THE HISTORY AND THE ROOT OF THE PRINCIPLE OF THE CONSERVATION OF ENERGY

I

INTRODUCTION

HE who calls to mind the time when he obtained his first view of the world from his mother's teaching will surely remember how upside-down and strange things then appeared to him. For instance, I recollect the fact that I found great difficulties in two phenomena especially. In the first place, I did not understand how people could like letting themselves be ruled by a king even for a minute. The second difficulty was that which Lessing so deliciously put into an epigram, which may be roughly rendered:

"One thing I've often thought is queer,"
Said Jack to Ted, "the which is
"That wealthy folk upon our sphere,
"Alone possess the riches."*

The many fruitless attempts of my mother to help me over these two problems must have led her to form a very poor opinion of my intelligence.

Everybody will remember similar experiences in his own youth. There are two ways of reconciling oneself with actuality: either one grows accustomed to the puzzles and they trouble one no more, or one learns to

*"Es ist doch sonderbar bestellt,"
Sprach Hänschen Schlau zu Vetter Fritzen,
"Dass nur die Reichen in der Welt
"Das meiste Geld besitzen."

understand them by the help of history and to consider them calmly from that point of view.

Quite analogous difficulties lie in wait for us when we go to school and take up more advanced studies, when propositions which have often cost several thousand years' labour of thought are represented to us as self-evident. Here too there is only one way to enlightenment: historical studies.

The following considerations, which, if I except my reading of Kant and Herbart, have arisen quite independently of the influence of others, are based upon some historical studies. The reason why, in discussion of these thoughts with able colleagues of mine, I could not, as a rule, come to agreement, and why my colleagues always tended to seek the ground of such "strange" views in some confusion of mine, was, without doubt, that historical studies are not so generally cultivated as they should be.[1]

However this may be, these thoughts, which, as the notes and quotations from my earlier writings show, are not of very recent date, but which I have held since the year 1862, were not suited for discussion with my colleagues—I, at least, soon tired of such discussions. With the exception of some short notices written on the occasion of other works and in journals little read by physicists, but which may suffice to prove my independence, I have published nothing about these thoughts.

[1] In fact, I have known only one man, Josef Popper, with whom I could discuss the views exposed here without rousing a horrified opposition. Popper and I, indeed, arrived at similar views on many points of physics independently of one another, which fact I take pleasure in mentioning here.

But now, since some renowned investigators have begun to set foot in this province, perhaps I, too, may bring my small contribution to the classification of the questions with which we are concerned. I must protest at once against this investigation being considered a metaphysical one. We are accustomed to call concepts metaphysical, if we have forgotten how we reached them. One can never lose one's footing, or come into collision with facts, if one always keeps in view the path by which one has come. This pamphlet merely contains straightforward reflections on some facts belonging both to natural science and to history.

Perhaps the following lines will also show the value of the historical method in teaching. Indeed, if from history one learned nothing else than the variability of views, it would be invaluable. Of science, more than anything else, Heraclitus's words are true: "One cannot go up the same stream twice." Attempts to fix the fair moment by means of textbooks have always failed. Let us, then, early get used to the fact that science is unfinished, variable.

Whoever knows only one view or one form of a view does not believe that another has ever stood in its place, or that another will ever succeed it; he neither doubts nor tests. If we extol, as we often do, the value of what is called a classical education, we can hardly maintain seriously that this results from an eight-years' discipline of declining and conjugating. We believe, rather, that it can do us no harm to know the point of view of another eminent nation, so that we can, on occasion, put ourselves in a different position from that in which we have been brought up. The essence of classical education is historical education.

But if this is correct, we have a much too narrow idea of classical education. Not the Greeks alone concern us, but all the cultured people of the past. Indeed there is, for the investigator of nature, a special classical education which consists in the knowledge of the historical development of his science.

Let us not let go the guiding hand of history. History has made all; history can alter all. Let us expect from history all, but first and foremost, and I hope this of my historical investigation, that it may not be too tedious.

II

ON THE HISTORY OF THE THEOREM OF THE CONSERVATION OF WORK

THE place given to the law of the conservation of energy in modern science is such a prominent one that the question as to its validity, which I will try to answer, obtrudes itself, as it were, of itself. I have allowed myself, in the headline, to call the law that of the conservation of work, because it appeared to me to be a name which is understood by all and prevents wrong ideas. Let us call to mind the considerations, laden with misunderstandings, of the great Faraday on the "law of the conservation of force," and a well-known controversy which was not much poorer in obscurities. One should say "law of the conservation of force" only when one, with J. R. Mayer, calls "force" what Euler called "*effort*" and Poncelet "*travail*." Of course, one cannot find fault with Mayer, who did not get his concepts from the schools, for using his own peculiar names.

Usually the theorem of the conservation of work is expressed in two forms:

1. $\frac{1}{2}\Sigma mv^2 - \frac{1}{2}\Sigma mv_0{}^2 = \int \Sigma(Xdx + Ydy + Zdz)$; or

2. It is impossible to create work out of nothing, or to construct a *perpetuum mobile*.

This theorem is usually considered as the flower of the mechanical view of the world, as the highest and most general theorem of natural science, to which the thought of many centuries has led.

I will now try to show:

Firstly, that this theorem, in the second form, is by no means so new as one tends to believe; that, indeed, almost all eminent investigators had a more or less confused idea of it, and since the time of Stevinus and Galileo, it has served as the foundation of the most important extensions of the physical sciences.

Secondly, that this theorem by no means stands and falls with the mechanical view of the world, but that its logical root is incomparably deeper in our mind than that view.

In the first place, as for the first part of my assertion, the proof must be drawn from original sources. Although, now, Lagrange, in his celebrated historical introductions to the sections of the *Mécanique analytique*,[1] repeatedly refers to the development of our theorem, one soon finds, if one takes the trouble to consult the originals themselves, that in his exposition this theorem does not play the part which it played in fact.

Although, now, the following facts, with the exception of a few, coincide with those mentioned by Lagrange, we derive from the important passages, given *in extenso*, another view than that which is found in Lagrange's work.

[1] [The first edition of this work was published at Paris in 1788 (1 vol.) under the title *Méchanique analitique*, the second at Paris, 1811–1813 (2 vols.), the third (ed. J. Bertrand), 1853, and the fourth (*Œuvres*, XI, XII, ed. G. Darboux), 1892.]

Let me emphasize only some points:

Simon Stevinus, in his work *Hypomnemata mathematica*, Tom. IV, *De statica*, of 1605,[2] treats of the equilibrium of bodies on inclined planes.

Over a triangular prism *A B C*, one side of which, *A C*, is horizontal, an endless cord or chain is slung, to which at equal distances apart fourteen balls of equal weight are attached, as represented in cross-section in Fig. 1. Since we can imagine the lower symmetrical part of the cord *A B C* taken away, Stevinus concludes that the four balls on *A B* hold in equilibrium the two balls on *B C*. For if the equilibrium were for a moment disturbed, it could never subsist: the cord would keep moving round forever in the same direction—we should have a perpetual motion. He says:

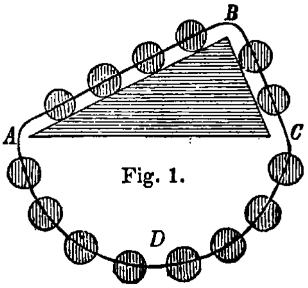


Fig. 1.

> But if this took place, our row or ring of balls would come once more into their original position, and from the same cause the eight globes to the left would again be heavier than the six to the right, and therefore those eight would sink a second time and these six rise, and all the globes would keep up, of themselves, *a continuous and unending motion, which is false.*[3]

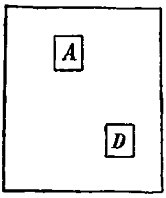
[2] Leiden, 1605, p. 34. [According to Moritz Cantor (*Vorlesungen über Geschichte der Mathematik*, II, 2. Aufl., Leipzig, 1900, p. 572), this work was first published in 1586, and a Latin translation, by Snellius, appeared in 1608. Cf. also Cantor, *ibid.*, pp. 576–577.]

[3] "Atqui hoc si sit, globorum series sive corona eundem situm cum priore habebit, eademque de causa octo globi sinistri pondero-

Stevinus, now, easily derives from this principle the laws of equilibrium on the inclined plane and numerous other fruitful consequences.

In the chapter "Hydrostatics" of the same work, p. 114, Stevinus sets up the following principle: "Aquam datam, datum sibi intra aquam locum servare"—a given mass of water preserves within water its given place. This principle is demonstrated as follows (see Fig. 2):

Fig. 2.



For, assuming it to be possible by natural means, let us suppose that *A* does not preserve the place assigned to it, but sinks down to D. This being posited, the water which succeeds *A* will, for the same reason, also flow down to *D; A* will be forced out of its place in *D;* and thus this body of water, for the conditions in it are everywhere the same, *will set up a perpetual motion, which is absurd.*[4]

From this all the principles of hydrostatics are deduced. On this occasion Stevinus also first develops the thought so fruitful for modern analytical mechanics that the equilibrium of a system is not destroyed by the addition of rigid connexions. As we know, the principle of the conservation of the centre of gravity is now sometimes deduced from d'Alembert's principle

siores erunt sex dextris, ideoque rursus octo illi descendent, sex illi ascendent, istique globi ex sese *continuum et aeternum motum efficient, quod est falsum.*"

[4] "A igitur (si ullo modo per naturam fieri possit), locum sibi tributum non servato, ac delabatur in *D;* quibus positis aqua quae ipsi *A* succedit eandem ob causam deffluet in *D*, eademque ab alia istinc expelletur, atque adeo aqua haec (cum ubique eadem ratio sit) *motum instituet perpetuum, quod absurdum fuerit.*"