Force and its Measure

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Force: present and past

What is force?
When asked in such general terms, this question seems almost devoid of sense. Today, one often hears people talking about many different kinds of force having little or nothing in common with each other: the force of personality, electrical and gravitational forces, military force, the force of muscles and the spiritual force necessary to face life's difficulties. The notion of "force" does not constitute a subject worth of interdisciplinary discussions between philosophers, scientists, theologian and technologists.

However, it has not always been this way: in the eighteenth century and in the first half of the nineteenth century it was possible to debate the nature, measure and conservation of force in a general sense. There was *one* force (Latin "vis", French "force", German "Kraft", Italian "forza"). That notion of force was a philosophical one, in that it was expected to have universal validity, but it was at the same time possible to search for its material manifestations, and for its measure.

When studying those discussions, it is usually difficult - if not impossible - to distinguish between philosophical disputes on the existence of a cosmic, unifying principle behind the perceived variety of the world, and discussion about what we today would regard as experiments or as mathematical models. This often happens in studying pre-modern natural philosophy, but the case of force is particularly interesting, because this notion was for a long time a point of exchange, a "trading zone", in which philosophy, mathematics and experiment met.[1] In this very brief, episodic sketch of early modern notions of force, I will try to show how they could be defined by philosophical-theological statements, experiments, mathematical concepts and, finally, by measurement procedures. We shall also see how the ideas of "measure" and "conservation of force" changed in the course of time.

Leibniz's force: metaphysical conservation and its measure

Around the end of the seventeenth century, Gottfried Wilhelm Leibniz (1646-1716) was engaged in a discussion with philosophers of the Cartesian school of thought: it was a debate on how to find the *true measure* of the force of a moving body. What did they mean be *true measure*? What was *the* force of a moving body for them?
Leibniz and his opponents shared two premises: first, the force of a moving body was its capacity of becoming itself cause of motion; second, force could neither be created nor destroyed, but could only pass on from one body to another.

For the Cartesians, the force of a body was proportional to its mass (M) and its velocity (V): the measure of force was therefore the product of the two: MV, an expression which both they

[1] On "trading zones" in the history of science, see: P. Galison, *Image and Logic. A material culture of microphysics* (Chicago 1997) p. 803-844.

and Leibniz referred to as "quantity of motion", as is still done today in physics. As the Cartesians knew, in many mechanical processes quantity of motion is conserved and was therefore the true measure of force. Leibniz, however, disagreed with them: for him, the quantity of motion of a body was only a relative property, apt to change according to the observation point and therefore unreal. As such, even if it happened to be conserved, it could never be identical to the *real* force of a body. This difference had a deep metaphysical significance:

> Cette consideration de la force distinguée de la quantité de mouvement est assez importante non seulement en physique, [...] mais encor dans la metaphysique; [...] car le mouvement, si on n'y considere que ce qu'il comprend precisement et formellement, c'est à dire un changement de place, n'est pas une chose entierement reelle [...] Mais la force ou cause prochâine de ces changements est quelque chose de plus reelle, et il y a assez de fondement pour l'attribuer à un corps plus qu'à l'autre.[2]

Using results obtained by Galileo Galilei (1564-1642), Leibniz claimed that the *true measure* of force was the quantity MV^2, which is conserved when bodies fall, and which he called "live force" ("vis viva"). Since "live force" is proportional to today's kinetic energy ($\frac{1}{2}MV^2$), historians and scientists have looked at Leibniz as the discoverer of energy conservation. However, for him the conservation of "live force", which could actually be observed and measured, did not constitute an argument in favour of the conservation of the *real* force – otherwise, also the conservation of quantity of motion would have been relevant. The conservation of force could only be demonstrated on the basis of metaphysical considerations, and experiments could only establish in which perceivable and measurable form force manifested itself.

Newton's force: mathematics, physics and divine will

In his works, Isaac Newton (1642-1727) used the term "force" (lat. "vis") in many different ways, whose interpretations remains the subject of debates. In his "Philosophiae naturalis principia matemathica" (1687), where he introduce the notion of gravitational force, Newton underscored how this gravitational force was nothing but a "mathematical notion" and should in no way be confused with "true and physical" forces:

> Hasce virium quantitates, brevitatis gratia, nominare licet vires motrices, acceleratrices, et absolutas [...] Mathematicus duntaxat est hic conceptus: nam virium causas et sedes physicas jam non expendo. [...] Unde caveat lector, ne per hujusmodi voces cogitet me speciem vel modum actionis causamve, aut rationem physicam, alicubi definire.[3]

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[2] G. W. Leibniz, *Discours de métaphysique* (1686), in: G. W. Leibniz, *Kleine Schriften zur Metaphysik*, ed. H. H. Holz (1996) p. 108-110.

[3] "For brevity's sake it is allowed to call the quantities of force simply "moving forces", "accelerating forces" and "absolute forces" [...] This notwithstanding, these are nothing but mathematical notions, because I make no reference to the causes of the forces and to where these physically reside. [...] Therfore, the reader should refrain from thinking, on the basis of this terminology, that I would anywhere in my text define the form or the modo of action or the cause, or also their physical reason.", I. Newton, *Philosophiae naturalis principia mathematica*, in: *Opera omnia* Vol. 2, ed. S. Horsley (1779-1785) p. 5-6.

It is not at all clear what "real and physical forces" would be according to Newton and, in the course of his life, he expresses very different opinions on the subject. In his *Optics*, for example, he wrote:

> It seems to me farther, that these particles [= particles of matter] have not only a *Vis inertiae,* accompanied with such Passive laws of motion as naturally result from that force; but also that they are moved by certain Active principles, such as is that of gravity, and that which causes fermentation, and the cohesion of bodies. These principles I consider not as Occult qualities, supposed to result from the specifick forms of things, but as general laws of Nature, by which the things themselves are formed: their truth appearing to us by phaenomena, though their causes be not yet discovered. For these are manifest qualities, and their causes only are occult.[4]

Whatever Newton's ideas on the real forces of nature, or “active principles”, may have been, one thing is sure: he did not believe in the conservation of force, and was instead convinced that, without a constant intervention of active principle of an immaterial nature, all motion in the universe would eventually come to an end. These active principles were a direct expression of the divine will: only the constant intervention of god could guarantee the stability of the solar system.

This opinion was fiercely opposed by Leibniz, who maintained that force subsists eternally unchanged, and claimed that Newton was assuming god to be in a condition in which he had no choice but continually make miracles. For Leibniz, this was tantamount to doubting god's omnipotence:

> Selon mon sentiment, la même force et vigeur y [i.e. in the world] subsiste tousjours, et passe seulement de matiere en matiere, suivant les loix de la nature, e le bel ordre preétabili. Et je tiens, quand Dieu fait des miracles, que ce n'est pas pour soutenir les besoins de la nature, mais pour ceux de la grace. En juger autrement, ce seroit avoir une idée fort basse de la sagesse et de la puissance de Dieu.[5]

Early seventeenth century: metaphysics, astrology, mathematics and horses

In the first decades of the eighteenth century, mathematical, metaphysical and theological reflections on force and its measure were combined with the results of procedures aimed at empirically determining various quantities, all of them called "force". The English naturalist Stephen Hales (1677-1761) experimentally compared the force of the sap rising within plants with the force of blood circulation in animals:

> The force of the rising sap in the morning is plainly owing to the energy of the root and stem. [...] Which force is near five times greater than the force of the blood in the great crural artery of a Horse; seven times greater than the force of the blood in the like artery of a Dog; and eight times greater than the blood's force in the same artery of a fallow Doe.[6]

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[4] I. Newton, *Optics*, in: *Opera omnia* Vol. 4, ed. S. Horsley (1779-1785) p. 260-261.
[5] G. W. Leibniz and S. Clarke, *Streitschriften zwischen Leibniz und Clarke 1715, 1716,* in: G. W. Leibniz., *Philosophischen Schrifte* Vol. 7, ed. C. I. Gerhardt (1890) p. 352.
[6] S. Hales, *Vegetable Staticks* (1726-27), ed. M. A. Hoskin (1961) p. 60-61.

In the *Encyclopédie* (35. vols., 1751-1780) of Denis Diderot (1713-1784), various methods were discussed through which the force of animals could be quantified and compare with that of workers of different nationalities:

> Un cheval est égal en *force*, pour tirer, à cinq travailleurs anglois, suivant les observations de Jonas Moore; à six ou sept françois, suivant nos auteurs; ou à 7 hollandois, selon Desaguliers: mais pour porter une charge sur le dos, deux hommes sont aussi forts, et quelquefois plus qu'un cheval.[7]

At the same time, European philosopher were discussing whether to accept the newtonian idea of a force of attraction acting at a distance between the planets. Some claimed that this notion of force was a relapse into the obscure and barbaric concept of astral influence. On this subject, Georg Matthias Bose (1710-1761) composed a satiric rhyme directed against newtonian gravitation::

> Actio per distans dabitur? tunc impediesne
> Quo minus in distans stella Talisman agat?
> Gaude Melanchton, redeunt horoscopus, Haly,
> Almutec, Athacir, Alcecadenor, Hylec.[8]

In this context, the discussions on the nature of force, on its measure and on its conservation became increasingly complex, and, in the years 1739-40, David Hume (1711-1776) wrote:

> I begin with observing that the terms of *efficacy*, *agency*, *power*, *force*, *energy*, *necessity*, *connexion* and *productive quality*, are all nearly synonimous; and therefore 'tis an absurdity to employ any of them in defining the rest.[9]

In the same years, Voltaire summarized the problem of the conservation of force in these words:

> Un homme a une certaine quantité de force active, mais où était cette force avant sa naissance? Si on dit qu'elle était dans le germe de l'enfant, qu'est-ce qu'une force qu'on ne peut exercer? Mais quand il est devenu homme, n'est-il pas libre? Ne peut-il pas employer plus ou moins de sa force? Je suppose qu'il exerce une force de trois cents livres pour mouvoir une machine; je suppose comme il est possible qu'il a exercé cette force en baissant un levier, et que la machine attachée à ce levier est dans le récipient du vide; la machine peut acquerir aisément une force de deux mille livres. L'operation étant fait, le bras retiré, le levier ôté, le poids immobile, je demande si le peu de matière qui était dans le récipient, a reçu de la machine une force de deux mille livre, toutes ce considérations ne font-elles pas voire que la force active se répare et se perd continuellement dans la nature?[10]

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[7] From: *Force*, in: *Encyclopédie ou dictionnaire raisonné des sciences, des arts et des métiers, par une societé de gens de lettres* Vol. 7 (1757, Rist. 1966) p. 122.

[8] "Shall then action at a distance exist? Or will you deny/ that a star acts at a distance on a talisman?/ Rejoice, Melnchton: horoscopes are coming back, Haly,/ Almutex, Athacir, Alceadenor, Hylec.", G. M. Bose, Sympathiam attractioni... (1757), quoted by: E. Garin, *Lo Zodiaco della vita. La polemica sull'astrologia dal Trecento al Cinquecento* (Roma-Bari 1976) p. 8.

[9] D. Hume, *A treatise on human nature,* in: D. Hume, *The philosophical works* Vol. 1, ed. T. H. Green et al. (1886, Rist. 1964) p. 451.

[10] Voltaire, *Éléments de la philosophie de Newton*, ed. R. L. Walters et al. (1992) p. 247-248.

Sceptical Enlightenment: can we know the real force?

In the following yeas, discussions in Europe about the conservation and the *true measure* of force became increasingly rare. At the same time, though, natural philosophers became attracted to the notion that, beside gravity, other phenomena, too, might be better understood with the help of mathematical forces.

This point of view assumed a very specific form in the case of Georges-Louis Leclerc Buffon (1707-1788), who claimed that a link of essential nature existed between a force and its mathematical expression. An elementary force of nature could only have a simple mathematical form, which was its measure:

> De quelque façon que nous puissions donc supposer qu'une qualité physique puisse varier, comme cette qualité est une, sa variation sera simple et toujours exprimable par un seul terme, qui en sera la mesure; et dès qu'on voudra employer deux termes, on détruira l'unité de la qualité physique, parce que ces deux termes représenteront deux variations différentes dans la même qualité, c'est-à-dire deux qualités au lieu d'une. Deux termes sont en effet deux mesures, toutes deux variables et inégalement variables; et dès-lors elles ne peuvent être appliquées à un sujet simple, à une seule qualité; et si on admet deux termes pour représenter l'effet de la force centrale d'un astre, il est nécessaire d'avouer qu'au lieu d'une force il y en a deux, dont l'une sera relative au premiere terme, et l'autre relative au seconde terme.[11]

However, force could not be known beyond its mathematical expression and its perceivable effect:

> L'on ne connait les forces qui animent l'univers, que par le mouvement et par ses effets: ce mot même de *forces* ne signifie rien de matériel, e n'indique rien de ce qui peut affecter nos organes, qui cependent sont nos seuls moyen de communication avec la nature.[12]

Buffon's statement reflected a certain tendency to scepticism which had become quite diffuse in Europe around the middle of the eighteenth century, and which had led many philosophers to doubt that it would ever be possible to know the *true forces* of nature. A few years later, the German physiologist Johann Friedrich Blumenbach (1752-1840) published a work on the "building impulse" of organic bodies. This impulse was the force determining reproduction and growth. In the passage in which he described the "building impulse" as a force, however, Blumenbach thought it important caution his readers:

> Hoffentlich ist für die mehrsten Leser die Erinnerung sehr überflüßig, daß das Wort Bildungstrieb so gut, wie die Worte Attraction, Schwere etc. zu nichts mehr und nichts weniger dienen soll, als eine Kraft zu bezeichnen, deren Constante Wirkung aus der Erfahrung anerkannt worden, deren Ursache aber so gut wie die Ursache der genannten, noch so allgemein anerkannten Naturkräfte, für uns

[11] G.-L. Leclerc comte de Buffon, *Histoire naturelle, générale et particuliére* Vol. 1, in: *Oeuvres completes de Buffon*, ed. A. Comte (1839) p. 206.

[12] Buffon, *Histoire* vol. 3 p. 76.

> qualitas occulta ist. Es gilt von allen diesen Kräften was Ovid sagt: causa latet, vis est notissima.[13]

The mathematical force: attraction and repulsion

Around the end of the century, however, the faith in mathematical analysis of motion as a new path to the knowledge of the forces of nature increased. Whereas, a few years earlier, philosophers doubted that Newton's mathematical expression of the gravitational force could correspond to any phyisical reality, now all forces of nature came to be thought of as central forces of attractive or repulsive character, with a mathematical expression similar to that of Newton's gravitation. These were not only "mathematical forces", as Newton had cautioned, but also the real, physical ones. A factor which certainly contributed to spread this view was the discovery and investigation of phenomena of electrical attraction and repulsion.

The British theologian and experimental natural philosopher Joseph Priestley (1733-1804) defined matter as characterized by attractive and repulsive powers:

> I define it [d. h.: die Materie] to be a substance possessed of the property of extension, and of powers of attraction and repulsion. [...] Matter is not impenetrable [...] but [...] consists of physical points only, endued with powers of attraction and repulsion, taking place at different distances, that is, surrounded with various spheres of attraction and repulsion; [...] Provided, therefore, that any body move with a sufficient degree of velocity, or have sufficient momentum to overcome any powers of repulsion that it may meet with, it will find no difficulty in making its way through any body whatever.[14]

Attractive and repulsive forces were at the basis of all material phenomena also according to Immanuel Kant (1724-1804) who, in his "Metaphysischen Anfangsgründe der Naturwissenschaft" (1786) wrote:

> Erklärung 2
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> Anziehungskraft ist diejenige bewegende Kraft, wodurch eine Materie die Ursache der Annäherung anderer zu ihr sein kann (oder, welches einerlei ist, dadurch sie der Entfernung anderer von ihr widersteht).
> Zurückstoßungskraft ist diejenige, wodurch eine Materie Ursache sein kann, andere von sich zu entfernen (oder, welches einerlei ist, wodurch sie der Annäherung anderer zu ihr widersteht). Die letztere werden wir auch zuweilen treibende, so wie die erstere ziehende Kräfte nennen.
>
> Zusatz
>
> Es lassen sich nur diese zwei bewegenden Kräfte der Materie denken. Denn alle Bewegung, die eine Materie einer anderen eindrücken kann, da in dieser Rücksicht jede derselben nur wie ein Punkt betrachtet wird, muß jederzeit als in der geraden Linie zwischen zweien Punkten erteilt angesehen werden. In dieser geraden Linie aber sind nur zweierlei Bewegungen möglich: die eine, dadurch sich jene Punkte von einander entfernen, die zweite, dadurch sie sich einander nähern. Die Kraft aber, die die Ursache der ersteren Bewegung ist, heißt Zurückstoßungs- und die der zweiten Anziehungskraft.

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[13] J. F. Blumenbach, *Über den Bildungstrieb* (1789) p. 25-26.
[14] J. Priestley, *Disquisitions relating to matter and spirit* (London, 1777, repr. 1976) p. XXXVIII and p. 19.

> Also können nur diese zwei Arten von Kräften, als solche, worauf alle Bewegungskräfte in der materiellen Natur zurückgeführt werden müssen, gedacht werden.[15]

For Kant, the mathematical form of Newton's gravitational theory was the model for all forces which could be rationally conceived. We would certainly disagree with this view, but we must note the powerful effect that the mathematical notion of attractive and repulsive force had had on the philosopher.

Pierre Simon Laplace (1749-1827), who was the undisputed leader of natural philosophy in Napoleonic France, based all research in his school on the assumption that all phenomena in nature could be explained and described in terms of attractive and repulsive forces having a mathematical form analogous to that of newtonian gravitation.[16] In his "Exposition du système du monde" (1796), Laplace wrote:

> L'attraction disparaît entre le corps d'une grandeur peu considérable: elle reparaît dans leurs élémens sous une infinité de formes. La solidité, la cristallisation, la réfraction de la lumière, l'élévation e l'abaissement des liquides dans les espaces capillaires, et généralement toutes les combinaisons chimiques sont le résultat de forces dont la connaissance est un des principaux objects de l'étude de la nature. Ainsi la matière est soumise à l'empire de diverses forces attractives: l'une d'elles s'étendant indéfiniment dans l'espace, régit les mouvemens de la terre et des corps célestes: tout ce qui tient à la constitution intime de substances qui les composent, dépend principalement des autres forces dont l'action n'est sensible qu'à des distances imperceptibles.[17]

However, the Lapalcian dream of explaining nature only in terms of central forces failed and, by the first decades of the nineteenth century, natural philosopher had abandoned the Laplacian approach, and felt free to use any mathematical models they might find appropriate, usually without attaching to them any particular epistemological significance.

Force and measure, again: the conservation of energy

Even though the idea of force had come to be closely associated with a very specific mathematical notion, there were still many authors who were not ready to accept the quantification and mathematisation of such a fundamental philosophical concept. One of them was Friedrich Wilhelm Joseph Schelling (1775-1854), whose works would be a source for the current of thought now known as "Naturphilosophie". The theme of the cosmic unity of forces was at the centre Schelling's early work, and later of "Naturphilosophie".

The young Schelling criticized the tendency of his time to undervalue or even forget the philosophical problems linked to the study of nature, and in particular to the definition of fundamental concepts such as "force":

> So wird mit dem Begriff von Kraft jetzt häufiger als je in der Physik gespielt, besonders seitdem man an der Materialität des Lichts u. s. w. zu zweifeln anfieng; hat man doch schon einigemale gefragt: Ob nicht die Elektricität vielleicht die *Lebenskraft* seyn möchte? Alle diese vage, in die Physik widerrechtlich

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[15] I. Kant, *Metaphysische Anfangsgründe der Naturwissenschaft* (1786), ed. K. Pollok (Hamburg 1997) A 34-35.
[16] R. Fox, Laplacian physics, in: R. C. Olby et al.(ed.), *Companion to the history of modern science* (London. 1990) p. 378-394
[17] P. S. Laplace, *Exposition du système du monde* (Paris 1835, Nachdr. 1984) p. 403.

> eingeführten Begriffe, mußte ich, da sie nur philosphisch zu berichtigen sind, im ersten Theil dieser Schrift in ihrer Unbestimmtheit lassen.[18]

Main feature of young Schelling's philosophy of nature was the principle of dynamical equilibrium between equal and opposite forces. Forces in dynamical equilibrium constantly interacted with each other, originating not only all material transformations, but also the conscience which humans have of such transformations:

> Nur einer freyen Thätigkeit in mir gegenüber nimmt, was frey auf mich wirkt, die Eigenschaften der Wirklichkeit an; nur an der ursprünglichen Kraft meines *Ich* bricht sich die Kraft einer Außenwelt. Aber umgekehrt auch, (so wie der Lichtstrahl nur an Körpern zur Farbe wird) wird die ursprüngliche Thätigkeit in mir erst am Objekte zum *Denken*, zum selbstbewußten *Vorstellen*. [...] Die Grundkräfte der Materie sind also nichts weiter, als der Ausdruck jener ursprünglichen Thätigkeiten *für den Verstand*, und so wird es uns leicht werden, sie vollends ganz zu *bestimmen*.[19]

The historian and philosopher of science Thomas S. Kuhn (1922-1996) published in 1969 an much discussed article on "Energy conservation as an example of simultaneous discovery"[20]. The subject of energy conservation is very relevant for us, because the term “energy” only became common after its conservation was discovered: the historical actors involved in the investigation instead spoke of the conservation of force.

Kuhn claimed that the discovery of energy conservation, which was made at the same time by a number of researchers during the first half of the nineteenth century, was the result of the combination of three factors: first, the discovery of processes of interconversion of mechanical work, electromotive power and heat; second, the interest in steam engines an in electric ones, which was due to the Industrial Revolution; third, the diffusion of ideas linked to "Naturphilosophie”. Once again, the notion of force was the meeting point – or the “trading zone” - between philosophy, science and technology.

In this context, a new measure of conserved force was born, obtained by transforming heat, electricity and chemical potential into mechanical work, and then measuring the latter by using it to raise a certain weight to a certain height. This time, however, the conserved force was not anymore defined on the grounds of the metaphysical principles of a specific philosophical system, as had been the case with Leibniz and the Cartesians: now, the measured force was defined by, and thus in practice identified with, its measurable effect:

> Eine Ursache, welche die Hebung einer Last bewirkt, ist eine Kraft; ihre Wirkung, die gehobene Last, ist also ebenfalls eine Kraft; allgemeiner ausgedrückt heisst dies: räumliche Differenz ponderabler Objekte ist eine Kraft.[21]

These words are taken from the article by Julius Robert Mayer (1814-1878) titled "Bemerkungen über die Kräfte der unbelebten Natur", which is considered one of the earliest essays to expound the idea of the conservation of energy. In this text, the notion of force

[18] F. W. J. Schelling, *Ideen zu einer Philosophie der Natur* (1797), ed. M. Durner, in: F. W. J. Schelling, *Historisch-kritische Ausgabe*, Vol. 1,5 (1994) p. 62-63.
[19] Schelling, *Ideen* p. 211 e 218.
[20] T. S. Kuhn, Energy conservation as an example of simultaneous discovery, in: M. Clagett (Ed.), *Critical problems in the history of science* (Madison 1969) p. 321-356.
[21] R. Mayer, *Bemerkungen über die Kräfte der unbelebten Natur* (1842) p. 234.

constitutes the point in which theoretical philosophy, experimental research and technical knowledge touch, superpose and mix with each other in a productive symbiosis. The same can be said for the works of other authors who are candidate to the title of "discoverer" of the law of energy conservation, as for example Hermann von Helmholtz (1821-1894), Michael Faraday (1791-1867) e James Prescott Joule (1818-1889). The latter wrote on the conservation of "live force":

> Thus, when a weight falls to the ground, it has been generally supposed that its living force is absolutely annihilated, and that the labour which may have been expended in raising it to the elevation from which it fell has been entirely thrown away and wasted, without the production of any permanent effect whatever. We may reason, a priori, that such absolute destruction of living force cannot possibly take place, because it is manifestly absurd to suppose that the powers with which God has endowed matter can be destroyed any more than that they can be created by man's agency; but we are not left with this argument alone, decisive as it must be to every unprejudiced mind. The common experience of every one teaches him that living force is not destroyed by the friction or collision of bodies. We have reason to believe that the manifestations of living force on our globe are, at present time, as extensive as those which have existed at any time since its creation, or, at any rate, since the deluge.[22]

The thoughts of Joule and Leibniz may appear similar, but they are very different: while Leibniz assumed the conservation of force and sought its measure in an empirically conserved quantity, Joule used the existence of such an empirically conserved measure as an argument in favour of the conservation of force.
However, for Joule as for Leibniz, the conservation of force was more than a simple regularity which could be empirically observed: it was a reality which could be reconnected to theological-metaphysical principles. According to Joule, the conservation of force derived from divine providence and omnipotence, but this argument, "decisive" as it was "to every unprejudiced mind" could and should be corroborated by experimental evidence. The *conserved force* thus tended to become indistinguishable from the *measurable force*.

Epilogue: what remains of a glorious past?

During the second half of the nineteenth century, the new scientific notion of a *conserved and measurable force* became associated with the term "energy". Thus, energy became the new force, which was and still is discussed between scientists, philosopher and technologists - but this is another story.

The term "force" continued being used in scientific fields almost only within the context of mathematical models (mechanical force, force of gravity, electromagnetic force field). At the same time, authors like Arthur Schopenhauer (1788-1860) used the term "force" to indicate non-measurable (an therefore non-scientific) notions, such as will:

> Bisher subsumierte man den Begriff *Wille* unter den Begriff *Kraft*; dagegen mache ich es gerade umgekehrt und will jede Kraft in der Natur als Wille gedacht wissen, [...] so haben wir in der That ein Unbekannteres auf ein unendlich

[22] J. P. Joule, *On matter, living force and heat* (1847), in: *The scientific papers of J. P. Joule*, Vol. 1 (London 1884) p. 265-276.

> Bekannteres, ja, auf das einzige uns wirklich unmittelbar und ganz und gar Bekannte zürückgeführt und unsere Erkenntniß um ein sehr großes erweitert.[23]

However, "force" never again regained its role as a point of exchange between philosophy, science and technology, and today we see a clear gap between measurable forces and non-measurable ones.

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[23] A. Schopenhauer, *Die welt als Wille und Vorstellung*, Vol. I (3a ed. Lipsia 1859) p. 165-166.