Applied Physics Research; Vol. 14, No. 1; 2022
ISSN 1916-9639 E-ISSN 1916-9647
Published by Canadian Center of Science and Education

‘Kinetic Energy’ (I): On the Physical Meaning of the Product mv^2: The Experiments of G. Poleni and of J. W. ‘sGravesande

Giancarlo Cavazzini[1]

[1] Consiglio Nazionale edelle Ricerche, Istituto di Geoscienze e Georisorse, Padova, Italy

Correspondence: Giancarlo Cavazzini, CNR Istituto di Geoscienze e Georisorse, Via G. Gradenigo 6, 35131 – Padova, Italy. Tel: 39-49-827-9137. E-mail: giancarlo.cavazzini@igg.cnr.it

Received: October 25, 2021 Accepted: November 29, 2021 Online Published: February 21, 2022

doi:10.5539/apr.v14n1p1 URL: https://doi.org/10.5539/apr.v14n1p1

Abstract

The results of renowned experimental works of Giovanni Poleni in 1718 and of Jakob W. ‘sGravesande in 1722 suggest that the ‘energy of motion’ or ‘kinetic energy’ of a material body which is moved in a vacuum in a reference frame by a gravitational process is proportional to the ’mass’ of the body and to the velocity of the body in the reference frame, and not to the mass and to the square of the velocity. Consequently, the amount of mechanical energy which is expended by gravitation in moving a body in a vacuum over a vertical distance z is not, as is currently believed, proportional to this distance, but it is proportional to the time-span of action of the process. The product between the mass of the body and the square of the velocity of the body is not proportional only to the amount of mechanical energy of motion of the body moved by the gravitational process, but it is proportional also to the power with which such an amount of ‘kinetic energy’ is consumed by collision with a plastic target at rest in the reference frame.

Keywords: gravitational process, kinetic energy, conservation, Poleni’s experiments, ‘sGravesande’s experiments

1. Introduction

A long time ago, a heated debate arose among scholars on how the ‘energy of motion’ of a material body should have been formulated (Caverni, 1898; Costabel, 1973; Engels, 1883; Grillenzoni, 1995; Iltis, 1971; Reichenberger, 2012; Suter, 1904). This debate mainly ranged between the viewpoint of R. Descartes on the one hand, and that of G. W. Leibniz on the other. These two standpoints divided the eminent scholars who studied theoretical mechanics in the 17th and 18th centuries, until J. B. Le Rond D’Alembert (Le Rond D’Alembert, 1743) tried to solve what he considered a “useless verbal dispute”.

Although in today's physics Leibniz’s view is claimed to be the correct one, the prolonged debate did not lead to any general and genuine agreement. There was no convincing answer to the question of whether the translational ‘energy of motion’ of a material body of mass m and velocity v in a reference frame is proportional to the mass of the body and to the velocity of the body in the reference frame, mv, (De Catelan, Descartes, Newton, Papin, Jurin, Kant, and also D’Alembert) (Le-Rond D’Alembert, 1743; De Catelan, 1686; Kant, 1746), or whether it is proportional to the mass of the body and to the square of the velocity of the body, mv^2, (Leibniz, J. Bernoulli, D. Bernoulli, ’s Gravesande, de Maupertuis, Du Chatelet, Joule) (Du Chatelet, 1740; Joule, 1850; Leibniz, 1686; Leibniz, 1695; Poleni, 1718; ‘sGravesande, 1722).

The matter is evidently a complex one, and it was therefore with understandable concern that this paper has been written. However, we hope that the following considerations about the physical meaning of the product mv^2 contribute to the discussion, and also be of interest in improving the understanding of the physics of the gravitational process.

2. The Concept of ‘Energy of Motion’ or ‘Kinetic Energy’

In this section, we propose a physical meaning for ‘energy of motion’ - or ‘kinetic energy’ - of a body moving in a reference frame. Let’s imagine grabbing a billiard ball in one hand, and moving the arm to accelerate it before sending it rolling free to the floor of the room. While we accelerate the billiard ball by moving the arm, we make a definite amount of mechanical effort (which is, certainly, proportional to the ‘mass’ of the billiard ball, because our effort must ‘win’ the continuous action of gravity).

Assume that we accelerate the billiard ball moving our arm in air. If we move our arm in air, a part of the amount of our mechanical effort is not used to accelerate the billiard ball, but it is used to overcome the air resistance. Let us therefore assume that we move our arm in a vacuum, and that when we send the ball rolling free to the floor there is no friction/resistance between the billiard ball and the floor. In this case, if we want to stop the billiard ball we have to exert, in the opposite direction of the movement of the billiard ball, an amount of mechanical effort exactly equivalent to the amount of effort we have exerted to put the billiard ball in such a state of motion.

Instead, if we put the billiard ball in state of motion in the presence of friction – the friction of the arm moving in air; the friction of the billiard ball rolling on the floor – to stop the billiard ball we have to exert an amount of mechanical effort which is lower than the amount of mechanical effort we have exerted to put the ball in such a state of motion.

We conclude that in the absence of processes which consume amounts of mechanical effort, to stop the movement of the billiard ball we have to exert an amount of mechanical effort which is exactly equivalent to the amount of effort we have exerted to put the billiard ball in that state of motion. In other words, we say that:

In the absence of processes which consume amounts of mechanical effort, the amount of mechanical effort exerted/'expended' to put a body in a state of motion is 'conserved' in the body in its own state of motion.

We call 'energy of motion' or 'kinetic energy' of a body in motion in a reference frame the amount of mechanical effort we have to exert/'expend' to stop the body in that reference frame. As mentioned above, in the absence of processes which consume amounts of mechanical effort, such an amount of mechanical effort is exactly equivalent to the amount of mechanical effort which has been exerted/expended to put the body in such a state of motion in the reference frame.

We speak of 'conservation' of the mechanical effort or 'conservation of the mechanical energy of motion', because, in the absence of processes which consume amounts of mechanical effort, the amount of effort exerted/expended is 'conserved' in the body in its own state of motion.

3. The 'Energy of Motion' of a Body Moved by a Gravitational Process

We now apply this view to the case when the billiard ball is put in state of motion by a gravitational process. When we let a billiard ball to 'fall' free due to the action of gravity, we can imagine that an invisible hand grabs the billiard ball and accelerates it downwards, exactly as our hand accelerates the billiard ball before sending it rolling free to the floor of the room. The only difference between these two cases is that, come to a certain point, we let the billiard ball go free on the floor, whereas the invisible 'hand' of the gravitational process continues to accelerate the ball until it touches the ground.

In the absence of processes which consume amounts of mechanical effort - *i.e*. if the gravitational process moves the billiard ball in a vacuum, or for sufficiently brief falls in air - the 'energy of motion' of the billiard ball is, at any instant, exactly equivalent to the amount of mechanical effort – we say also to the amount of 'mechanical energy' - which has been exerted/expended by the gravitational process to put the billiard ball in its respective instantaneous state of motion.

Therefore, in the absence of processes that consume amounts of mechanical effort, this amount of 'mechanical energy' is 'conserved' in the billiard ball in its own state of motion. In other words, the gravitational process 'expends' mechanical effort – we say 'expends' 'mechanical energy' - producing an equivalent amount of mechanical energy, which is represented by the amount of the 'energy of motion' of the billiard ball. What is the formula/expression that calculates this amount of 'energy of motion' is the matter for the discussion that follows.

4. The Experiments of Giovanni Poleni and of Jakob W. 'sGravesande

In 1718, Giovanni Poleni, a mathematician and engineer of the Venetian 'Serenissima' Republic, Italy (Poleni, 1718), and, in 1722, Jakob W. 'sGravesande, a physicist at the University of Leiden (The Netherlands) ('sGravesande, 1722) measured the dents produced in plane surfaces of plastic materials by spherical bodies in 'free fall'. The plastic material used by Poleni was tallow, whereas 'sGravesande used plastic clay. Both Poleni and 'sGravesande did not vary the dimensions of their spherical bodies, but they changed the mass (*i.e*., the weight) of the bodies, and the heights from which the bodies were dropped.

They obtained the following result: the volume of the dent – we call this volume here, the 'deformation' - was proportional to the mass of the spherical body and to the height from which the body was dropped. Calling *def* the deformation, *m* the mass, and *z* the height:

$$def \propto mz \tag{1}$$

Since (Galilei, 1938)

$$z \propto v2,$$

in which v is the velocity of the spherical body at the moment when it collides with the plastic material, the results of Poleni and of ‘sGravesande can be written also as:

$$def \propto mv^2. \tag{2}$$

Now, it may be reasonable to hypothesize, as Leibniz did (Leibniz, 1695), that the ‘effects’ of an amount E of ‘energy of motion’ are proportional to the amount of energy of motion, in the case such an an amount of mechanical energy is completely consumed. In other words, it may be reasonable to suppose, as Poleni and ‘sGravesande did in interpreting their experimental results, that the deformation caused in a plastic material by the collision of a spherical body in free fall - the effect - is proportional to the amount of ‘energy of motion’ - or ‘kinetic energy’ - of the spherical body at the moment when it collides with the plastic material. In other words, we could suppose that

$$def \propto E. \tag{3}$$

If this hypothesis is correct, the amount of ‘kinetic energy’ of the spherical body at the moment of the collision is proportional to the respective product mv^2 (formula (2)):

$$E \propto mv^2 \tag{4}$$

In the following, we investigate whether this hypothesis is physically correct or not, *i.e.*, we investigate if the deformation of the plastic material observed by Poleni and by ‘sGravesande in their experimental works is proportional to *and only to* the amount of ‘kinetic energy’ of the spherical body at the moment of its collision with the plastic material. Our discussion shows what the physical meaning of the deformation observed by Poleni and by ‘sGravesande in their experimental works is, *i.e.*, the physical meaning of the product mv^2.

5. An Ideal Experiment

Let us imagine doing an ideal experiment. Let us assume that someone shoots at us a gunshot, and that, when the bullet comes to touch our body, we move back very very quickly in the direction of movement of the bullet, as Superman would be able to do, at a speed which is off by a very tiny fraction of the speed of the bullet.

Assume that we continue moving back: the bullet is continuously leaned against our body, but it does not penetrate our body. After a certain time has passed, the bullet falls to the ground, and our body has no deformation. Instead, if we are at rest in the reference frame, the bullet penetrates our body creating a cavity, a deformation.

This ideal experiment shows that although the energy of motion of the bullet is the same, the deformation our body suffers can be very different. The energy of motion of the bullet is certainly not 0, but the deformation can be 0. Therefore, if the deformation is proportional to the amount of energy of motion of the bullet, certainly it is not proportional only to the amount of energy of motion of the bullet.

The ideal experiment shows that the amount of deformation of the target is related to the state of motion of the target in the reference frame at the moment of the collision with the bullet. However, what the state of motion of the target does have to do with the amount of energy of motion of the bullet? Of course, it has nothing to do with.

The state of motion of the target is related to the time interval in which the bullet is stopped in the reference frame, so that the amount of deformation is proportional to the power with which the amount of energy of motion of the bullet is consumed. If we move back very quickly in the direction of motion of the bullet at a speed just below the speed of the bullet, the energy of motion of the bullet is consumed in a time-span significantly longer than the time-span in which it is consumed when we are at rest in the reference frame. If the time-span in which the amount of energy of motion of the bullet is consumed is significantly long, the power is very low, close to 0, and the deformation is close to 0.

The amount of the energy of motion of the bullet is completely independent from the modalities of consumption of such an amount of mechanical energy, which can be any. Therefore, the amount of energy of motion of the bullet and the power of consumption of this amount of mechanical energy are completely independent variables. Calling P the power of consumption of the mechanical energy of motion, we write

$$def \propto E \cdot P. \tag{5}$$

We now return to the experimental works of Giovanni Poleni and of Jakob W. ‘sGravesande. We consider the deformation caused in the plastic material by a spherical body of mass *m* repeatedly dropped through an equivalent vertical distance *z* before colliding with the plastic material. Let’s imagine we move the plastic material in different ways. At the moment of colliding, the plastic material can be in motion upwards in the reference frame, or it can be in motion downwards, or it can be at rest in the reference frame. All other conditions being equal, we observe that in the case the plastic material, at the moment of the collision with the spherical body, is moving upwards in the referemce frame, the deformation is larger than in the case the plastic material, at the moment of the collision, is at rest in the reference frame; and that in the case the plastic material, at the moment of the collision, is at rest in the reference frame, the deformation is larger than in the case the plastic material is moving downwards in the reference frame.

The height of drop before the collision – *i.e.* the time-span of fall - is the same in all these cases, so that the state of motion of the spherical body in the reference frame at the moment of the collision with the plastic material is certainly the same. Thus, also the amount of ‘energy of motion’ of the spherical body at the moment of the collision with the plastic material is certainly the same. However, the deformation of the plastic material is not the same. The deformation depends on the state of motion of the plastic material in the reference frame at the moment the collision occurs.

Therefore, if the deformation of the plastic material is proportional to the amount of energy of motion of the spherical body at the moment the collision occurs, the deformation is not just proportional to the amount of energy of motion of the body at the moment the collision occurs. The deformation evidently depends on the state of motion of the plastic material in the reference frame at the moment of the collision.

If the plastic material is moving upwards at the moment the collision occurs, the deformation of the plastic material per unit of time – *i.e*. the amount of plastic material that comes into contact with the surface of the spherical body in the unit of time as a result of the deformation of the plastic material - is higher than in the case the plastic material is at rest in the reference frame, all other variables being equal. Thus, the state of motion of the plastic material in the reference frame at the moment of the collision is related to the time interval in which the falling body is stopped in the reference frame.

If the state of motion of the plastic material in the reference frame at the moment the collision occurs is related to the time interval in which the falling body is stopped in the reference frame, the state of motion of the plastic material in the reference frame at the time of the collision is related to the mechanical power with which the mechanical energy of motion of the falling body is consumed in the collision.

We conclude that if the deformation caused by the collision of a spherical body in free fall in a plastic material is proportional to the amount of energy of motion of the body at the moment when it collides with the plastic material, the deformation is not just proportional to the amount of energy of motion of the body. Hypothesis (3) – (4) is not correct. The deformation of the plastic material also depends on the state of motion of the plastic material at the moment the collision occurs, *i.e*. it is proportional to the mechanical power with which the amount of energy of motion of the body is consumed in the collision.

In Poleni’s and in ‘sGravesande’s experiments, the plastic material was at rest in the reference frame at the moment the collision occurred. The case of the plastic material at rest in the reference frame at the moment the collision occurs is not different from any other case in which the plastic material is moving at the moment the collision occurs. To be at rest in the reference frame is to be in a particular state of motion, which corresponds to a particular value of the mechanical power of consumption of the amount of energy of motion of the falling body. Therefore, if the deformation observed by Poleni and by ‘sGravesande in the respective plastic materials was proportional to the amount of mechanical energy of motion of the spherical body at the moment when it collided with the plastic material, the deformation was also proportional to the value of the mechanical power of consumption of such amount of mechanical energy of motion in the case the plastic material was at rest in the reference frame.

The state of motion of the plastic material in the reference frame at the moment the collision occurs is not related to the amount of energy of motion of the falling body. The latter, at any time during fall, is related to the action of the gravitational process. The movement of the plastic material at the time the collision occurs has nothing to do with the action of this physical process, and can be any. Therefore, the mechanical energy of motion of the falling body at the moment of the collision and the mechanical power of consumption of this mechanical energy of motion are completely independent variables.

6. Interpretation of the Results of the Experiments of Giovanni Poleni and of Jakob W. 'sGravesande

According to discussion in Section 5., we assume that under the conditions of the experiments of Poleni and of 'sGravesande the deformation caused in the plastic material by the collision with a spherical body is proportional to the amount of energy of motion of the body, and to the mechanical power with which this amount of mechanical energy is consumed in the collision (formula (5)).

We write the time interval t in which the spherical body is stopped in the reference frame in terms of the acceleration of the body, a. If v is the velocity of the body at the moment of the collision:

$$a = (0 - v)/t \tag{6}$$

so that

$$1/t = - a/v \tag{7}$$

Substituting $1/t$ into eq. (5) we obtain:

$$def \propto E{\cdot}E{\cdot}a/v \tag{8}$$

Acceleration a of the spherical body is proportional to the difference in velocity, in the reference frame, between the spherical body and the plastic material at the time of the collision. Calling v_m the velocity of the plastic material at the time of the collision, the acceleration is proportional to the algebraic difference between the velocity of the spherical body and the velocity of the plastic material, $v–v_m$. If v is positive, and v_m is negative - *i.e.*, the plastic material is moving upwards at the moment when the collision occurs - the algebraic difference of the two velocities is the sum of the two velocities. In this case, in the collision, the deformation of the plastic material per unit of time – *i.e.* the amount of plastic material that comes into contact with the surface of the spherical body in the unit of time - is higher than in the case the plastic material is at rest in the reference frame. Thus, causing higher acceleration of the body.

Moreover, the acceleration of the body is inversely proportional to the mass of the body, because a higher mass, *ceteris paribus*, determines a higher inertia, a higher impetus of penetration in the plastic material. Therefore, substituting a in formula (8), we write:

$$def \propto E{\cdot}E/v{\cdot}(v - v_m)/m \tag{9}$$

Since in the experiments of Poleni and of 'sGravesande the plastic material is at rest in the reference frame, v_m = 0 so that:

$$def \propto E^2/m \tag{10}$$

Thus, our analysis suggests that the deformation caused in the plastic material in the experimental works of Poleni and of 'sGravesande is proportional to the square of the amount of energy of motion of the spherical body at the moment it collides with the plastic material, and inversely proportional to the mass of the spherical body.

Since both Poleni and 'sGravesande observed the deformation of the plastic material to be proportional to the product mv^2 (formula (2)), according to this analysis E^2/m is proportional to mv^2:

$$E^2/m \propto mv^2 \tag{11}$$

i.e.

$$E^2 \propto m^2v^2, \tag{12}$$

and we solve this formula for the amount E of mechanical energy of motion of the spherical body:

$$E \propto mv. \tag{13}$$

Therefore, according to this interpretive view of the results of the experiments of Giovanni Poleni and of Jakob W. 'sGravesande, the amount of 'energy of motion' – the 'kinetic energy' - of a body in free fall is, at any instant, proportional to the mass of the body and to the velocity of the body, and not proportional to the mass of the body and to the square of the velocity of the body.

7. Conclusions

In this study, we have proposed an interpretive analysis of the deformation data obtained by Giovanni Poleni and by Jakob W. 'sGravesande in their respective experimental works. If this interpretive view is close to be correct for the conditions of the experiments of Poleni and of 'sGravesande, the amount of 'energy of motion' of a body which is moved by a gravitational process in a reference frame is not proportional to the mass of the body and to the square of the velocity of the body in the reference frame, but it is proportional to the mass of the body and to the velocity of the body in the reference frame.

In Sections 2-3., we have shown that in the absence of processes which consume amounts of mechanical effort/energy the amount of ‘energy of motion’ of a body moved by a gravitational process is at any moment exactly equivalent to the amount of mechanical effort/energy which has been ‘expended’ by the gravitational process to put the body in such a state of motion. Thus, we speak of ‘conservation’ of the mechanical effort/energy, because the amount of mechanical energy expended by the process is ‘conserved’ in the body in its own state of motion. For this reason, a gravitational process, by moving a body in a vacuum, expends a certain amount of mechanical energy, and simultaneously produces an equivalent amount of mechanical energy represented by the body in its state of motion.

In a gravitational motion the product mz of a body of mass m moved by a gravitational process through a vertical distance z - *i.e.* the product mv^2, because in a gravitational motion the vertical distance z is proportional to the square of the velocity of the body in the reference frame - is presently called the ‘kinetic energy’ – *i.e*. the ‘energy of motion’ - of the body. However, we have shown here that the physical meaning of mv^2 is only partly related to the amount of ‘energy of motion’ of the body in the reference frame. Of course, even now, we can decide, we can decide *to define* the product mv^2 to be the amount of ‘energy of motion’, the amount of ‘kinetic energy’, of a body of mass m which is moved to a velocity v in the reference frame by a gravitational process. Nevertheless, this denomination is misleading.

Misone of Chene (VIth century B.C.) said that it is good to find proper words to describe ‘things’ after careful study of the meaning of the ‘things’ that such words must describe; and that it is not good to study ‘things’ starting from words. Accordingly, it is not proper to call the product between the mass and the square of the velocity of a body moved by a gravitational process ‘kinetic energy’ of the body, because this product is not proportional only to the amount of mechanical energy of motion of the body, but it is also proportional to the power with which such an amount of mechanical energy is consumed by collision of the body with a plastic object at rest in the reference frame.

According to the proposed interpretive analysis, the amount of mechanical energy of motion of a body moved in a vacuum by a gravitational process is, at any instant, proportional to the velocity of the body. If this is correct, since the process, under certain limits, accelerates the body at a constant rate, we infer that a gravitational process, in its time span of action, expends/produces mechanical energy at a constant rate. In other words, in the unknown process which is at the origin of the production of gravitational mechanical energy, the amount of energy the process expends/produces in moving a body in a vacuum over a vertical distance z is not, as it is currently believed, proportional to this distance, but proportional to the time span of action of the process.

The unknown process at the origin of the expenditure/production of mechanical energy in gravitation has certainly its origin in some physical conditions. If those conditions are not fulfilled, the process does not/cannot take place, and if those physical conditions do not change in the time-span of action of the process, the expenditure/production of mechanical energy per unit of time does not/cannot change with time as the process works. In other words, if the physical conditions which are at the origin of the process of expenditure/production of gravitational mechanical energy do not change in the time span the process operates, the expenditure/production of mechanical energy of motion occurs/must occur at a constant rate.

This is consistent with the interpretive model proposed in this study, but it is not consistent with the model proposed by Leibniz. In the model proposed by Leibniz (Leibniz, 1686; 1695), the amount of energy of motion, mv^2, is proportional to the *square* of the time of action of the process. This means that according to Leibniz’s model, in the process which stands at the origin of the expenditure/production of gravitational mechanical energy, the rate of expenditure/production of mechanical energy changes (increases) linearly with the time. Therefore, if the model of Leibniz in calculating the amount of energy of motion of a body moved by a gravitational process is assumed to be the correct model, it should be explained the reasons why in the process which stands at the origin of the expenditure/production of gravitational mechanical energy the rate of energy expenditure/production changes without being changed any condition, as, for example, certainly occurs for short-z falls.

Acknowledgments

This work was financially supported by the Italian National Council for Research (C.N.R.), Istituto di Geoscienze e Georisorse.

References

Caverni, R. (1898). *Storia del metodo sperimentale in Italia*. Tomo V pp. 633-643. Firenze, Civelli.

Costabel, P. (1973). *Leibniz and Dynamics: the Texts of 1692*. Paris, Editions Hermann.

De Catelan, F. (1686). Court remarque de M. l'abbé de C. ou l'on monstre a M. G.G. Leibnits le paralogisme contenu dans l'objection precedente. *Nouvelles de la Republique des Lettres 8*: 1000-1005.

Du Chatelet, G. E. (1740). *Institutions de Physique*. Paris, Prault.

Galilei, G. (1638). *Discorsi e Dimostrazioni Matematiche intorno a Due Nuove Scienze attinenti alla Meccanica ed i Movimenti Locali*. Leiden: Elsevier.

Grillenzoni, P. (1995). *Kant e la Scienza: 1747-1755*. Milano, Vita e Pensiero.

Iltis, C. (1971). Leibniz and the Vis Viva Controversy. *Isis, 62*, 21-35. https://doi.org/10.1086/350705

Joule, J. P. (1850). On the mechanical equivalent of heat. *Philos. Trans. Royal Soc. London, 140*, 61-82. https://doi.org/doi:10.1098/rstl.1850.0004

Kant, I. (1746). *Gedanken von der wahren Schätzung der lebendigen Kräfte und Beurteilung der Beweise derer sich Herr von Leibniz und andere Mechaniker in dieser Streitsache bedienet haben, nebst einigen vorhergehenden Betrachtungen welche die Kraft der Körper überhaupt betreffen*. Königsberg, M. E. Dorn.

Leibniz, G. W. (1686). Brevis demonstratio erroris memorabilis Cartesii et aliorum circa legem naturalem, secundum quam volunt a Deo eandem semper quantitatem motus conservari; qua et in re mechanica abutuntur. *Acta Eruditorum*, 161-163. A translation in English appears in *Gottfried Wilhelm Leibniz, Philosophical Papers and Letters* (trans. Leroy E. Loemker, 1956, Vol. I, pp. 455-463). Chicago, Univ. of Chicago Press.

Leibniz, G. W. (1695). Specimen Dynamicum. *Acta Eruditorum*, April 1695. In L. E. Loemker (Ed.), *Philosophical Papers and Letters (1989). The New Synthese Historical Library (Texts and Studies in the History of Philosophy)* (Vol. 2, pp. 435-452). Dordrecht, Springer. https://doi.org/10.1007/978-94-010-1426-7_47

Le-Rond D'Alembert, J. B. (1743). *Traité de Dynamique*. Paris, Chez David Libraire.

Poleni, G. (1718). *De Castellis per quae derivantur fluviorum aquae habentibus latera convergentia liber. Quo etiam continentur nova experimenta ad aquas fluentes et ad percussionis vires pertinentia.* Padova, Giuseppe Comino Tipografo.

Reichenberger, A. (2012). Leibniz's quantity of force: a 'heresy'? Emilie du Chatelet Institutions in the context of the Vis Viva controversy. In R. Hagengruber (Ed.), Emilie du Chatelet between Leibniz and Newton. *Intern. Archives of the History of Ideas 205* (pp. 157-172). Heidelberg, Springer.

'sGravesande, W. J. (1722). Essai d'une nouvelle theorie du choc des corps fondee su l'experience. *Journal Literaire de la Haye, Volume XII part I*, La Haye, T. Johnson.

Suter, H. (1904). Zur Geschichte der Mathematik bei den Indern und Arabern. Verh. d. 3. Internat. Mathematiker-Kongr., Heidelberg.

Copyrights