoire, Siméon Denis Poisson (1781–1840), was working, or was about to start working, on the deflection of artillery grenades. That would result in 1837 in a mémoire « Extrait de la 1ère partie d'un Mémoire sur le mouvement des projectiles dans l'air, en ayant égard à leur

2. In a previous *BibNum* contribution (A. Persson, "How Newton might have derived the Coriolis acceleration?", July 2017), the non-trivial problems to give this a graphical presentation are discussed.

rotation et à l'influence du mouvement diurne de la Terre », *Comptes Rendus des Séances de l'Académie des Sciences*, 5, 660-667.

Poisson did not seem to have taken impression of Coriolis paper, at least it is not referred to in his work. It might be more likely that Poisson relied on the works by Laplace (1749-1827) who in the 1770's had derived the full equations of motions on a rotating planet and in 1803 together with Friedrich Gauss (1777-1855) estimated the deflection of falling objects[3].

3. Bertrand's 1848 memoire

Bertrand's mémoire started with some thoughtful reflexions:

> *Trop souvent, après avoir étudié la mécanique analytique, on croirait faire une chose inutile en cherchant à compléter l'étude de cette science par la lecture des travaux épars dont les prédécesseurs de Lagrange ont enrichi les recueils académiques du XVIII^e siècle. Je crois que cette tendance, malheureusement très-générale, est de nature à nuire aux progrès de la mécanique, et qu'elle a déjà produit de fâcheux résultats : la trop grande habitude de tout déduire des formules fait perdre jusqu'à un certain point le sentiment net et précis des vérités mécaniques considérées en elles-mêmes...*[4]

> [Too often, after having studied analytic mechanics, one would think it would be useless to attempt to complete the study of this science by reading the scattered works of which the predecessors of Lagrange have enriched the academic collections of the 18th century. I believe that this tendency, unfortunately very common, is likely to be detrimental to the progress of mechanics, and that it has already produced unfortunate results. The too common habit of deducing everything from formulas is to a certain extent a loss of the clear and precise feeling of the mechanical truths considered in themselves.]

These thoughts came to him after having read two articles, written within a century's interval. One was Coriolis's 1835 mémoire, the other was a mémoire by the renowned scientist Alexis Claude Clairaut. The latter had addressed, in 1742, the problem about relative motion in a rotating system some thoughts in "Sur

3. See a previous *BibNum* contribution presenting and analyzing this text (A. Persson, "Proving that the Earth rotates by measuring the deflection of objects dropped in a deep mine The French-German mathematical contest between Pierre Simon de Laplace and Friedrich Gauß 1803", August 2014).
4. See also A. Moatti, *Le Mystère Coriolis*, CNRS Editions, 2014, p. 107.

quelques principes donnant la solution d'un grand nombre de problèmes" *Mém. Acad. Sci. Berlin,* pt. 1 (1742): 370-72.

Bertrand had to his surprise found that Coriolis, "without knowing it, had done the same as the illustrious Clairaut":

> *M. Coriolis […] s'est rencontré, sans le savoir, avec l'illustre Clairaut, qui […] avait résolu plusieurs problèmes, en faisant précisément usage du principe de M. Coriolis".*
>
> *Mais ce principe qui, dans le Mémoire plus récent [Coriolis] n'est démontré que par des calculs compliqués, semble à Clairaut tellement évident, qu'il néglige d'entrer dans le détail des raisonnements synthétiques qui l'y ont conduit, et se borne à en énoncer en quelques lignes le principe.*
>
> [But this principle, in the most recent mémoire [*by Coriolis*] only demonstrated with complicated calculations, seemed so obvious to Clairaut, that he neglects to go into the details of the synthetic reasoning which led him there and confines himself to stating the principle in a few lines.]

***Figure 2:* Alexis Claude Clairaut (1713-1765), a key scientist of his time, was instrumental in establishing the validity of the principles and results that Isaac Newton had outlined in the Principia.** *He was therefore one of the prominent members in the 1736-1737 expedition to Lapland to measure the shape of the earth and thereby confirm Newton's hypothesis that it was flattened at the poles (engraved portrait by C.-N. Cochin & L.J. Cathelin, from a drawing by Carmontelle; Wikimedia Commons).*

And Bertrand goes on:

Ainsi se trouvent mis en évidence, de la manière la plus nette, les avantages et les dangers que présentent en mécanique les raisonnements a priori : ils sont la plupart du temps plus rapides, toujours plus satisfaisants pour l'esprit; mais Clairaut lui-même est exposé à s'y tromper.

[In this way, the advantages and the dangers presented in mechanics by a priori reasoning are most clearly shown: they are for the most part quicker, always more satisfying to the mind, but even Clairaut himself is liable to make a mistake.]

Le but que je me propose ici est d'exposer avec détail la démonstration trop peu connue de Clairaut, de la rectifier en montrant pourquoi le théorème dont il est question ne s'applique qu'au principe des forces vives, et de faire voir enfin comment, en suivant les idées de Clairaut, on parvient sans aucun calcul à la notion des forces centrifuges composées, introduites par M. Coriolis dans son second Mémoire sur les mouvements relatifs.

[The goal I propose here is to expose in detail Clairaut's little-known demonstration, to rectify it by showing why the theorem in question only applies to the principle of the living forces, and finally to show how, following the ideas of Clairaut, we arrive without any calculation to the notion of composite centrifugal forces, introduced by M. Coriolis in his second Memoir on relative motions.]

4. CLAIRAUT'S 1742 MÉMOIRE

In his first chapter *"Pour trouver les Mouvemens des systèmes de Corps entraînez avec les plans sur lesquels ils sont placez",* Clairaut envisaged a rectangle moving along a curved trajectory while at the same time a body is moving inside the rectangle (figure 3).

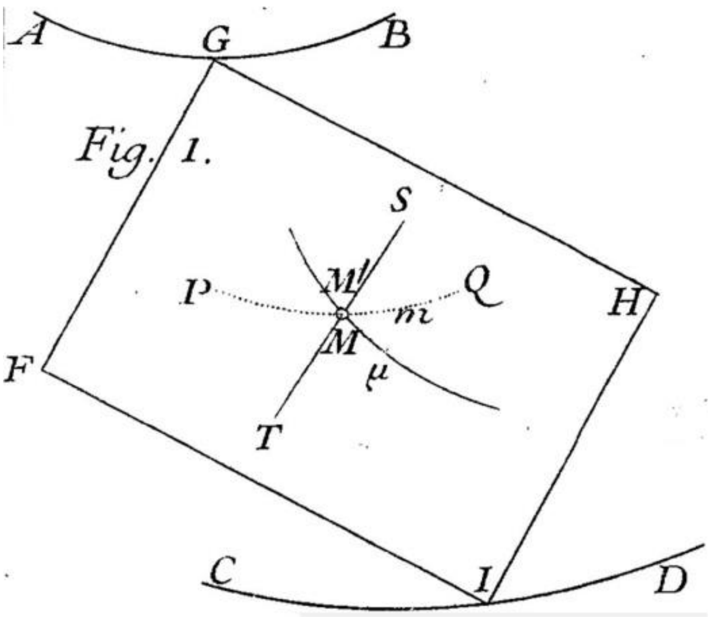

Figure 3: How Clairaut tried to visualize relative motion, the body M moving along μ on a rectangle FGHI gliding on two curved "rails" AB and CD with equal speed on both.

Clairaut now made the opposite corner-points *G* and *I* move with the same velocity. This turned out to be a crucial mistake. Even if the rectangle followed a curved trajectory, it would not necessarily mean that it rotated. That a curved motion does not necessarily involve rotation is schematically explained in figure figure 4.

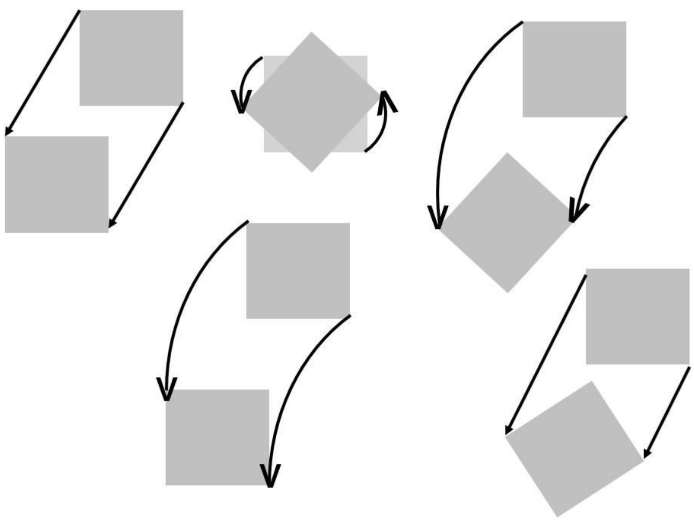

Figure 4: A schematic image of the difference between translational and rotational motion. *A curved motion does not have to involve rotation (lower left). On the other hand a translational motion can very well involve rotation (lower right).*

Bertrand identified Clairaut's mistake, and even highlighted the crucial sentence: "[on laissât] le plan FGHI *se mouvoir uniformément et en ligne droite*" which expressed an inaccurate idea, corrected by Bertrand:

> *On sait, en effet, fort bien, qu'un système abandonné à lui-même ne se meut pas d'un mouvement rectiligne et uniforme; c'est pour cette raison que la conclusion à laquelle parvient Clairaut n'est pas exacte*[5].
>
> [We know, indeed, very well, that a system left to itself does not move with a rectilinear and uniform movement, it is for this reason that the conclusion reached by Clairaut is not accurate.]

René Dugas was in his *A History of Mechanics* (p. 354-57)[6] not only apprehensive about Clairaut's model (as he labelled "incomplete"), he was not willing to follow Bertrand's "corrected" version either. However, the present author is not quite happy with Dugas's version. Below is an attempt to explain what Bertrand had in mind, taking Dugas's version into some account.

5. Relative motion under rotation

We define a coordinate system with x- and y-axes and origin in *M'*, where there is also an object *M* (figure 5).

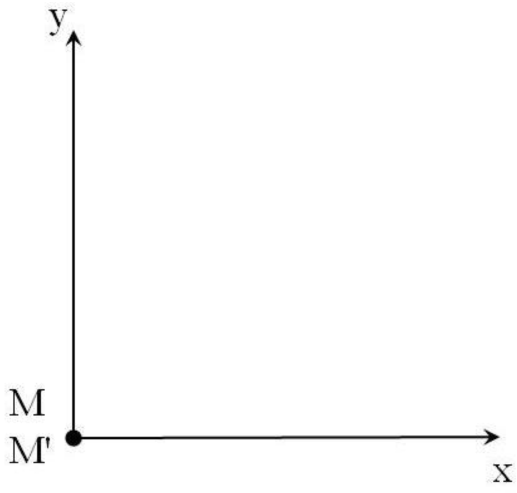

Figure 5: *The defined coordinate system x,y with origin M' and a point M at the origin free to move in any direction.*

5. Here Bertrand must have mistakenly have left out some words such "a system under rotation", since his formulation is against Newton's first law!
6. (New York: Dover, 1955), transl. from R. Dugas, *Histoire de la mécanique* (1950)

Bertrand now subjected this coordinate system to a combination of translation and rotation, while the point *M* moved rectilinearly in an arbitrary direction. We will first only consider the translation of the origin from *M'* to *K*, while at the same time *M* moves, with the same speed, to point *P* (figure 6).

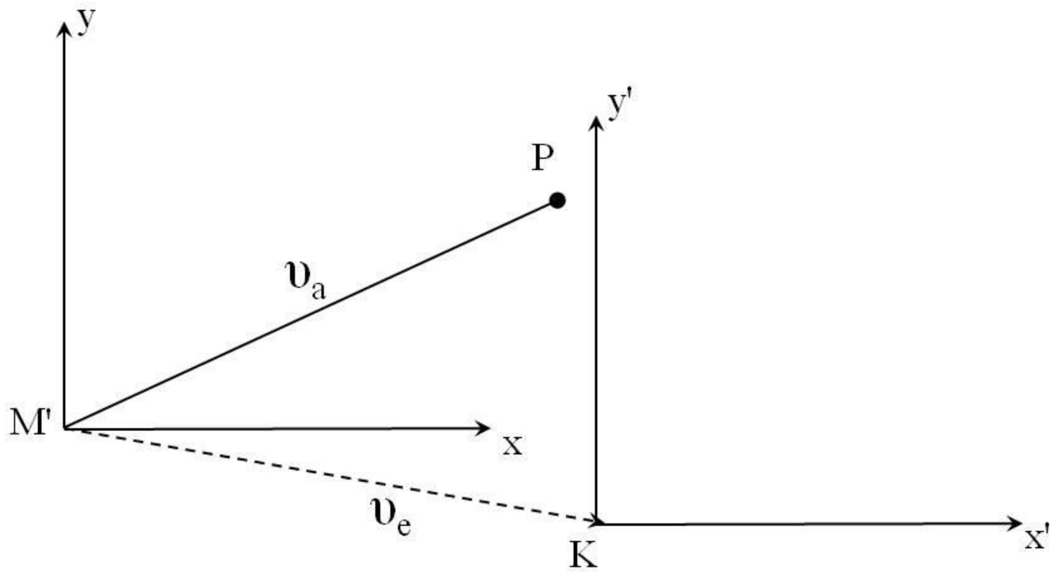

Figure 6: *The coordinate system is translated from M' to K, while object M is rectilinearly moving to P, both with speeds* $\upsilon_a = \upsilon_e$.

Seen from the frame of reference of the coordinate system, now labeled x',y', the body has moved slightly backward (figure 7).

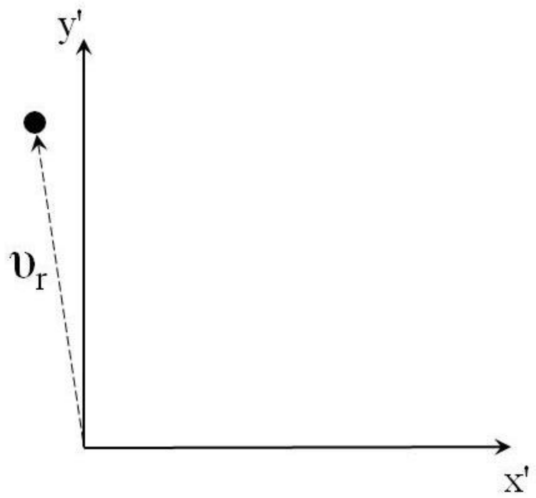

Figure 7: *Seen from the frame of reference of the coordinate system, the body has moved slightly backward, or to the left of the y-axis, with a relative velocity* υ_r.

However, while being translated the coordinate system has also been rotated with an angular velocity of ω rad/sec (figure 8).

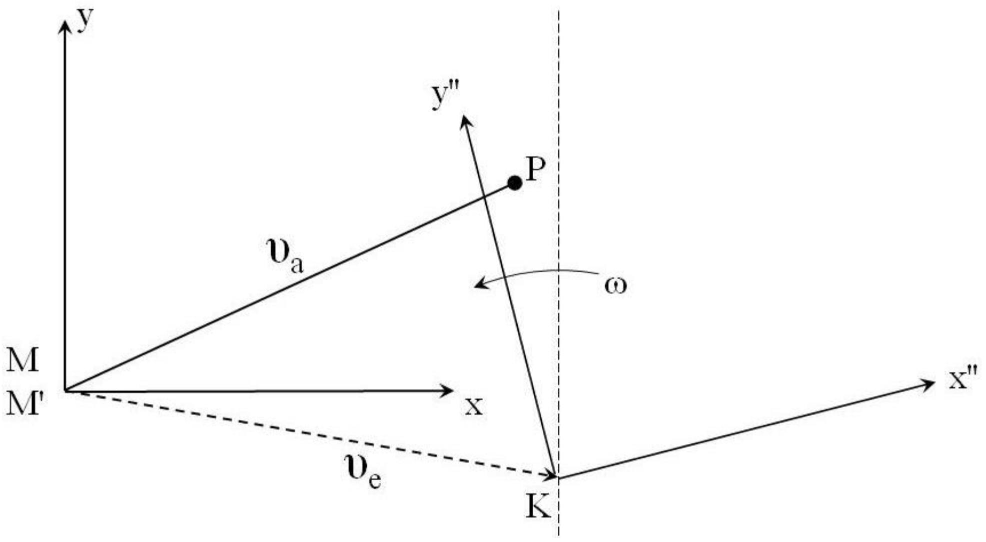

Figure 8: *The coordinate system, while being translated is also rotated anti-clockwise with angular velocity ω.*

Seen from the coordinate system the point *M* ends up at a different location relative to the coordinate system, now labeled x'', y'' (figure 9).

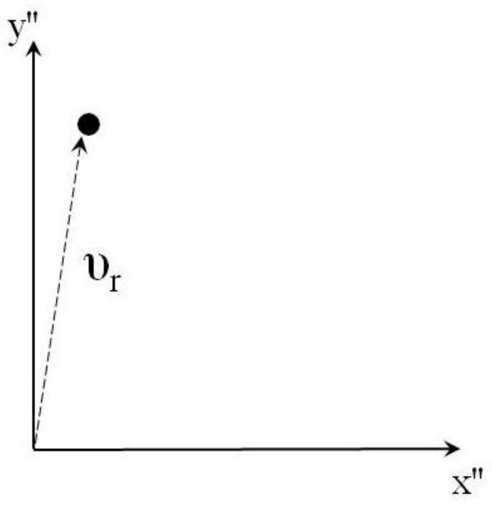

Figure 9: *Seen from the frame of reference of the coordinate system, the body has moved slightly forward, or to the right of the y-axis, with a relative velocity* υ_r.

The change of position, can be seen as the result of a clock-wise (rotational) acceleration **a** to the right over a distance $\upsilon_r dt \cdot \omega dt$ (figure 10).

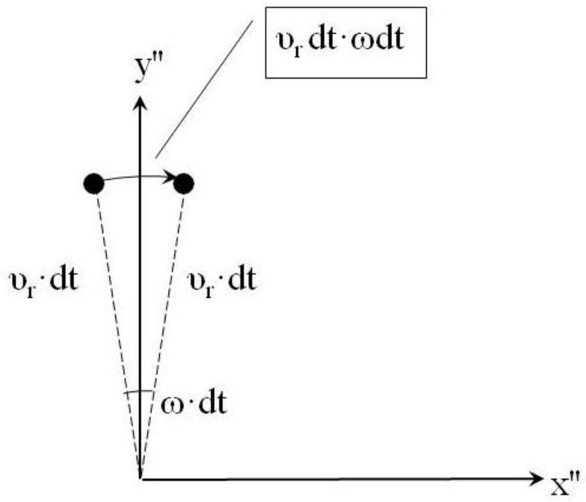

Figure 10: *The relative motion ur in the rotating coordinate system has resulted in a clockwise deflection or acceleration covering a distance $\upsilon_r dt \cdot \omega dt$.*

The deflection, expressed as occurring over a distance S, can be formulated in two ways

$$S = \upsilon_r dt \cdot \omega dt = \frac{a \cdot dt^2}{2} \qquad (3a)$$

where **a** is an acceleration. This yields

$$a = 2\omega \cdot \upsilon_r \qquad (3b)$$

which is the scalar version of the Coriolis term.

6. Pros and cons of the "simplified derivation"

Later in the 19th century Bertrand's derivation became known as "the simplified derivation" of the Coriolis force. As such we normally meet it in this design (figure 11).

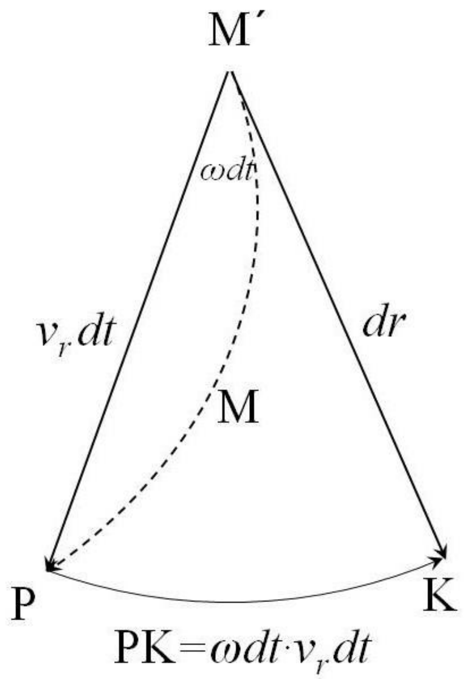

Figure 11: *A schematic version of Bertrand's derivation: a body* M *is moving radially from the centre of rotation* M'*, while the underlying platform (coordinate system) rotates counter clockwise an angle ωdt. This leads to a deflection PK of ωdt·$v_r$dt and finally to the 2ωv_r term.*

Bertrand's derivation is mathematically and physically correct and is found in many popular textbooks as an intuitive explanation of the Coriolis effect.

But there is a *caveat*. The simplicity has come with a price: ***it is a special case.*** It is only valid at, or very close to the centre of rotation of the carousel. Here the distance to the center of rotation *dr* ≈ 0 and the centrifugal force, dependent on the distance, is therefore also ≈ 0.

This condition, closeness to the centre of rotation, is often violated in textbooks. The moving body is depicted to start its journey clearly away from the centre of rotation. It means that the version below, although geometrically correct, is physically incorrect (figure 12).

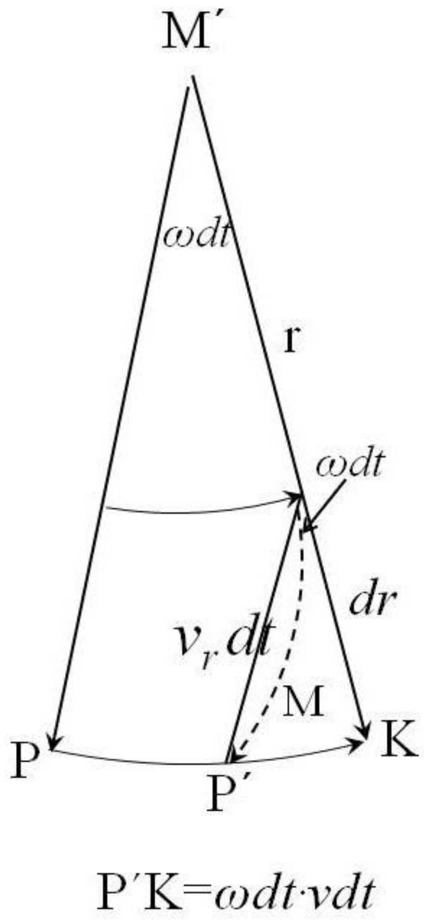

Figure 12: *The erroneous application of Bertrand's "simplified" derivation of the Coriolis force, far away from the centre of rotation.*

Away from the center of rotation there is, according to equation (1), with increasing distance **R**, an increasing centrifugal force, which is missing in figure 12.

7. Is Bertrand's derivation applicable on the rotating Earth?

So far we have only considered a rotating carousel; but what about the rotating Earth? Many textbooks illustrate the Coriolis effect with polar bears at the North Pole walking southward. Isn't this in line with Bertrand's derivation?

Yes and no. The centrifugal force is zero at the poles, just as in Bertrand's derivation. But whereas in Bertrand's version we can neglect the centrifugal force only there, on the Earth we can disregard the horizontal component of the centrifugal force everywhere!

This is not covered by Bertrand's mathematics. Although the trajectory of an object moving over the surface of a rotating planet may be described by the *$2\Omega V_r$* term alone, the centrifugal force is nevertheless present. It is, however, due to the Earth's non-spherity (caused by the rotation), balanced by a component of gravitation directed in the opposite direction.

We hope to come back to this in a special article since it was a topic of discussion at the Academy in autumn 1859.

8. A LITMUS TEST FOR THE CORIOLIS EFFECT

To orientate oneself among the different "derivations" of the Coriolis effect the following rule might be useful: Since the Coriolis force is perpendicular to the motion, and constant in strength for a constant velocity, it will act as a "central force" and therefore drive all motion into circular trajectories, so called "inertia circles" (figure 13).

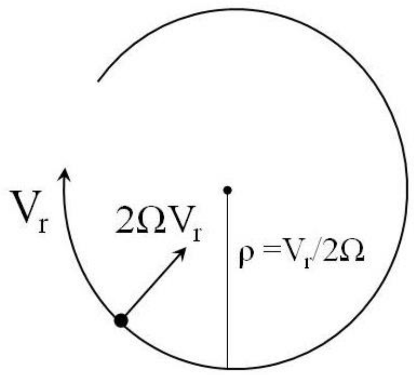

Figure 13: *By being perpendicular to the motion (V_r) of an object the Coriolis deflection will drive it into an "inertia circle" trajectory. Its radius ρ is calculated considering that $2\Omega Vr$ also can be seen as a centripetal force V_r^2/ρ.*

If the derivation does not, mathematically or conceptually, yield a circular motion, the derivation is incomplete, misleading or erroneous. So for example if a centrifugal force is also present, the trajectory will be an ever increasing Archimedean spiral (figure 14).

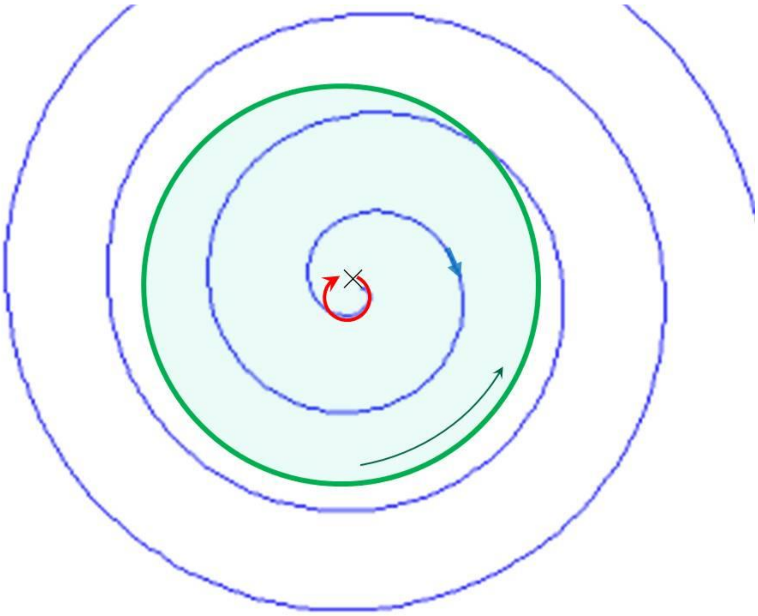

Figure 14: *The Coriolis force alone on a counter-clockwise rotating carousel (green area) would ideally have kept the moving body in a circular trajectory close to the centre of rotation (red line). Instead the body will gradually, due to the centrifugal force, accelerate outwards (blue line).*

But what can be said about the curved trajectory M´P in figure 11? Is it part of a circle, an "inertia circle", or not? Since the acceleration we derived is $2\Omega V_r$ and is perpendicular (in the infinitesimal $dr \rightarrow 0$) we can trust that the trajectory is part of an "inertia circle".

But this is a 100% logical approach, not very intuitive. To make it more intuitively plausible that the curve is part of a circle, we have to make two compromises. The first is to abandon the infinitesimal viewpoint as being too counter-intuitive. The differentials should therefore be interpreted as non-infinitesimal entities.

But then the centrifugal force would make itself apparent, so the next compromise is to abandon the dynamic-physical approach for a kinematic-geometrical.

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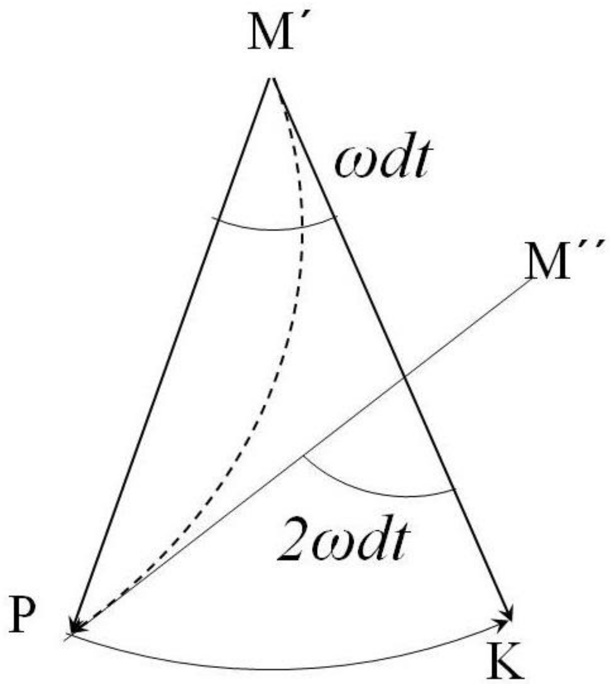
We can first note that the deflection of the moving object is twice the change of direction due to rotation alone (figure 15).



<u>Figure 15:</u> *The tangent PM′′ measures the deflective angle* 2ωdt *which is twice the change of direction due to the rotation* ωdt*.*

When the rotational angle has increased to 90º (PM′ is perpendicular to M′K) the deflective angle is 180º, i.e. PM′′ is parallel to the line M′K.

Figure 16 below is not a proof, but an attempt to provide kinematic-geometrical arguments that the trajectory is part of an inertia circle, with half the radius of the bigger rotating platform (the outer circle in figure 16).

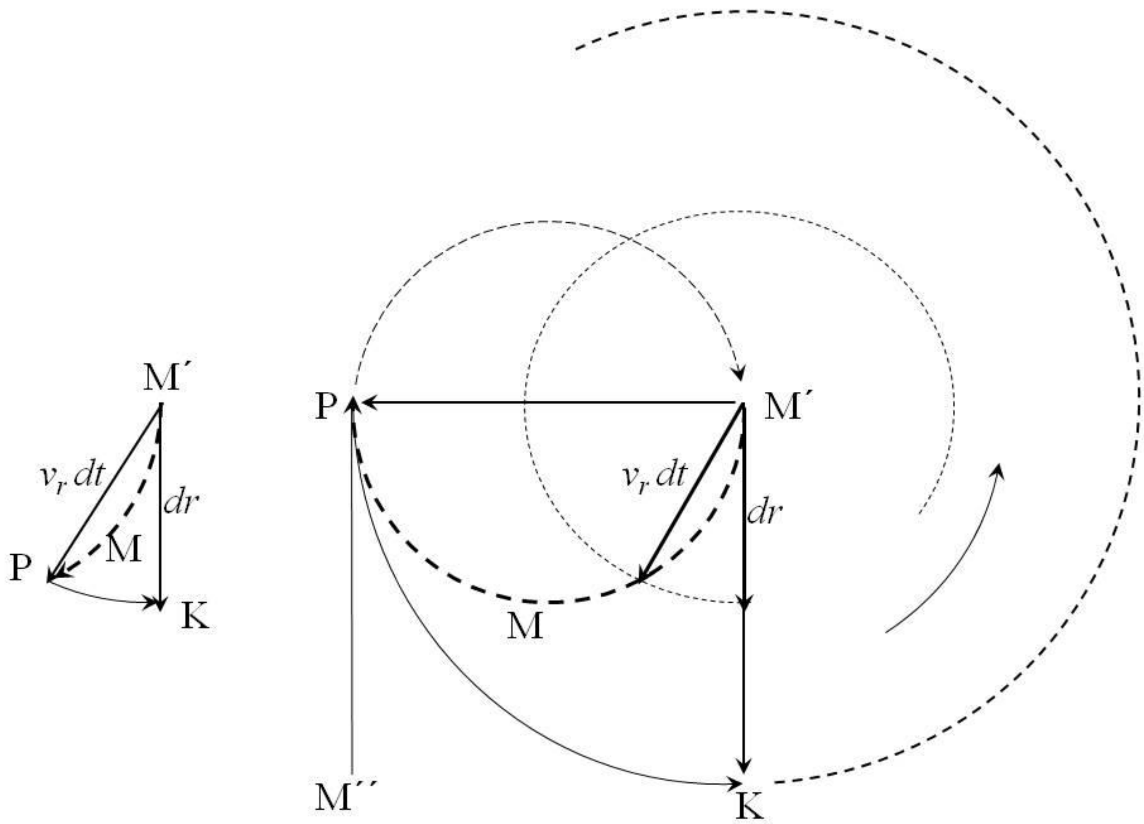


Figure 16: *To the left a simplified copy of figure 15, to the right the same geometrical figure inserted in the total rotational system. When this system has rotated 90º (PM´ is perpendicular to M'K) the direction of the deflected motion (along PM'') is parallel to its original direction (along M'K) and the moving object has followed a semi-circle, half of an "inertia circle".*

An alternative way to illustrate the importance of the infinitesimal distance to the centre of rotation is shown in figure 17 where an object is moving over a rotating carousel. Let's assume the rotation of the carousel is one revolution in 8 seconds which yields $\Omega = 2\pi/8 = \pi/4$, the radius of the carousel 2 meters and the velocity 1 m/s. Under "ideal" conditions, i.e. with only the Coriolis force and no centrifugal force, this would for 1 m/s motion anywhere on the surface of the carousel yield a circular trajectory with the radius $\rho = 2/\pi \approx 0.6$ meters.

Under normal, non-ideal conditions, an object is moving straight over the rotating carousel, passing exactly over the centre of rotation. Outside the centre of rotation there is an influence of the centrifugal force which prevents the trajectory from being a "pure" inertia circle, and instead becomes a "loop". At or infinitesimally close to the centre of rotation the curvature of the loop, however, agrees well with the radius of an "ideal" inertia circle.

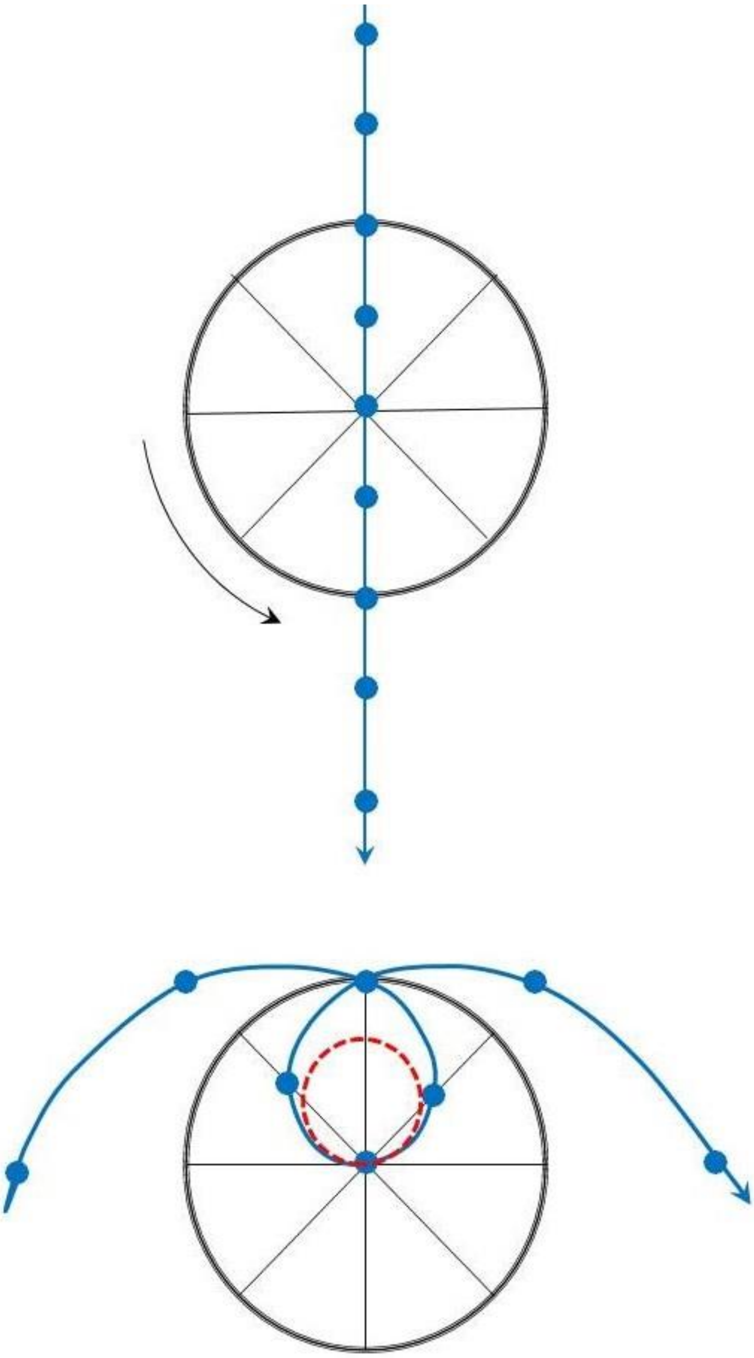


Figure 17: *An object is moving over an anti-clockwise rotating carousel passing exactly over its centre of rotation (blue line with blue filled circles). As seen from an absolute frame of reference the trajectory is a straight line (above), seen from the relative frame of reference on the carousel the trajectory is a loop (below). At (or infinitesimally close to) the centre of rotation the curvature of the trajectory agrees with the curvature of an inertia circle (red dashed line), for the ideal case of "pure" Coriolis deflection, without any influence of a centrifugal force.*

It is a popular laboratory exercise to roll balls over a rotating carousel and observe the deflection. With figure 17 in mind the students can make the ball pass over or well beside the centre of rotation and note the more or less quasi-inertia circle trajectories that will result.

A note of caution: the ideal object is not a ball, but an object that will slide along the surface of the carousel, like an ice-hockey puck. The reason why rolling a ball is less suitable if because the ball's angular momentum, due to the spin, will slightly complicate the motion.

9. Peer review of Bertrand's mémoire

As Bertrand was at that time not yet a member of the Institute, his mémoire was reviewed by three distinguished mathematicians: Augustin-Louis Cauchy (1789-1857), Gabriel Lamé (1795-1870) and Charles Combes (1801-72). In their "Rapport sur un Mémoire de M. J. Bertrand concernant la théorie des mouvements relatifs***",*** *Comptes Rendus des Séances de l'Académie des Sciences*. Paris, **27**, 210-213 dated 21 June 1848, they approved Bertrand's paper which they found had been written *"dans un excellent esprit".*

Although the theorem as such was not new, they wrote, the nature of Bertrand's explanation improved the understanding of its extent and utility. Their next sentence happens to encompass more or less the objectives of this *BibNum* project:

> *Le fruit que M. Bertrand a tiré de la lecture des ouvrages des géomètres de la fin du VIIe et de la première moitié du XVIII^{e} siècle, engagera sans doute les jeunes mathématiciens à étudier les œuvres, peut-être trop négligées aujourd'hui, de ces grands maîtres de la science.*
>
> [The fruit that Bertrand has drawn from the reading of the works of the mathematicians of the late 18th and first half of the 19th century, will undoubtedly engage young mathematicians to study the works, perhaps too neglected today, of these great masters of science.]

They did not, however, agree that Coriolis plagiarized Clairaut: "*Coriolis, n'avait pas lu le Mémoire de Clairaut",* whose reasoning is anyhow "*en défaut*". To demonstrate how easy it is to suspect a plagiarism, when there is none, they took a recent book on mechanics by Jean-Baptiste Bélanger *Cours de Mécanique* (it had just been published and contained a discussion of Coriolis's theorem); the reviewers opine:

> *Ainsi MM. Bertrand et Bélanger ont pu arriver au même résultat, à peu près en même temps, et par des méthodes semblables, sans qu'aucun d'eux eût connaissance des travaux de l'autre.*
>
> [Thus Bertrand and Bélanger were able to arrive at the same result, at about the same time, and by similar methods, without any of them having knowledge of the works of the other.]

Bertrand had presented his mémoire the 21 June 1847, when Bélanger's book was still in press[7].

10. The aftermath of the 1848 discussion

Joseph Bertrand had made a correct analysis of deflection of relative motion in a rotational system. But the analysis was incomplete in the sense that is was a special case. Bertrand therefore never quite understood the deeper implications. This became apparent some ten years later when the Academy devoted a major part of autumn 1859 to discuss the problem of the Earth's rotation and its affect on moving objects. In polemic with his academic colleagues Bertrand maintained, for example, that the deflection only works for north-south motion.

This view was not only supported by a popular but erroneous explanation, the so-called Dove-Hadley derivation. It had been promoted by the influential German meteorologist Heinrich Dove (1803-79) but later named after the British meteorologists George Hadley (1685-1768)[8].

Another source of misunderstanding came from the Baltic-German scientist Karl Ernst van Baer (1792-1876). In 1835 he had tried to explain the meandering of the south to north flowing Siberian rivers as a consequence of the Earth's rotation[9]. So Bertrand was not alone with his misunderstandings.

The 1851 Foucault pendulum experiment, where the deflection was independent of the direction of the motion, should have clarified the matter. But some scientists held on to their erroneous view, while others changed them

7. It is the opinion of this author that Coriolis most probably had read Clairaut's mémoire, but did not find anything useful in its contents.
8. See figure 7 in our *BibNum* article, December 2014, analysing a Sarrabat's text.
9. See our *BibNum* article, July 2015, "Albert Einstein et la tasse de thé de Mme Schrödinger ».

without really understanding why. One strong argument for many, has it been said, was that the Seine and the Loire rivers were also meandering – and they were both flowing from east to west!

There seems to be a general opinion that Coriolis's 1835 mémoire got its well deserved attention only in 1851 after Foucault's pendulum experiment.[10] It might rather have been the debate and controversy around Bertrand's 1848 mémoire that increased the attention and interest in Coriolis's work. In a public lecture the following year Jacques Babinet (1794-1872) explained how the Earth's rotation affected the ocean currents. In the audience was Léon Foucault, a gifted journalists and popularizer, who not only wrote a review in *Journal des Débats* (June 30th, 1849) but also started to think about how the earth's rotation affected motions over its surface…

■

(January 2019)

10 A mention by Frédric Reech's "Mémoire sur les machines à vapeur et leur application à la navigation" where Coriolis is credited of having found "un beau théoreme" seems to refer to Coriolis' 1832 « Mémoire sur le principe des forces vives dans les mouvements relatifs des machines » in Journal de l'École Polytechnique, vol. 13, no 21, p. 268-302.