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Physics and Jurisprudence: A Didactic Illuminating Example

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Abstract: The teaching of physics is a very important social task even when it concerns only basic physics. In fact, in this article, the case of a real trial is reported in which bad knowledge and a bad application of physics laws led a monocratic judge to issue a judgment based on erroneous physical conclusions.

The relevant thing is that the monocratic judge was misled by a technical report prepared by an alleged expert.

To highlight the mistakes contained in the technical report, firstly the physical solution of the problem will be presented and then a fairly thorough analysis of the conceptual and methodological mistakes contained in the technical report and that led the judge to erroneous conclusions.

Key words: projectile motion, momentum-impulse theorem, physics teaching, restitution coefficients, action-reaction pair

1. Introduction

It is often difficult for a physics teacher to imagine what concepts may be misunderstood by students because, especially in the case of basic physics, teachers tend to believe that what is clear to them is equally clear to students.

Reality shows that even basic physics concepts, generally considered well and widely understood, are often not understood at all. In fact, in this article, the case of a real trial, in which a bad knowledge of physics laws led a monocratic judge to issue a judgment based on erroneous physical conclusions, is reported.

The monocratic judge was misled by a technical report prepared by an alleged expert.

The technical report contains conceptual mistakes of basic physics, shared by the monocratic judge, so numerous and serious that it would be very difficult to even believe that they could have actually been committed. Proof of these mistakes is that both the technical report and the judgment are parts of official legal documents published and filed at the court of Nola, Italy (Court of Nola, 2020).

The analysis of the technical report and the conceptual errors it contains can be a useful help for physics teachers to identify some physics concepts that could be misunderstood by students, and that should be explored in depth. In addition, this article could be a useful and interesting reading for students of basic physics courses so that they can appreciate even more the real importance of what they study and can better understand the principles of basic physics.

As another important didactic aspect, the technical report contains serious methodological deficiencies: physics teaching should go hand in hand with education towards a scientific and methodological approach.

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To highlight the errors contained in the technical report, the physical solution of the problem first and then a fairly thorough analysis of its conceptual mistakes will be presented; people's names will be omitted.

2. The Legal Issue

In the trial, the defendant, Mr. DS (Defendant for Slander), was accused of slander; in particular, Mr. DS would have falsely accused, by means of a summons, his neighbor, Mr. OP (Offended Person), of having caused him damage for which he would have demanded undue compensation.

The harm would have been caused by plaster flakes that would have detached from the balustrade of Mr. OP's property and would have reached Mr. DS in his garden, more than a meter away from the OP's building facade, injuring him in his head. To understand the dispute and the physical problem, we sketch the physical context in Figure 1.

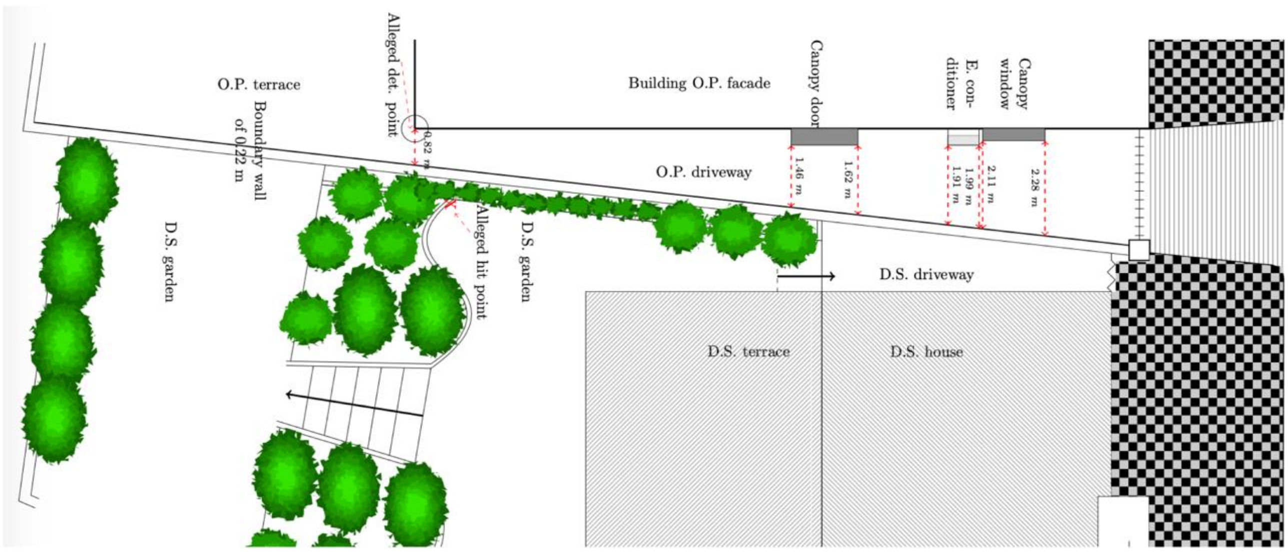

Figure 1 OP's Building Facade From Which the Alleged Plaster Flakes Would Come Off. A Red X Indicates the Point Where Mr. DS Would Have Been Hit by the Plaster Flakes. This Point Is Well Over 1.30 m From the Detachment Point, Denoted by a Circle.

3. The Physical Solution

In recent papers by authors (Indovina et al., 2021a; Indovina et al., 2021b) the physical solution has been published.

As it is known, a body, dropped at rest, falls under the action of the weight force along the vertical. To allow the body to move horizontally while falling, a horizontal velocity component must be initially imparted. External plaster pieces can acquire a horizontal component of velocity if they are either transported by a strong gust of wind and/or if they undergo some impact during the fall.

In the trial, it was stated that on the day and at the hour of the alleged accident, the wind was such that it did not affect the trajectories of the alleged external plaster pieces (wind intensity equal to 1–3 on the Beaufort scale). Then, one must assume a collision with the cornice, as assumed in the trial (Figure 2). Friction with air can be neglected because, in any case, it has a breaking effect leading a shortening of the horizontal range.

To calculate the motion of the object, one must consider the motion subdivided in three-time intervals:

Time interval A: from the moment the plaster piece comes off the wall to the moment it collides with the cornice.

Time interval B: is the infinitesimal time interval in which the plaster piece collides with the cornice.

Time interval C: after the collision with the cornice.

Figure 2 Profile of Mr. OP's Building at the Minimum Distance From the Boundary Wall. An X Indicates the Point Where Mr. DS Would Have Been Hit by the Plaster Piece, Point Which Is Not on the Same Plane. This Point Is Well Over 1.30 *m* From the Facade of the Building From Which the Plaster Pieces Would Have Detached.

During time intervals **A** and **C**, if friction with air is neglected, the only force to be considered acting on an external plaster piece during its motion is the weight force. Its equations of motion will be (Indovina et al., 2021a; Indovina et al., 2021b):

$$\vec{P}_g = m\vec{\mathbf{g}} = m\vec{a}_c \tag{1}$$

$$\vec{\tau}_e = 0 = I_u \frac{d\vec{\omega}}{dt} \tag{2}$$

where $\vec{a}_c$ is the acceleration of the center of mass, $\vec{g}$ the gravitational acceleration, $\vec{\tau}_e = 0$ is the $\vec{P}_g$ moment relative to the center of mass C, I_u is the moment of inertia relative to an axis *u* passing through C, and $\vec{\omega}$ is the angular velocity around the *u* axis.

Equation (1) describes the motion of the center of mass C, that is where the plaster pieces may arrive, whereas (2) describes rotations about the center of mass C and tells us that the rotation speed remains constant. To establish if external plaster pieces might have reached Mr. DS in his garden, one must consider only (1), which allows to estimate the distance that they might have travelled.

During the infinitesimal time interval **B**, the reaction force of the supporting plane, $\vec{R}_v$, an unknown impulsive force strong enough to overlook, during the impact, the effect of other forces (weight force and friction force), acts.

This $\vec{R}_v$ force cannot be determined either by the equations of dynamics or by those of statics but only by applying the impulse theory (Alrasheed, 2019) and Newton's theory of restitution coefficients (Weir et al., 2005; Green et al., 2010).

On the other hand, in this case, it is not necessary to calculate $\vec{R}_v$, useful only to determine, by the third principle of dynamics, the stress suffered by the cornice due to the impact of a plaster piece, whereas the effect of the collision on a plaster piece is described by normal and tangential restitution coefficients. In fact, Newton's theory of coefficients of restitution allows to calculate the velocity and angular momentum of the plaster immediately after the impact, data that constitute the initial conditions of the motion of the projectile in the time interval **C**. After the collision, in the time interval **C**, the plaster piece resumes its projectile motion subject only to the weight force.

All equations were described, and ten million simulations were conducted in recent papers by authors (Indovina et al., 2021a; Indovina et al., 2021b) and results were $x_g = 47\ cm \pm 7\ cm$, with a maximum $x_{gmax} = 71\ cm$.

Monte Carlo simulations show that the external plaster pieces would not have even reached the separation wall and then could not have hit Mr. DS, who was beyond the wall at not less than 1.30 *m* from the facade (Figure 2).

4. The Technical Report

The purpose of the technician, Mr. DS's consultant[1], was to demonstrate how it was physically plausible that plaster flakes detached from the OP's property could had been found in the garden of Mr. DS to show how it was physically plausible that plaster flakes hit Mr. DS more than one meter away from the detachment wall (see Figure 1 and Figure 2).

The technical report parts that describe the physical aspects are reported here below in quoted cursive style, while footnotes are added to give the readers some information about the case which can aid to better understand the technical report methodological lacks.

Once the detachment point of the material (reported by a circle in Figure 2) has been identified, the technical report continues: "*the stones*[2] *found inside the DS's property can be splinters resulting from a simple or double fragmentation of the material or non-fragmented stones which have preserved their integrity even after the fall. In all cases, the cornice is involved, which constitutes not only the main obstacle to the falling stones but is also the*

[1] Party Technical Consultant.

[2] The cover from which they would have detached was not made of stones but of cement mortar dehydrated by atmospheric agents, that is it was external plaster flake.

one that determines the possible trajectories of the stones themselves, according to their masses and to their geometric shapes. The height of fall does not matter, which is the one determined by the distance between the cover and the cornice, in this case it is about 80 cm, the fundamental thing is the point of application of the reaction force, which is the force action that the cornice exerts on the stone.

Therefore, in the collision between a stone and the cornice, a system of forces is thus generated, all applied to the mass of the falling stones (see Figure 3). Of course, for the trajectories, it is necessary to know not only the system of applied forces, but also the mass and geometry of the individual stones that hit the cornice[3]*. In the double fragmentation, on the other hand, it was assumed that the stones had beaten not only on the cornice but also on the boundary wall of the two lots. The phenomenon of fragmentation, which characterizes the disintegration or breakage of any material, arises when it is stressed by a system of forces that exceed the limit value of the material's resistance.*

The trajectories of the fragments, on the other hand, are characterized by the set of points of application of the resultant of all the forces acting on the fragments throughout the path."

Let us consider the physics description of the technical report. In the technical report, collision theory is not considered at all. The impulsive contact force, $\vec{R}_v$, due to the cornice, is treated as a force acting on the plaster flakes during their entire motion *("... Therefore, in the collision between a stone and the cornice, a system of forces is thus generated, all applied to the mass of the falling stones. Of course, for the trajectories, it is necessary to know not only the system of applied forces, but also the mass and geometry of the individual stones that hit the cornice...")* and, above all, determined by static considerations (as said in the following), is considered equal and contrary to the gravitational force $\vec{P}_g$, that is $\vec{R}_v = -\vec{P}_g$ (see Figure 3, which is a reproduction of the figure made by the technician and attached to the expert report).

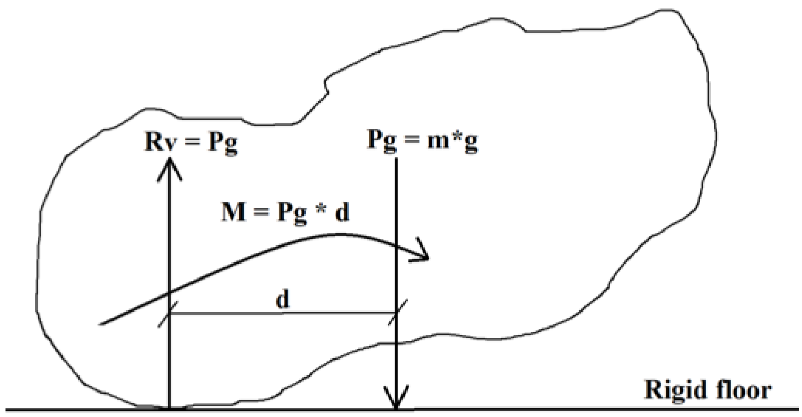

Figure 3 Scheme of Forces Acting on a Rigid Plane According to the Technical Report.

The technician does not realize that his description is so wrong as to lead to an absurd equation of the motion of the center of mass after the collision. In fact, if it were the case, the equation of motion would be:

$$\vec{R}_v + \vec{P}_g = m\vec{a}_c = -\vec{P}_g + \vec{P}_g = 0 \tag{3}$$

that is, the center of mass of the plaster flakes would have zero acceleration, or worse, in the same direction of the friction force, if the friction force were not neglected, which is clearly absurd.

[3] The mass and geometry of the stones that would have hit Mr. DS are unknown because Mr. DS stated that he did not find them after being hit. In this case, however, it is important the motion of the center of mass and not the rotations around it (Indovina et al., 2021a, Indovina et al., 2021b).

From the section 2., the numerous and profound mistakes contained in the physical description of this part of the technical report are so evident, that it is not necessary to say more.

Let us remark here a methodological mistake: having not yet established whether a stone may reach the boundary wall or not, in the technical report it is already assumed that it has reached it and has shattered on the same; all that without having written any equation and made any numerical evaluation.

"*The second hypothesis is that of the fall of intact stones, that is, those that, after the impact with the cornice, still manage to keep their original shape entirely. Also, in the second case, the hypothesis of the discovery of materials within Mr. DS's lot appears possible and legitimate because there is not only a system of forces acting on the bodies (stones) but also of moment solicitation that inevitably cause the onset of rotation of the mass of bodies. In fact, in our case, in addition to the gravitational force applied to the center of gravity of the mass, there is also another force that arises as a reaction to the gravitational one, and it is the force exerted by the cornice on the mass of material falling from above. The latter is equal and opposite to gravitation and applied at a point other than the barycenter because it is a geometrically non-definable body with uncertain shapes and of non-homogeneous material*.

In the statics of bodies, two forces of the opposite sense, which maintain the same direction, the same intensity, but which are applied in different points, give rise to a couple that imparts to the stone a rotary motion (Figure 3). And it is this couple of forces that, in my opinion, determined the removal of the stones until they reached the Mr. DS's property."

According to the technical report, the force due to the cornice, $\vec{R}_v$, and the gravitational force, $\vec{P}_g$, are a third law (an action — reaction) force pair and therefore are equal in magnitude and opposite in direction $\vec{R}_v = -\vec{P}_g$, while it is evident that it is not so.

In fact, the force due to the cornice, $\vec{R}_v$, and the gravitational force, $\vec{P}_g$, applied to the stones (plaster flakes) are not an action — reaction pair, because action — reaction forces always act on different bodies; in a true action — reaction pair, if one force acts on a body, the other acts on the other body (Resnick et al., 2014); the third-law reaction force of the gravitational force, $\vec{P}_g$, applied to a stone (a plaster flake) is the gravitational force with which the stone (the plaster flake) attracts the Earth.

Furthermore, the cornice reaction force, $\vec{R}_v$, is a contact force and cannot be equal and opposite to the gravitational force, $\vec{P}_g$, which is an action-at-a-distance force and always acting, while the cornice contact force acts only during the contact.

In the technical report, the cornice reaction force, $\vec{R}_v$, unknown of the problem, is statically evaluated, while the problem is dynamic.

Let us consider an object having a mass *m* posed on a table (Figure 4a): in this static situation, on the mass act the weight force $\vec{P}_g = m\vec{g}$, due to the Earth attraction, and the force, $\vec{R}_r$, that the table makes over the object at rest.

Being the object at rest, the equation of forces is:

$$\vec{R}_r + \vec{P}_g = \vec{R}_r + m\,\vec{g} = 0 \tag{4}$$

and then $\vec{R}_r = -m\,\vec{g}$.

Let us consider the same mass that is dropped by a height of $h = 5\ m$ above the table (Figure 4b). The mass collides with the table and after the collision it arrives at a height which depends on the restitution coefficient *e*. Let us suppose that *e* = 0.20, that is the mass arrives at a height of $h' = e^2 h = 0.2\ m$ above the table. In this dynamic situation, the impulse theory (Alrasheed 2019) tells us that the mean force, $\vec{R}_d$, acting on the object only during the collision, is given by $R_d = \Delta\vec{P}/\tau$, where $\Delta\vec{P}$ is the momentum variation and τ is the collision duration time, of the order of the tenth of a second $\tau \cong 10^{-1}$ s.

Due to mechanical energy conservation (Resnick et al., 2014) and the coefficient of restitution approach (Weir et al., 2005; Green et al., 2010),

$$\Delta\vec{P} = -e\, m\, \vec{g}\sqrt{\frac{2h}{g}} - m\,\vec{g}\sqrt{\frac{2h}{g}} = -(e+1)\, m\,\vec{g}\sqrt{\frac{2h}{g}} \tag{5}$$

and the mean force

$$\vec{R}_d = -\frac{(e+1)}{\tau}\, m\,\vec{g}\sqrt{\frac{2h}{g}} \tag{6}$$

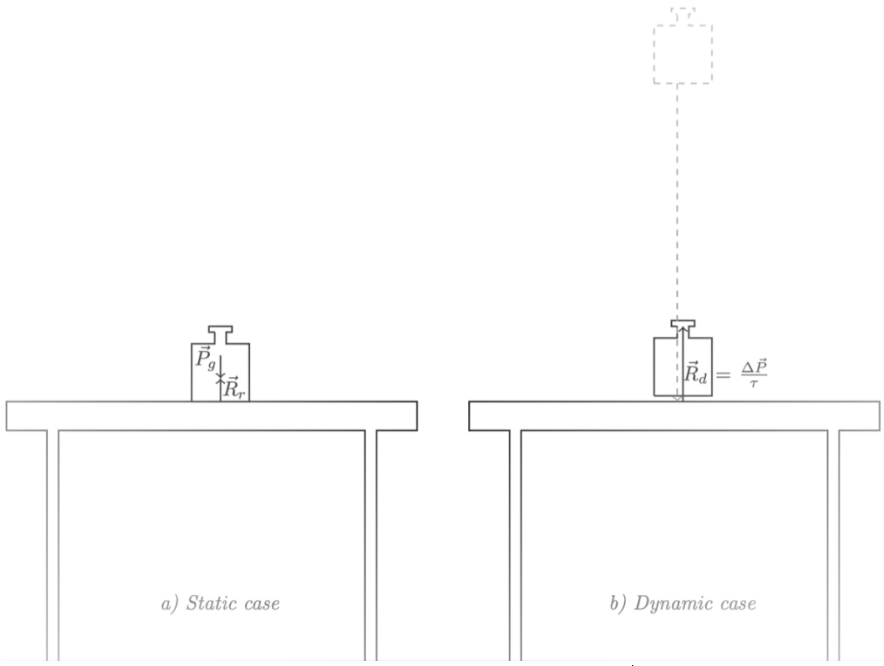

Figure 4 a) Mass *m* at Rest Over a Table (Static Case): The Reaction Force, $\vec{R}_r$, Balances the Weight Force $\vec{P}_g$, So That $\vec{R}_r = -\vec{P}_g$. b) a Mass *m* Dropped by a Height *h* Collides With a Table. In This Dynamic Situation the Reaction Force, $\vec{R}_d$, is an Impulsive Force Acting Only During the Collision and Very Greater Than the Weight Force $\vec{P}_g$, Which Can Be Neglected, So That, During the Collision, the Only Impulsive Reaction Force, $\vec{R}_d$, Acts. It Is Calculated by Impulse Theory (Alrasheed, 2019) and Is $R_d = \frac{\Delta\vec{P}}{\tau}$, Where $\Delta\vec{P}$ Is the Momentum Variation and τ Is the Collision Duration Time.

By comparing the intensities $R_r = mg$ and $R_d = \frac{(e+1)}{\tau}\, m\, g\sqrt{\frac{2h}{g}}$, one has:

$$\frac{R_d}{R_r} = \frac{(e+1)}{\tau}\sqrt{\frac{2h}{g}} \tag{7}$$

that is, assuming $e = 0.20$ and $h = 5\ m$,

$$R_d \geq 12\, R_r \tag{8}$$

By (8), the reaction force of the support plane in a dynamic situation, $\vec{R}_d$, is much greater than the reaction force of the support plane calculated statically, $\vec{R}_r$.

For the third principle of dynamics, the impulsive force acting on the table in the dynamic case is equal and opposite to $\vec{R}_d$: in the dynamic case the table is subjected to a much greater stress than that to which it is subjected in the static case. On the other hand, common sense is enough to make this concept clear: everyone would tolerate to put a mass of *5 kg* on his head at rest, while no one would drop the same mass on his head falling from a height of *5 m*.

As seen in section 2., it is not necessary to evaluate $\vec{R}_v$ because it acts only during the collision and not during all the motion, so it does not enter in the equations of motion; the great physical mistake contained in the technical report is to consider the action of this force acting during all the motion.

Another evident great physical mistake is not to consider the effect of the inelastic collision. It is evident that the physical description in the technical report is erroneous because it makes no difference whether the collision is due to a plaster flake or to a tennis ball: without considering the restitution coefficients, which depend on the objects, all the objects would collide in the same manner and that it is evidently false; once again common sense would be sufficient: that is why tennis balls are not made of plaster flakes.

Furthermore, gravitational force and its third-law reaction force do not constitute a couple of forces[4] (Walker et al., 2014; McGraw-Hill, 2002; Yadav, 2016) for the simple fact that they share the line of action and, above all, are applied on different bodies, in fact the gravitational force, $\vec{P}_g$, is applied to the plaster flake, while the other, its third-law reaction force, the gravitational force with which the plaster flake attracts the Earth, is applied to the Earth. Therefore, there is no torque acting on a plaster flake during its motion.

During the motion, if the friction with the air is neglected, only the gravitational force, $\vec{P}_g$, acts, whose torque about the center of mass is zero. The rotational effect is, as seen above, imparted by the reaction force of the cornice during the impact, when the piece of plaster and cornice are in touch. After the collision, as there is no acting torque (friction force is neglected), the spin angular velocity acquired in the collision is maintained during the subsequent motion.

However, even if a couple of forces acted (Walker et al., 2014; McGraw-Hill, 2002; Yadav, 2016) during the motion, it would imply a rotation of the body assumed to be rigid, but it would not change the trajectory of the center of mass of the body (in this case a plaster flake) in any way, adding a zero contribution to the sum of all the forces applied to the body that determine the acceleration and trajectory of its center of mass (I and II cardinal equation in the dynamics of systems). In addition, if the rotational motion of the body around the center of mass was even considered, the horizontal range is even smaller because a part of mechanical energy is subtracted from the kinetic energy of translation (kinetic energy of the center of mass which determines the length of the horizontal range), to be spent in rotational kinetic energy.

The technical report continues.

"The transformation of the potential energy into the kinematic[5] one also gives the stones an increase in forces and motion that allows them to reach even significant distances from the point of fall."

In the transformation of potential into kinetic energy, there is no increase in forces. For example, in a mass-Earth system, if friction with air is neglected, mechanical energy, $E = mgh + \frac{1}{2}mv^2$, i.e., the sum of the gravitational potential energy, mgh, and kinetic energy, $\frac{1}{2}mv^2$, is conserved, that is, it remains constant during the

[4] Two equal and unlike parallel forces (i.e. forces equal in magnitude, with lines of action parallel to each other and acting, on the same body, in opposite directions) are said to form a couple. Under a couple's action, a rigid body tends only to rotate about a line normal to the couple's plane. The total force of a couple is zero. The total moment (torque) of a couple is identical at any point.

[5] Kinematic and not Kinetic in the Italian text.

motion of the object. If the initial height of the object is at h_0 and its initial speed is v_0, its initial mechanical energy is $E_0 = mgh_0 + \frac{1}{2}mv_0^2$; during motion, altitude and speed can vary, but always in such a way that $E = E_0$. In any case, their variation does not change the acting force, which remains and is always the constant gravitational force $\vec{P}_g = m\vec{\mathbf{g}}$.

As far as motion is concerned, it is not clear what is meant by increased motion because it is not a well-defined physical expression. If it is meant an increase in speed, the maximum speed that the object can reach on the surface of the ground is limited by the value of the mechanical energy E_0, which should remain constant or at most decrease because of inelastic collisions and the negligible air friction. Furthermore, the increase in speed is the acceleration which is determined by the $\vec{P}_g$ force, which remains constant throughout the motion. If it is meant an increase in the horizontal range, the horizontal range is determined by the value of the horizontal component of the initial velocity $v_{0,horizontal}$ and therefore does not depend on the variations of potential or kinetic energy.

"Before finishing the technical report, I invite anyone to have the experience of dropping a small stone from his hand and checking its distance reached after the fall, he will notice that in some cases it even exceeds one meter. All this happens precisely because the mass of the stone, geometry, strength and stiffness come into play, as well as the stresses deriving from the application of the system of forces which are: P_g, R_v and M."

A stone dropped from the hand, by definition, has zero initial velocity and therefore, having no horizontal component of the initial velocity, its horizontal range (Resnick et al. 2014) is zero, that is it falls vertically to the ground (if the effect of the negligible Coriolis force due to the Earth's rotation is neglected, as it is legitimate in the case of a stone which falls from few meters). When it reaches the ground, the stone hits the ground, and, according to the speed with which it falls and the point of fall, it bounces, making another projectile motion. The impact is inelastic, and there is, in the case of plaster flake, a great loss of energy as the return coefficient is, for plaster flakes, at most 0.18, so that a plaster flake dropped from a meter rises at most for 3–4 cm, and the second motion of the plaster flake will have a horizontal range of a few centimeters.

There should be no confusion between the horizontal range of the projectile and the rolling distance of a body once it touches the ground. In fact, for Mr. DS to be hit in his head by a plaster flake, the horizontal range of the projectile motion would be greater than at least 1.30 m, while where the projectile can roll after it has touched the ground has no importance. If you drop a stone from your hand, the horizontal range is zero, while the rolling motion on the ground can cause the stone to stop after a few centimeters.

The physics part of the technical report is finished.

4. The Judgment Part Concerning the Physical Aspect

The judgment part is reported in quoted cursive style.

"*Indeed, the Judge believes that the technical appreciation provided by the consultant*[5] *can be shared, who specified that the stones found within the property of the accused could be splinters resulting from a simple or double fragmentation of the material or fragmental that have preserved their integrity even after the fall. In both, the presence of a cornice (see photographic annexes in documents) constitutes not only the obstacle to the falling stones, but also determines their possible trajectories, depending on their geometric shapes. Indeed, in the collision between stone and cornice, a system of forces is generated, all applied to the mass of the falling stones: in this case, the*

[5] The technical report author, Mr. DS consultant (Party Technical Consultant).

hypothesis of the discovery of materials within the DS's property appears possible because there is not only a system of forces acting on the stones, but also of stress that cause the rotation of the mass of the bodies. In fact, to the gravitational force applied to the center of gravity of the mass, there is also another force that as a reaction to the gravitational force and is the force exerted by the cornice on the mass of material falling from above: precisely this couple of forces has determined the removal of the stones to reach the property of the DS in the closest point to the OP property."

Evidently, the Judge shares the physical conceptual mistakes contained in the technical report, already analyzed.

5. Conclusion

In this article the case of a real trial, in which a bad knowledge of the physics laws led a monocratic judge to issue a judgment based on erroneous physical conclusions, has been analyzed. The monocratic judge was misled by a technical report prepared by an alleged expert.

The technical report contains conceptual mistakes of basic physics, shared by the monocratic judge, so numerous and serious that it would be very difficult to even believe that they could have been committed if it were not that both the technical report and the judgment are parts of official legal documents published and filed at the court of Nola, Italy (Court of Nola, 2020).

In this article, to highlight the mistakes contained in the technical report, firstly the physical solution of the problem was presented and then a thorough analysis of the conceptual and methodological errors contained in the technical report shared by the judge was conducted.

The technical report is very lacking from a methodological point of view, as what needs to be demonstrated is taken as a starting hypothesis. It contains only opinions and imaginative, subjective interpretations, moreover erroneous, of some physical laws; the contained conclusions are not the result of any mathematical model (and could not have been given the erroneous physical setting) and do not express any verifiable numerical data. Furthermore, many of the physical mistakes contained in the technical report led to conclusions contrary to common sense and, therefore, it would have been enough to examine it a little more carefully to notice them.

This article shows how the teaching of physics must go hand in hand with the habit of methodological analysis and the application of common sense. As such, the case study here analyzed can be a useful educational tool as it can show students the implications of what they study and how important it is to study correctly, always analyzing each statement, guided by common sense and a correct methodological approach.

What boots it, that for thee Justinian
The bridle mend, if empty be the saddle?
Withouten this the shame would be the less.
Dante Alighieri, Divine Commedy, Purgatory, Canto VI, 88–90.

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