CHAPTER 2

FORCE LIKE WATER

It remained for the eighteenth century to define
the concept of force with adequate rigour.
Richard S. Westfall[1]

2.1 A BRIEF ARCHEOLOGY OF THE CONCEPT OF FORCE IN THE SEVENTEENTH CENTURY

Force occupies a central position within classic mechanics. Seventeenth-century mechanics had restricted the use of forces to statics and the laws of impact (other motions being regarded solely as kinematic), but after Newton, mechanics linked forces and motion almost by definition. For example, d'Alembert defined mechanics in 1765 as the science "that considers movement and motive forces, their nature, their laws and their effects within machines."[2] Newton's and Leibniz's work in the field of mechanics can be viewed as the motive force that moved the concept of force to center stage. However, this shift in the concept of force from the realm of everyday experience and the peripheral regions of occult phenomena to the center of mechanics did not take place without difficulty. Distinctions within the concept of force had to be introduced or refined, such as the distinctions between 'inertia' and 'cause of acceleration', between 'momentum' and 'kinetic energy' and between 'contact force' and 'action-at-a-distance'. The process of making these distinctions was often accompanied by an extensive battle in which conflicting viewpoints were defended tooth and nail.

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[1] Westfal, *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century* (1971), 476.

[2] "qui considere le mouvement & les forces motrices, leur nature, leur loix & leurs effets dans les machines" (D'Alembert, "Méchanique" (1765), 222). Lagrange provides us with another example, giving the following definition of the two branches of mechanics—statics and dynamics: "Statics is the science of the equilibrium of forces" ("La Statique est la science de l'équilibre des forces") (Lagrange, *Méchanique analitique* (1788), 1); "Dynamics is the science of accelerating and retarding forces, and the various movements which they can produce" ("La Dynamique est la science des forces accélératrices ou retardatrices, et des mouvements variés qu'elles doivent produire") *(ibidem,* 207).

The best-known example of a dispute of this kind can be found in the history of the force of gravity. Ever since Newton's cautious postulation of the universal force of gravity as action-at-a-distance, in his *Principia mathematica* of 1687, there had been an unremitting struggle between those who wanted to explain gravity using ether theories and those who regarded a force of this kind as fundamental and irreducible.[3] This struggle moved to the background only after the appearance of field theories at the end of the nineteenth century.

During the development of mechanics, the distinctions made within the concept of force did indeed become generally accepted, but the concept of force also acquired an entirely different meaning. Except for their subject matter, Lagrangian and Hamiltonian formulations of mechanics have little in common with the ponderous and laborious way in which Newton related aspects such as the action of compounded forces to the action of the individual forces.[4] Although the advantages of the modern formulation are patently obvious, it also has its drawbacks; it has become more difficult to understand the historical development, if only because the original meanings seem strange or even bizarre from the viewpoint of the modern formulation.

Faced with the term 'force', the modern physicist thinks only of the modern formulation of Newton's second law, in which force is the product of mass and acceleration: $\underline{F} = m \times \underline{a}$. For him, the fact that the inertial force has the formal name of 'force' is no more than a residual trace of a very early philosophy of nature, in which forces were quite simply considered responsible for everything that moved. After all, it is as clear as daylight that inertia is a property that needs no cause! The same applies to the concept of 'living force' which today is, at best, regarded as an old name for kinetic energy[5], but which no longer has anything in common with Newton's concept of force.

Naturally, this kind of attitude is inadequate if one is to understand what happened to the concept of force during the development of mechanics; a physicist would also acknowledge this. Nevertheless, it appears to be very difficult to gain a real sensitivity to the meaning of questions connected with previous (and in a way outdated) conceptions of force. The historiography concerning the controversy about the true measure of living force, for example, all too often gives the impression that the dispute was about essentially non-physical matters, involving mere wars of words and power struggles, rather than the subject itself. Lack of sensitivity to the meaning of the old concept of force appears to be a major cause of this reduction.

In the history of ideas, it is not unusual to find that very different ideas originate historically from a common concept. Frequently, the common term is then reserved

[3] For an excellent survey of this conflict, see Van Lunteren, *Framing Hypotheses; Conceptions of Gravity in the 18th and 19th Centuries* (1991).

[4] Newton, *Philosophiae naturalis principia mathematica* (1687), Liber I, Leges Motus, Corollaries I and II, 14r.21-17r.10.

[5] For which a conversion factor of ½ has to be applied to the formula for *vis viva*.

for one of these ideas, while the others acquire new names. The relationship between the historical unity and historical diversity may be a simple species/genus, as in the distinction between various zebra finches where previously only a single species was recognized. But it need not be restricted to this. Cases in which there has been a *change in viewpoint* are much more interesting. For example, the meaning of the Greek ψυχή (psyche) in the *Iliad* was a unification of breath and soul: it was the force that breathes in life, the 'soul-breath'.[6] The distinction between these two meanings only came into existence later, when breath was connected with the body, and the soul with consciousness. This distinction does not reside in a difference between 'species', but in another view of life in general, and of humankind in particular. Other examples include the development of adolescence as an intermediate stage between 'child' and 'adult'[7] and the distinction between a word and the thing it indicates (resulting in an extremely troubled relationship between modern man and the biblical myth of Creation). Every one of these distinctions is taken for granted in our own times, yet each retains its own assumptions. The historical approach offers the possibility of revealing the transition from the original unity to the modern distinction that we take for granted; by this means we can turn something that goes without saying into something that can *truly* speak for itself.

In order to realize this potential, I shall devote a good deal of this chapter to an investigation of the original meaning of the concept of mechanical force. In other words, I will search for the historical basis of the identical, or at least analogous, approach that was taken to kinds of force that are, according to the modern conception, entirely different from each other. These kinds of force include energy, power, and the forces of inertia, impact, and gravity. My starting point is the end of the seventeenth century, when Leibniz made his famous distinction between dead and living force. From this vantage point, I shall return to earlier times, to Galileo and Descartes, and even to the Paris nominalists so that, just as in an archeological expedition, we may uncover shards and fragments from the deeper layers that can clarify the original unity of Leibniz's distinction. Finally, I will clarify the relationship between this unity and substantial-metaphysical considerations.

After this I will take the reader back to the eighteenth century by another route, via different stages of the concept of inertia. During the return journey it will become clear that the original unity of the concept of mechanical force also percolated through to the eighteenth century by another, completely different, route: in Newton's concepts of inertia and of force.

I now invite you to accompany me on this expedition. As we proceed I will frequently draw attention to a variety of matters that are important to our objective. I have found outstanding guides for the expedition, although not for its objective, in

[6] Derived from 'ψύχω' ('psycho'): 'to blow'. Compare also with the Sanskrit 'prana', meaning not only 'breath' but also 'life' and 'soul'.

[7] See Philippe Ariès, *Centuries of Childhood* (1960), especially part 1; and Marc Kleijwegt, *Ancient Youth. The Ambiguity of Youth and the Absence of Adolescense in Greco-Roman Society* (1991).

the historians E.J. Dijksterhuis, R.S. Westfall and I.B. Cohen.[8] Their work places the history of the concept of force firmly within its intellectual context.

However, to ensure sufficiently discerning observation on our journey of discovery, I will first ask you to accompany me on an exploratory mission to examine the background of the relationship between 'quantity' and 'quality' in the seventeenth and eighteenth centuries. During this mission we shall also discuss the concept of 'measure', a discussion which some of you will certainly have been expecting to encounter.

2.2 QUANTITY AND QUALITY

2.2.1 The Distinction According to Aristotle

The heritage of Aristotle and the scholastics included the distinction between 'quantity' and 'quality'. In his *Metaphysics,* Aristotle defined these two as categories of being. For him, the quantitative (ποσόν) was that which can be divided up in such a way that each part can have independent existence according to its nature. For example, length is a quantity because every part of it is also a length. Within the category of quantity he further distinguished between 'size' and 'number' as the measurable and the countable, respectively.[9]

Unfortunately, where the category of quality (ποιόν) is concerned, he did not succeed in providing a clear definition, and had to limit his attempt to descriptions and examples. The term 'quality' indicates firstly the essential difference in substances, and secondly the definitions of the changeable as changeable and the differences in these changes.[10] "Quality is one of the factors that determine form: a difference in quality is a difference in essence, in condition or in motion (in the general Aristotelian sense)."[11] Therefore a man and a horse are qualitatively different because the first is bipedal and the second is a quadruped.[12] Examples of qualities indicating a condition are: good and bad; hot and cold; white and black. Heaviness and lightness, on the other hand, are examples of qualities pertaining to motion.[13]

An important difference between 'quantity' and 'quality' is the way in which one can speak here of 'more' and 'less'. The length of a piece of wood or the price of a

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[8] It goes without saying that this list is not complete. Jammer, Pierson, Whiteside and Kutschmann must certainly be included. However, the present chapter does not pretend to be comprehensive: it should be taken by the reader together with Chapter 3 as a preparation for the central chapters of this book. Moreover, later authors have not come significantly farther than the three cited above in relation to the interpretation of the relationship between force and substance.

[9] Aristotle, *Metaphysics,* 105-106 (book Δ (5), 1020a7-32).

[10] *Ibidem,* 106-107 (book Δ (5), 1020a33-1020b25).

[11] "De qualiteit is een der factoren, die den vorm bepalen: verschil in qualiteit is verschil in wezen, in toestand of in beweging (in algemeenen aristotelischen zin)" (Eduard Jan Dijksterhuis, *Val en worp; een bijdrage tot de geschiedenis der mechanica van Aristoteles tot Newton* (1924), 89).

[12] *Aristoteles, Metaphysics,* 106 (book Δ (5), 1020a).

[13] *Ibidem,* 107 (book Δ (5), 1020b).

loaf can be reduced, the number of employees can be increased. Quantities are thus comparable in terms of size or number. But what about differences in qualities: the whiteness of laundry, the heat of two ovens, the weight of two hammers? We can perceive the difference, but only as 'stronger' or 'weaker', not as 'larger' or 'smaller', although in some cases we can relate a qualitative difference to a quantitative one. We can get a better sense of why quantification was problematical if we consider the limits it has today. Within certain limits, quantification is generally accepted; outside these limits a few people may attempt it, but others fight against it all the more fiercely. Happiness and beauty, for example, are beyond the scope of quantification.[14] The value of the environment in prosperity is a quality that verges on the limit itself: it is still not clear whether modern economists will succeed in bringing it within the scope of quantification.[15] The quizzical looks that usually greet attempts to quantify such concepts now, were probably just as common in the fourteenth century for qualities such as velocity and heat.

Clearly, where the possibility and range of quantification are concerned, we cannot simply lump all qualities together. We could define a complete quantification (based on Aristotle's definition of quantity) as one in which the *parts* of the quantity bear the same relationship to the quality in question as the *whole* quantity. In those cases one can posit an absolute linear scale in which values can be added and subtracted without losing the relation to the original quality. Duration would then be a 'completely quantified' quality: a time scale can be divided into parts, each of which also represents a duration. The sum of two parts of the time scale is equal to the total of the corresponding durations. The success of this quantification explains why, in modern physics, the duration of time is identified with its quantification.[16]

One example of a less far-reaching quantification is Celcius' temperature scale. Heat and cold—or as we say now, 'temperature'—is converted into a linear scale by measuring the expansion of the volume of a material such as mercury. The freezing point and boiling point of water at a pressure of one atmosphere serve as the cali-

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[14] This does not alter the fact that history reveals many attempts to do so. An elegant example concerning the cocnept of happiness is provided by the chemist and philosopher Wilhelm Ostwald (see Hakfoort, "Science Deified: Wilhelm Ostwald's Energeticist World-View and the History of Scientism" (1992)). In the eighteenth century Moses Mendelssohn tried to adapt mathematics to ethics and esthetics (see Mendelssohn, *Abhandlung über die* Evidenz in metaphysischen Wissenschaften (1764)).

[15] See for example the method, developed under Hueting's guidance, for quantifying the value of the environment in national prosperity by means of an adjusted Gross National Income, the 'Sustainable National Income' (R. Hueting, P. Bosch and B. de Boer, *Methodology for the Calculation of Sustainable National Income*, Central Bureau for Statistics of the Netherlands (1991)).

[16] Despite this success, something important appears to be lost in the quantification of time: what a time scale represents is time as it appears in physics, and not as it is experienced in daily life. The French philosopher Henri Bergson and the Dutch philosopher Jan Hendrik van den Berg in particular have focused on this problem (for example, see Henri Bergson, *Essai sur les données immediates de la conscience* (1989) and Jan Hendrik van den Berg, *Metabletica van de materie I. Meetkundige beschouwingen* (1968)).

http://www.springer.com/978-1-4020-0233-5

What was Mechanical about Mechanics
The Concept of Force between Metaphysics and Mechanics from Newton to Lagrange
Boudri, J.C.
2002, XVI, 280 p., Hardcover
ISBN: 978-1-4020-0233-5