

Center of Gravity—from Archimedes to Clausewitz

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Introduction

Over the last 40 years, the modern concept of Center of Gravity, when applied to warfare, has become doctrinally important for US armed forces and, through US influence, has become important to many others state actors worldwide as well. This concept has historically been assumed to derive from General Carl von Clausewitz's 1832 posthumous book, *Vom Kriege* (*On War*), in which Clausewitz used *Schwerpunkt* to describe center of gravity dozens of times in his original text, as in the following excerpt, when presenting the first of two principles of war planning:

... to reduce the weight of the enemy's power into as few centres of gravity [*Schwerpunkte*] as possible, into one if it can be done; again, to confine the attack against these centres of force to as few principal undertakings as possible, to one if possible; lastly, to keep all secondary undertakings as subordinate as possible. In a word, the first principle is, *to act concentrated as much as possible*.¹

However, since the 1990s, many authors have questioned its meaning and even its practical utility.² The purpose of this article is to investigate, from a historical perspective, the origin of the Center of Gravity concept and how it reached Clausewitz's time.

After a brief overview, this study will focus on the work from Arquimedes, the great mathematician and inventor from ancient Greece, which catapulted the original Center of Gravity concept into modern times after it was translated into Latin and other languages. This study will then examine how Isaac Newton and Pierre-Simon Laplace used the term center of gravity in their works and how it was translated into German. Finally, this article presents the etymology of *Schwerpunkt*, how English-German and German-English dictionaries from the 18th and 19th centuries translated this term; and how German books from that period employed it.

Contextualization of the Discussions

As previously mentioned, many authors have pointed out various issues with the Center of Gravity concept since the 1990s.³ This modern body of work suggests that the Center of Gravity concept is a problematic, controversial, and maybe even a useless concept. What's more, in his 2007 Military Review article, "Clausewitz's *Schwerpunkt*: Mistranslated from German—Misunderstood in English," Milan Vego, PhD, went so far as to write that 1) Clausewitz never used the term center of gravity; and 2) *Schwerpunkt* does not mean center of gravity:

Massive amounts of time, energy, ink, and paper have been expended on defining, analyzing, and arguing how the concept should be properly applied within the context of a supposed Clausewitzian paradigm of war. Unfortunately, the major problem with this, at least from a historical perspective, is that Clausewitz never used the term center of gravity. The term from which the Center of Gravity concept has been extrapolated, *Schwerpunkt*, really means "weight (or focus) of effort."⁴

Dale C. Eikmeier, in his article "Give Carl von Clausewitz and the Center of Gravity a Divorce," agrees with Vego, asserting that Colonel James John Graham's 1874 English language translation of *On War* mistranslated *Schwerpunkt* as center of gravity.⁵ To investigate the true meaning of the Center of Gravity concept, this paper first dives into its ancient Greek origins.

Archimedes—The Greatest Mathematician of Antiquity

Archimedes was a citizen of Syracuse, Sicily (then part of Greece), who contributed greatly to geometry, mechanics, and hydrostatics.⁶ The following sections discuss the *Planorum Aequilibriis I* and *II* (*On the Equilibrium of Planes*)/*Centra Gravitatis Planae* (*Centers of Gravity Plane*) book of Archimedes, to evaluate how κέντρον του βάρους (center of weight), the main expression Archimedes used for the Center of Gravity concept, was first translated from Greek to Latin, and then German and English.*

The Works of Archimedes

Translations of Archimedes' works first emerged in Arabic in the ninth century, which played a significant role in preserving and disseminating his contributions, with Latin versions appearing in the twelfth and thirteenth centuries (unfortunately, several works by Archimedes discussing the Center of Gravity concept,

**Planorum Aequilibriis I* and *II* (*On the Equilibrium of Planes*) and *Centra Gravitatis Planae* (*Centers of Gravity Plane*) were two different Latin variations used as the title translations for the same book.

such as *On the Centers of Gravity*, *On the Center of Gravity and Law of the Lever*, *Equilibria*, and *On Balances/Levers*, remain lost).⁷ With the invention of the Gutenberg press, most of his known works in Greek and Latin began to be printed as well.⁸ In 1670, *On the Equilibrium of Planes I and II* were translated from Latin into German.⁹ It took over 100 years for French versions to appear and over 200 years for his work to be translated into English.¹⁰

Κέντρον του βάρους—Center of Weight

The idea that a rigid body can be balanced when supported by a rigid surface has been around for centuries. However, the scientific study of the equilibrium of bodies on Earth began in Greece, with Archimedes being one of the leading Greek scholars to investigate the concept of Center of Gravity and contributing significantly to the theoretical and practical understanding of this construct.¹¹ According to Andre Koch Torres Assis, in his book *Archimedes, the Center of Gravity and the First Law of Mechanics*, Archimedes was the first to demonstrate that the center of gravity of a circle coincides with its center and, in parallelograms, it is the point of intersection of its diagonals. He was also the first to demonstrate how to find the center of gravity of a triangle.¹²

The actual definition of center of gravity by Archimedes is not directly known, as it is assumed to have been defined in one of his lost works. According to Assis, however, there are references in citations from works of other ancient authors, such as Pappus and Simplicius, that are available.¹³ According to Simplicius, the definition is:

The center of gravity is a certain point in the body such that, if the body is hung up by a string attached to that point, it will remain in its position without inclining in any direction.¹⁴

Archimedes' Greek term for center of gravity was *κέντρον του βάρους* pronounced *kéntron tou várou* (heavy center). Of note, the *βάρους* component can also be pronounced *baros* or *barús*, which interestingly enough, is the root of the English barycenter (a late 19th-century scientific term), barometer, brigadier, brute, and baritone terms—highlighting the enduring influence of these ideas.

Now that the *κέντρον του βάρους* expression and its historical context has been explored, this article will analyze Archimedes earliest work which, coincidentally, deals with the topic.

The Planorum Aequilibris/Centra Gravitatis Planae

As previously mentioned, the work in which Archimedes presents and defines the concept of Center of Gravity has not survived in modern times. However, *Planorum Aequilibris I and II (On the Equilibrium of Planes)/Centra Gravitatis Planae (Centers of Gravity Plane)*, in which he mentions this concept, have.¹⁵ For this study, the authors examined the first volume of *Planorum Aequilibris*.

Planorum Aequilibris I has seven postulates. In postulates one through three, Archimedes states that, on a balance, equal weights placed at equal distances from the fulcrum will be in equilibrium. He further explains that if anything adds or subtracts from these weights, they are no longer in balance.¹⁶ In the fourth postulate, Archimedes uses *κέντρον του βάρους*, which throughout the centuries has been translated as *centra gravitatis* in Latin, centers of gravity in English, and *Schwerpunkte* in German.¹⁷

In proposition five of postulate seven, Archimedes considers a situation involving three identical bodies A, B, and Γ, where Γ (gamma) is the central body, with their center of gravity aligned in a straight horizontal line. The line segments ΑΓ and ΓΒ are also equal. The author states that the center of gravity of the system of the three bodies is the central point Γ. This is because, when considering A and B together, the center of gravity coincides with point Γ due to their equidistance.¹⁸ *κέντρον του βάρους*, appears throughout this proposition, always translated into Latin as *centrum/centra gravitatis* (center/centers of gravity).¹⁹

The following table provides an overview of the various spellings and frequency of *κέντρον του βάρους*, in *Planorum Aequilibris I*, and how they were translated into other languages.

Greek ²⁰	Latin ²¹	English ²²	German ²³
<i>κέντρον του βάρους</i> (58) <i>κέντρον τον βάρους</i> (29) <i>κέντρα του βάρους</i> (15) <i>κεντρα των βαρέων</i> (2) <i>κεντρα βαρεων</i> (1)	<i>centrum gravitatis</i> (86) <i>centra gravitatis</i> (21) <i>centris gravitatis</i> (1) <i>gravitatis centra</i> (1)	center of gravity (52) centers of gravity (17)	<i>Schwerpunkt</i> (90) <i>Schwerpunkte</i> (25) <i>Schwerpunkten</i> (3) <i>Mittelpunkt der Schwere</i> (1)
104	109	69	117

Table 1. Variations and frequency of *κέντρον του βάρους/centra gravitatis/center of gravity/Schwerpunkt* in the various versions of *Planorum Aequilibris I*

Source: The Authors

The following observations can be drawn from this data: First, every time the original Greek version used *κέντρον του βάρους*, the Latin and German versions used *centra gravitatis* and *Schwerpunkt* respectively. Second, while the Latin version has a high degree of parity with the original Greek, the German version used

Schwerpunkt approximately ten percent more frequently, because it translated even indirect references to *κέντρον του βάρους* as *Schwerpunkt*. Third, the English version by Eduard Jan Dijksterhuis frequently compressed two or three paragraphs into one.

It is important to note, however, that apart from the term *Mittelpunkt der Schwere* (midpoint of gravity), which appears only once in the German version, center of gravity and *Schwerpunkt* have been the terms most used to translate the Greek and Latin expressions in the English and German versions respectively; thus, indicating a high degree of consistency.

Planorum Aequilibriis I was translated into German in 1670, long before the French and English versions.²⁴ In this German version, in the first postulate, the expression *Schwáre-Punct* (ancestor of *Schwerpunkt*) is followed by *centro gravitatis* in parentheses in the translator's comments—110 years before the birth of Clausewitz, thus providing strong evidence that *Schwerpunkt* was already used to denote center of gravity.²⁵

Beyond Archimedes' work, there are at least two other celebrated works from the 17th and 18th centuries that mention the center of gravity term. Next, this article researches these works, their authors, and how their ideas involving center of gravity were translated into German.

Newton, Laplace, and Gravitational Attraction

Isaac Newton and Pierre-Simon Laplace played fundamental roles in the development of theories to understand the motions of celestial bodies.²⁶ Newton, with his famous law of universal gravitation, established that the force of attraction between two bodies is proportional to their masses and inversely proportional to the square of the distance between them.²⁷ This discovery allowed for an explanation of the orbits of planets around the sun and laid the groundwork for a deeper understanding of the universe. Laplace, in turn, contributed with his theory of scientific determinism, advocating that if the initial conditions of a system are known, the laws of physics can predict its future behavior. This deterministic approach influenced the study of gravitational attraction, enabling precise calculations and advanced mathematical modeling.²⁸

Newton's *Mathematical Principles of Natural Philosophy* was composed of three volumes and first published in 1687, with revisions in 1713 and 1726.²⁹ Newton wrote this book in Latin, as was the custom of the academic world at the time, under the title *Philosophiae Naturalis Principia Mathematica*, also simply called *Principia*, as it will be referred to from now on.

Recent research by the California Institute of Technology has revealed that, contrary to popular belief, access to *Principia* was not a privilege for a few. In a

recent census, they discovered twice as many copies of the first edition as originally thought in the 1950 census of the same work. Through old annotations and letters, they realized that the work was also understood in a broader context and had reached a wider audience.³⁰ This study found that the expressions *centro/centrum gravitatis* and *gravitatis centro/um* appear fifteen times in the third volume of the *Principia*.³¹ Just as in Archimedes' *Planorum Aequilibriis I*, all 15 occurrences in the third book of *Principia* are translated as center of gravity in English and *Schwerpunkt(e)* in German versions—a perfect consistency across languages!

Laplace's masterpiece, in turn, was *Exposition du Système du Monde*. The following is an excerpt that makes use of *centre de gravité* in its original French version (1796) and *Schwerpunkt* in the German version (1797):

<p>"Nous choisissons ce parallèle; parce que la attraction de la terre sur le points correspondan de sa surface, est à très-peu pré comme à la distance de la lune, égale a la masse de la terre, divisée par le carré de la distance à son centre de gravité. Le rayon mené dun point de ce parallèle, au centre de gravité de la terre, est de 19614648 pieds (...)"³²</p>	<p>"Wir wählen diesen Parallel, weil die Attraction der Erde in den übereinstimmenden Punkten seiner Fläche, sehr nahe wie in der Entfernung des Mondes, der Masse der Erde, dividirt durch das Quadrat der Entfernung von ihrem Schwerpunkt gleich ist. Der von einem Punkte dieses Parallels nach dem Schwerpunkt der Erde gehende Halbmesser ist 19614648 Fufs grofz (...)"³³</p>
<p>English Translation: "We choose this parallel because the attraction of the Earth on the corresponding point of its surface is very nearly, at the distance of the Moon, equal to the mass of the Earth divided by the square of the distance to its center of gravity. The radius drawn from a point on this parallel to the center of gravity of the Earth is 19,614,648 feet"</p>	

Table 2. Centre de gravité/Schwerpunkt in Laplace

Source: The Authors

This is yet another work in which the center of gravity term is clearly used in its physical sense and translated into German as *Schwerpunkt*. Next, this article studies the etymology and dictionary translations from Clausewitz's era.

Schwerpunkt's Etymology and Dictionary Translations from XVIII and XIX Centuries

Lenilson Ferreira, in his article "O prazer etimológico em Sigmund Freud (Etymological pleasure in Sigmund Freud)," refers to etymology as a microscope that permits a better understanding of discourses.³⁴ Even if a word evolves, in most cases (although not always), its original meaning prevails or, in some way, emerges or is implied. This seems especially true with *Schwerpunkt*, which comes from the combination of *Schwere* + *Punkt*: *Schwere* (weight or difficulty) from Old High German *Swāri* (8th century) and Middle High German *Swære* (suffering, pain, sorrow, distress, great weight).³⁵ On the other hand, *Punkt* (point, center,

moment, circumstance) from the Late Latin *pūctus/punctum* (pricked or punctured), used in Old High German as *Puncto* (12th century manuscript) and Middle High German as *pun(c)t*, *Punkt*, *Puncte*. Thus, *Schwerpunkt* literally means center of mass/center of gravity—like the Greek expression *κέντρον του βάρους* used by Archimedes—and metaphorically, main point (18th century).³⁶ It is no wonder then that this word *Schwerpunkt* was used in the 1872 German edition of Newton's *Principia* to translate all 15 uses of the *centro/centrum gravitatis* term from the original Latin.

Dictionaries, in turn, play an important role in understanding an era and a society, as they provide linguistic, cultural, and historical insights. They are like snapshots in time capturing the evolution of the meaning, spelling, and usage of words over time. Although *Schwäre-Punct* was already used in 1670 to represent *κέντρον του βάρους* in the works of Archimedes, it seems that dictionaries in the early 18th century did not yet register the expression. However, Johann Heinrich Zedler, in his 1733 *Grosses vollständiges Universal-Lexicon aller Wissenschaften und Künste* (Large Complete Universal Lexicon of All Sciences and Arts), when explaining the Latin term *basis corporis gravis* (base of a heavy body), states that *daher auch dieser Punct der Mittel-Punct der Schwere oder centrum gravitatis genennet wird* (hence this point is called the center of gravity or *centrum gravitatis*); thus, providing proof of the correlation of these expressions with *Schwerpunkt*, as outlined in Table 1 (the expression *Mittelpunkt der Schwere* appears in three more dictionaries later in this article).³⁷

Modern dictionaries attribute a wide range of meanings to *Schwerpunkt*.³⁸ However, in Clausewitz's time, they did not. Table 3 outlines linguistic snapshots from the 18th and 19th centuries verifying the usage of the terms center of gravity/*Schwerpunkt*.

Year/Author	English/ French	German	English
1736 (Ludwig) ³⁹	<i>grávitý</i>	<i>die Schwere</i>	-x-x-x-
1763 (Rogler) ⁴⁰	gravity	<i>die Schwere</i> (<i>gravité</i> , in french)	-x-x-x-
1770 (Choffin) ⁴¹	<i>centre de gravité</i> (French)	<i>der Punkt; worinn ein Schwere körper ruht; der ruhepunkt; centrum gravitatis (latim)</i>	-x-x-x-
1797 (Fahrenkrüger) ⁴²	-x-x-x-	<i>Schwer-Punkt</i>	Point of gravity
1798 (Ebers) ⁴³	-x-x-x-	<i>ruhepunkt;</i> <i>Schwerer körper</i>	center of gravity
1799 (Ebers) ⁴⁴	-x-x-x-	<i>Schwerpunkt (der Mittelpunkt der Schwere)</i>	the point; the center of gravity of a body
1801 (Bailey) ⁴⁵	-x-x-x-	<i>Schwere</i>	weight, gravity
		<i>Schwer-Punkt</i>	<i>der Mittelpunkt der Schwere</i> - the center of gravity; point of gravity
1808 (Ludovici) ⁴⁶	-x-x-x-	<i>Schwerpunkt</i>	center of gravity
1823 (Burckhardt) ⁴⁷	-x-x-x-	<i>Schwere</i>	weight, gravity, heaviness. fig. hardness, difficulty
		<i>Schwerpunkt</i>	center of gravity
1828 (Hilpert) ⁴⁸	center of gravity	<i>Schwerpunkt</i>	-x-x-x-
1834 (Bernays) ⁴⁹	-x-x-x-	<i>Schwere</i>	weight, gravity, heaviness. fig. hardness, difficulty
		<i>Schwerfläche</i>	plane in which is the center of gravity or which moves through storm; the center of gravity
		<i>Schwerpunkt</i>	point of gravity; center of gravity
1837 (Military Dictionary) ⁵⁰	center of gravity	<i>der Mittelpunkt der Schwere eines körpers</i>	-x-x-x-
1854 (Tolhausen and Gardissal) ⁵¹	center of gravity	<i>Schwerpunkt; Mittelpunkt der Schwere;</i> <i>center de gravité (fr)</i>	-x-x-x-
1856 (Flugel) ⁵²	center of gravity	<i>der Schwerpunkt</i>	-x-x-x-

Table 3: Translations of center of gravity/Schwerpunkt from 18th and 19th centuries

Source: The Authors

Occasionally, this study found that English-German dictionaries translated the word difficulty as *ein(e) Schwere(r) Punct*.⁵³ This makes sense, as the etymology of the word *Schwerer* and the various dictionary translations of difficulty, hardness, suffering, and pain are figurative senses of *Schwere*, as described in Table 3. However, this does not detract from the value of center of gravity as the primary meaning assigned to *Schwerpunkt*, considering that:

- In the academic world, since the 17th century, the relationship between the concepts of *centra gravitatis*, *Schwerpunkt* and center of gravity has been well established, as evidenced by the translations of the works of Archimedes, Newton, and Laplace.
- The etymologies of *Schwerpunkt* and *κέντρον του βάρους* are similar (center of weight).
- The linguistic snapshots outlined in Table 3, which demonstrate the evolution in the perception of the correlation between these two expressions by a larger audience, since dictionaries represent a mode of expression for a broader stratum of the population.

Thus, we can conclude that in Clausewitz's lifetime, *Schwerpunkt*, and its *der Punkt*, *Mittelpunkt der Schwere*, and *Ruhpunkt* synonyms, were all understood as center of gravity and vice versa. To further support and complete this research, this study will now present the use of *Schwerpunkt* by other writers of the 18th century.

Eighteenth Century German texts with Schwerpunkt

In the eighteenth century, dozens of German works in Mathematics, Mechanics, Optics, Astronomy, and Architecture used the term *Schwerpunkt* in the same context as Archimedes. Here is an example translated from 1777, on hydrostatics, with original German and Latin terms in brackets:

In every solid body, there is a point such that if this point is supported, the body will remain in equilibrium. This point is called the center of mass [*Mittelpunkt der Schwere*] or the center of gravity [*Schwerpunkt*] of the body [*centrum gravitatis corporis*].⁵⁴

Another scientific article, in a 1753 compendium on science, regarding “*Die Lage des Mittelpuncts der Schwere* (The location of the Center of Gravity),” explains how a ship's *Schwerpunkt* relates to the four forces acting on it.⁵⁵ Another text, from 1754, teaches about the *Schwerpunkt* of fish—which in carp is located in the middle of the chest, due to the large size of their head (this work uses *Mittelpunkt der Schwere* as a synonym as well).⁵⁶ The concept also appears in several historical

and legal works, and was even used by Immanuel Kant in his book on *Metaphysical Principles of Natural Science*.⁵⁷ Even religious works, such as the 1789 *Handbook of Godliness: dedicated to the quiet in the land* uses *Schwerpunkt*: “the center of gravity [*Schwerpunkt*] of your soul, or what is the same, the ultimate goal of your existence and rest, is in God.”⁵⁸

The authors’ research also found a military science textbook for infantry and cavalry officers from 1795, with an emphasis on mathematics, in which *Schwerpunkt* appears more than 100 times, always in the same context used by Archimedes.⁵⁹ Young German officers had to master this part of mechanics, indispensable for the practical use of weapons. At that time, Clausewitz was 15 years old, had already been in the army since he was 12, and had participated in war in 1793.⁶⁰ Finally, a 1790 manual on the applications of “war sciences,” which has a section called *Schwerpunkt*, states:

The center of gravity [*schwerpunkt*] of the rifle must not be more than 2 feet 6 inches from the lower end of the stock when the bayonet is attached. This is because the left hand rests at about 2 feet 3-5 inches, without being too extended. If the center of gravity [*Schwerpunkt*] falls further towards the muzzle, the rifle becomes heavier at the front and has a trembling movement when aiming.⁶¹

In addition to being further historical evidence of the use and meaning of *Schwerpunkt*—center of gravity in Clausewitz’s time, the above manual was written by then Captain Scharnhorst, who as a General became the main figure in the reform of the Prussian army at the beginning of the 19th century and became Clausewitz’ professor, mentor and greatest friend.⁶²

Final Considerations

This work began with an exposition of how the concept of Center of Gravity, which has been a part of modern military campaign planning for over 40 years, has been historically assumed to have been derived from General Carl von Clausewitz’s 1832 posthumous book, *Vom Kriege (On War)*. It then focused on a body of research that questioned the utility of the concept and its historical underpinnings due to the possible misinterpretation of the meaning of the term *Schwerpunkt*, as used by Clausewitz.

With the goal of tracing the emergence of *Schwerpunkt* from a historical perspective, and the meaning it had in Clausewitz’s era, this research tracked the origins of the concept back to *κέντρον του βάρους* the Greek term used by Archimedes to denote center of weight. This study then established that when Archimedes’ work was translated into German (1670), French (1787) and English (1872), the corresponding words for *κέντρον του βάρους* were *Schwerpunkt*, *centré*

de gravité, and center of gravity, respectively. This work also confirmed that the *Schwerpunkt* term was used as the German translation of both Newton's and Laplace's use of *centra gravitates/centre de gravité* in their respective works.

Additionally, this work also showed that in Clausewitz's days, English-German dictionaries translated center of gravity as either *Schwerpunkt* or similar expressions like *Mittelpunkt der Schwere*, and German-English dictionaries translated *Schwerpunkt* as center of gravity. Finally, this research found that when *Schwerpunkt* appeared in various types of German books in the 18th century, the meaning was mostly consistent with Archimedes' *κέντρον του βάρους*. Thus, this work unequivocally proves that the concept of *Schwerpunkt* is closely related to the Archimedean concept of the Center of Gravity and that this interpretation was predominant during Clausewitz's time. □

Notes

1. General Carl von Clausewitz, *On War*, trans. Colonel James John Graham (London: Wildside Press, 2009), 429, ISBN978-1-43440496-1.

2. Joseph L. Strange and Richard Iron, "Center of Gravity: What Clausewitz Really Meant," *Joint Forces Quarterly*, 35, (2004), <https://apps.dtic.mil/sti/pdfs/ADA520980.pdf>; John B. Saxman, "The Concept of Center of Gravity: Does it Have Utility in Joint Doctrine and Campaign Planning?" (graduate research paper, School of Advanced Military Studies, US Army Command and General Staff College, 1992), <https://apps.dtic.mil/sti/pdfs/ADA254161.pdf>.

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4. Milan Vego, PhD, "Clausewitz's Schwerpunkt: Mistranslated from German—Misunderstood in English," *Military Review*, (January 2007), 101, https://www.armyupress.army.mil/Portal/7/military-review/Archives/English/MilitaryReview_20070228_art014.pdf.

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6. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics* (Montreal: Apeiron, 2010), 17, <https://www.ifi.unicamp.br/~assis/Archimedes-2nd-edition.pdf>

; “Archimedes,” Complete Dictionary of Scientific Biography, *Encyclopedia.com*, <https://www.encyclopedia.com/people/science-and-technology/mathematics-biographies/archimedes>.

7. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 35–36.

8. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 28.

9. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 27–28.

10. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 28.

11. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 123–124.

12. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 53–54.

13. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 130.

14. Thomas Heath, *A History of Greek Mathematics* (Oxford: Clarendon Press, 1921), 2:24, 350; Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 130.

15. Andre Koch Torres Assis, *Archimedes, the Center of Gravity and the First Law of Mechanics*, 28.

16. Eduard Jan Dijksterhuis, *Archimedes* (Princeton: Princeton University Press, 1987), 286–287.

17. Archimedes, *Opera Omnia - Cum Commentariis Eutocii (Opera Omnia - With the Commentaries of Eutocius)*, ed. Johan Ludvig Heiberg (Leipzig: B. G. Teubneris, 1881), 2:146–47; Eduard Jan Dijksterhuis, *Archimedes*, 287–288.

18. Archimedes, *Opera omnia - Cum Commentariis Eutocii*, 2:148–51; Eduard Jan Dijksterhuis, *Archimedes* (Princeton: Princeton University Press, 1987), 289.

19. Archimedes, *Opera omnia - Cum Commentariis Eutocii*, 2:148–151; Archimedes, *Die Quadratur der Parabel*, 3.

20. Archimedes, *Opera omnia - Cum Commentariis Eutocii*, 2:142–87.

21. Archimedes, *Opera omnia - Cum Commentariis Eutocii*, 2:142–87.

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