Studies in History and Philosophy of Science 51 (2015) 1–10

Contents lists available at ScienceDirect

Studies in History and Philosophy of Science

journal homepage: www.elsevier.com/locate/shpsa

Qualitative novelty in seventeenth-century science: Hydrostatics from Stevin to Pascal

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ARTICLE INFO

Article history:
Received 25 August 2014
Received in revised form
18 December 2014
Available online 3 February 2015

Keywords:
Hydrostatics;
Pressure;
Simon Stevin;
Blaise Pascal;
Experiment;
Mechanism

ABSTRACT

Two works on hydrostatics, by Simon Stevin in 1586 and by Blaise Pascal in 1654, are analysed and compared. The contrast between the two serves to highlight aspects of the qualitative novelty involved in changes within science in the first half of the seventeenth century. Stevin attempted to derive his theory from unproblematic postulates drawn from common sense but failed to achieve his goal insofar as he needed to incorporate assumptions involved in his engineering practice but not sanctioned by his postulates. Pascal's theory went beyond common sense by introducing a novel concept, pressure. Theoretical reflection on novel experiments was involved in the construction of the new concept and experiment also provided important evidence for the theory that deployed it. The new experimental reasoning was qualitatively different from the Euclidean style of reasoning adopted by Stevin. The fact that a conceptualization of a technical sense of pressure adequate for hydrostatics was far from obvious is evident from the work of those, such as Galileo and Descartes, who did not make significant moves in that direction.

1. Introduction

In this paper I aim to shed light on the nature of the changes that took place in science in the first half of the seventeenth century by looking at the move beyond the science of weight to include hydrostatics. In particular, I compare two texts on hydrostatics composed sixty eight years apart, *The Elements of Hydrostatics*, written by Simon Stevin in 1586 and *The Equilibrium of Liquids*, the first of two treatises written by Blaise Pascal in 1654 and published posthumously in 1663, the second one being concerned with pneumatics rather than hydrostatics.[1]

Some immediately apparent features of the two texts signal the need for a discerning reading of the situation. Stevin's text is somewhat alien to a reader trained in physics, appearing as one more akin to Euclidean geometry than empirical science. By contrast, Pascal's text would not be out of place in a modern course on undergraduate physics. However, it is also the case that most of the consequences of Pascal's hydrostatics can be seen as consequences of Stevin's version or some modest extension of it. It may be tempting to take Pascal's rhetoric at face value and see the emphasis on experimental support as the novel feature of his approach. There are two prima facie difficulties to be confronted here. Firstly, many of the experiments described by Pascal are modifications of situations described by Stevin. Secondly, it is very likely that Pascal did not in fact perform many of the experiments described in his text. Such conundrums help set the scene for my exploration of the case.

I end this introduction by foreshadowing the conclusions I will reach. Stevin interpreted geometry and the science of weight as a body of theorems deduced from unproblematic postulates. To extend this approach to hydrostatics Stevin needed postulates that, on the one hand, had sufficient content to yield theorems constituting the new science and, on the other hand, were sufficiently unproblematic to be granted at the outset. Because significant hydrostatic phenomena transcended and posed problems for the common sense knowledge of the time, Stevin was unable to satisfy this demand. Stevin's presentation of his hydrostatics in Euclidean

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http://dx.doi.org/10.1016/j.shpsa.2015.01.001
0039-3681/

guise masked the extent to which he introduced hydrostatic knowledge into his theory that went beyond what was licensed by his postulates. Stevin did not succeed in achieving a theoretical grasp of the difference between liquids and solids that would make possible a science of hydrostatics that went beyond the science of weight. In their dealings with hydrostatics, Galileo, Beeckman and Descartes met with no more success than Stevin in solving this problem. It was not until Pascal that the move was made to a distinction between solids and liquids via the addition of the concept of pressure to the concept of weight. Because the new concept moved beyond common sense, it became necessary to recognise that the case for the new hydrostatics was essentially empirical or experimental rather than relying on proofs from pregiven, unproblematic postulates, Euclidean style.

2. The background to Stevin's hydrostatics

There is a notion of mechanism that is as old as civilisation itself. Levers, slings and tow ropes are mechanisms in the sense I have in mind. By Stevin's time clocks were familiar enough to serve as archetypal mechanisms. Characteristic of such mechanisms is the way in which a cause brings about its effect by way of the pushes and pulls acting between neighbouring parts of the system that links them. In the following I refer to such mechanisms as clockwork mechanisms and to explanations that invoke them as clockwork explanations. Clockwork explanations are intelligible in a common sense and are useful. They facilitate purposeful manipulation of the material world.

Clockwork mechanisms were theorised in what I will refer to as the science of weight. That science, having origins in Pseudo-Aristotle and Archimedes, encompassed balances, levers, pulleys and the like and had been developed with sophistication and in detail by the end of the sixteenth century. Not only did this 'science' provide truths that could be taken for granted, such as the law of the lever, but it also served as a model of a theorised, mathematized body of knowledge.

Archimedes had moved a little beyond the science of weight to formulate the beginnings of hydrostatics in his work on floating bodies. A solid immersed in a liquid experiences an upthrust equal to the weight of a mass of the liquid equal in volume to that of the immersed solid. As we shall see, Stevin was able, not only to take advantage of the substance of Archimedes work on floating bodies, but also to adopt its Euclidean style.

A scholar aiming to develop a science of hydrostatics in the late sixteenth century did not need to invent a distinction between solids and liquids any more than Archimedes discovered the phenomenon of floating. Like a working knowledge of weight, a grasp of the distinction between liquids and solids was incorporated into everyday life and into technologies long before precise and mathematized versions of such notions were fashioned. Liquids flow whereas solids do not. As a result, solids sink or float in liquids, but not in other solids. If water is transmitted from a lake at high altitude via a pipe then it is as liable to leak from the top as the bottom of the pipe, and the flow will not be halted if the pipe needs to rise over a subsidiary hill whose maximum height lies beneath the lake. Neither of these qualitative facts is true in the case of pipes transferring sand or gravel from a high to a low altitude, and sand or gravel ejected from such pipes will form a pile in a way that liquids will not. If a perforated bladder filled with water is squeezed, the water is ejected in all directions, and not only in the direction of the squeeze. Water finds its own level.

Some common hydrostatic phenomena could be seen as problematic, as indeed they are if one's thinking is confined to weight. Two columns of liquid with different diameters and in communication via their base will rest in equilibrium with their heights level, raising the puzzle of how the lighter amount of liquid in the narrower tube can support the heavier amount in the other.[2]

I complete these introductory remarks on the background to the formalization of hydrostatics with some reflections on use of the term 'pressure'. The term had a wide range of uses long before the modern technical sense of it was fashioned in the seventeenth century. The Latin terms *pressio/pressionem* stemming from the verb *premo*, to press, were used in a variety of senses that overlap with everyday usage of 'pressure' in the seventeenth century and in modern times. The most common usage involved the forces resulting from weights bearing down on surfaces but extended more widely to include the results of various kinds of pressing, such as that used to mould clay or to force contents into a container. Insofar as the common sense of the term pressure was linked to pressing, it suggested a directed force, whereas pressure in the technical sense is undirected. It is a scalar not a vector. Our analysis must clearly probe deeper than the mere identification of usage of the term. As a matter of fact, the noun 'pressure' is not used either by Stevin (*druck)* or by Pascal (*la pression*) in their respective treatises on hydrostatics although they do talk freely about pressing. The English translations of the two treatises both freely employ the term 'pressure' and so raise the danger of reading more into the texts than is warranted.

3. Simon Stevin and *The Art of Weighing*

Stevin was one of that new breed of mathematically trained engineers who made contributions to knowledge construction outside of a university context. He was actively involved in the renewed interest in mathematics fed by the increased availability of Ancient sources, especially the works of Archimedes, and was actively involved in responses to the practical demands of a rapidly changing society. Soon after matriculating at the University of Leyden in 1583 he was publishing original works in arithmetic and geometry whilst making his way as an engineer. During the 1580s he had been granted patents for various devices, a number of them connected with drainage and dredging, and formed a business partnership with his friend Johan Cornets de Groot in order to put his inventions to practical use. In the early 1590s he entered the service of Prince Maurice of Nasssau, acting as his tutor and also advisor on various practical matters. Most of Stevin's publications after his association with Prince Maurice were written in the form of textbooks for the edification of his patron and student. They covered a range of areas including astronomy, navigation, military science, architecture, music and optics. These later works involved an opportunistic and far from uniform combination of empirical and mathematical considerations which contrasts with the strict mathematical character of his earlier works. The two books by Stevin which are relevant for the concerns of this paper, *The Art of Weighing* and *The Elements of Hydrostatics*, were presented as mathematical works in the style of Euclid and Archimedes. They were published in 1586, more than half a decade before Stevin's professional association with Prince Maurice began.

The *Art of Weighing* is presented as a body of theorems derived from postulates. The latter include idealizations, such as the assumptions that the arms of a balance are inflexible and that verticals are parallel, and also assumptions with empirical content, such as the postulate that equal weights hung from equal balance arms will be in equilibrium. The subsequent theory, outlined in Book 1 of the work, extends treatment of vertically acting weights to non-vertical actions mediated by inclined planes and pulleys. Book 2 is concerned with the calculation of centres of gravity of a range of plane and solid figures. The mathematical techniques employed include splitting the action of a weight into its components, adding weights using the parallelogram of forces, and locating centres of