ALAN F. CHALMERS, *One Hundred Years of Pressure: Hydrostatics from Stevin to Newton*. Dordrecht: Springer, 2017, ix + 197 pp. $99.99; £72.00. ISBN 978-3-319-56528-6 (*Archimedes: New Studies in the History and Philosophy of Science and Technology,* vol. 51, ISBN 1385-0180)

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Readers of Alan Chalmers's widely reprinted, revised and translated textbook *What is this thing called Science?* know that he is a virtuoso of both history of science and philosophy of science, who also brings into play a professional training in physics. With *One Hundred Years of Pressure* he has given us his scholarly masterpiece. It is a work whose somewhat arcane topic and odd title belie what is arguably one of the most important pieces of technical history of science written about the Scientific Revolution so far this century. These days it is hard to imagine such a work being widely read, let alone written, in the remaining great HPS programmes. But that, for me, will now be the touchstone of evaluation: *"Are your students reading Chalmers on hydrostatics in the Scientific Revolution? If not, why not?"* Chalmers's work on mechanism and atomism as hindrances to the advance of chemistry in the early modern period is well known and has been controversial, although I have always tended to agree with him. Here, in the case of hydrostatics, Chalmers has done something similar and again I think he is correct, although there are questions to be raised about what he thinks this means for the larger picture of the Scientific Revolution.

During the Scientific Revolution there emerged new, recognizably modern versions of some older disciplines such as astronomy, mechanics and optics. These had existed in classical antiquity and been refined and improved, but not revolutionized, during their passage through Medieval Islam, the high European Middle Ages and Renaissance. Hydrostatics, embodied chiefly in Archimedes's *On Floating Bodies,* was one of these disciplines, recovered in full during the Renaissance and interestingly articulated by the practical mathematics and engineering maestro Simon Stevin in 1586. But, as Chalmers shows, hydrostatics only began to be transformed into a recognizably modern discipline by Pascal and Boyle in the third generation of the seventeenth century. It was then to all intents and purposes put on its modern foundations by Newton in his *Principia* in 1687.

Chalmers's approach begins with this premise: the necessary and sufficient condition for a modern, fruitful hydrostatics was construction of the modern concept of hydrostatic pressure. This involves conceiving of (non-elastic) fluids as incompressible, continuous (non-particulate 'all the way down' as physicists say) and, unlike solids, giving way completely to distorting forces. If a force per unit area is applied anywhere to a surface containing such a fluid, it is converted into a scalar, isotropic genuine 'pressure' in all directions at every point in the fluid. If one adds consideration of the weight of the fluid thus contained, the force per unit area on any containing surface will be the product of the depth of the fluid to that point and the surface area being considered, regardless of whether that surface is horizontal, vertical or any angle in between. Because of these properties, hydrostatic pressure can 'turn corners' and display the paradoxical behaviours originally pointed out by Simon Stevin in 1586.

Following Robert Boyle, Chalmers labels this type of theoretical concept as 'intermediate'. It was grounded in and articulated through experiment by means of sophisticated theoretical reflection. It did not reduce to or arise from an immediate phenomenology of appearances, let alone everyday understandings or descriptions. Nor was it connected to any deep natural philosophical categories of matter and cause. In particular, thinking about fluids in terms of ultimate atoms or corpuscles, as in the mechanical philosophy, was a hindrance to ever conceptualizing the fluidity and continuity of liquids and hence deriving the properties of scientific pressure.

Given this understanding of the concept of pressure, Chalmers's historical approach is recursive in the manner promoted by Gaston Bachelard. We keep in mind the end of the story, grasping the modern concept of fluid pressure. We then recur through stages of development. We do not retrace our steps Whiggishly, teleologically and linearly. Rather, we try to discern the struggles, the sheer craftiness — theoretical and practical — through which 'obstacles' — conceptual and practical — were worked over and through by a sequence of savants who certainly never intended or envisioned the eventual end point. ('Obstacle' of course is a Bachelardian concept, much invoked by Chalmers.[1]) Central to the story is the constant presence of everyday, common sense notions of pressure. These constituted obstacles to be overcome if modern 'pressure' was ever to be constructed.

Another obstacle to the maturation of hydrostatics resided at the very core of classical and Renaissance hydrostatics. From Archimedes down through Galileo, this obstacle was posed by seeing the weight of a fluid as *the* constitutive cause of hydrostatic phenomena. This was the case, even though common sense and craft practices long recognized that solids differ from liquids and that liquids do exert force on the sides of their containers, while a solid of identical density and weight does not. Chalmers explores what could and could not be done in hydrostatics labouring under that obstacle, even by such luminaries as Archimedes, Simon Stevin and Galileo. He then unfolds in detail how Pascal and Boyle broke through toward the new concept, consolidated by Newton.

Chalmers deftly shows that the existing scholarship has not grasped how the modern technical concept emerged. It almost always confuses common sense notions of pressure with stages of the emergent scientific concept. Every sentence in the literature dealing with the genealogy of the modern concept of pressure needs to be picked apart to see where, how and to what effect the modern concept was read into use of the common-sense term. This changes how we must read previous research from Pierre Duhem through W.E.K. Middleton down to Steven Shapin and Simon Schaffer's *Leviathan and the Air Pump*. On the latter, see the rather portentous footnote on page 121.

As I have said, Chalmers is at pains to show how the new 'middle level' theoretical concept 'pressure' did not derive from, or depend upon, any 'deep' theories of matter and cause that the protagonists might have dredged up from the natural philosophies of the day. Intrusions from natural philosophy constituted obstacles to the advance of scientificity. Convinced that his case study provides a widely applicable model for the new sciences of the day, Chalmers is suggesting we see the Scientific Revolution in the main as a concatenated series of such breakthroughs, thus solidifying his 'anti-natural philosophical' view of the Scientific Revolution widely on display in his many papers on the history of early chemistry, atomism and the work of Boyle. The book thus offers not just a textured, neo-Bachelardian genealogy of 'scientific' pressure from Stevin to Newton. Historiographically it stakes out an approach to the wider content of the Scientific Revolution, while in historical epistemology it makes a strong case for what the new experimental/mathematical sciences consisted of and how they came to be. In keeping with this rich historiographical and epistemological contextualization, Chalmers devotes five of the twelve chapters, almost one-third of the entire work, to wider matters: [Chap. 1] Liquids: A Challenge for 17th Century Mechanics; [Chap. 2] The Historical Background to Stevin's Hydrostatics; [Chap. 10] Fashioning a Novel Concept of Pressure: One Hundred Years; [Chap. 11] Hydrostatics and Experiment; and [Chap. 12] Hydrostatics and the Scientific Revolution. The seven middle chapters set out the recursive tale from Stevin to Newton. Each of the middle chapters brings out new insights and findings about the major players.

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[1] Gaston Bachelard, *La Formation de L'Esprit Scientifique* (Paris, 1975), p. 13: 'Quand on cherche les conditions psychologiques des progrès de la science, on arrive bientôt à cette conviction que c'est en termes d'obstacles qu'il faut poser le problème de la connaissance scientifique'.

Chalmers has made a number of fundamental discoveries about the hydrostatics of Simon Stevin, the brilliant master of practical mathematics and mechanics. It is usually asserted, for example by Duhem, E. J. Dijksterhuis and more recent scholars, that Stevin followed a rigorous Archimedean/Euclidean procedure to deduce the hydrostatic paradox. Chalmers bursts this myth, showing that Stevin's postulates — which he asserted were drawn from common sense and easily accepted by everyone — actually tacitly embodied assumptions involved in his practical mathematics and engineering practices and experience. Importantly, the reason Stevin was driven to these expedients was that he still saw weight as the operative cause in hydrostatical phenomena, and he had not theorized other technical facts with which he was perfectly well familiar, such as that force is exerted by liquids on the sides of their containers.

After a valuable chapter on Galileo's hydrostatics — still weight driven but productive of new insights — Chalmers turns to the anti-hero in the tale of recurrence: the young René Descartes. Isaac Beeckman, Descartes's early mentor in corpuscular-mechanical natural philosophizing, pointed him to Stevin's hydrostatics. The apparent rigour of Stevin's theory of macroscopic hydrostatical situations was merely the starting point for the ambitious Descartes. He wanted to show that Stevin's triumphant modern results arose due to the behaviour, the weighing down, of the atoms or corpuscles making up liquids.[2] Chalmers correctly shows that Descartes's attempted subsumption of Stevin's hydrostatics within (his version of) corpuscularian natural philosophy was a dead-end. The middle level causal category 'pressure' would not and could not emerge here.

The chapters on Pascal and Boyle form the pivot of Chalmers's story and contain an array of new insights and corrections to previous scholarship. The usual story, according to Chalmers, sees little development from the former to the latter, and it stresses the contrasts between the two figures, with Pascal bogged down with merely imaginary, or impossible, experiments, while Boyle is seen as a Baconian-style practical experimenter. Additionally, such accounts suffer from the ambiguities and slippages Chalmers has identified in scholarly understandings of 'everyday' and 'scientific' notions of pressure. Chalmers's clarity about the modern conception of pressure and his long view, grounded in recurrence, allow him to fashion a new interpretation of how the work of Pascal and Boyle fits together in a wider, deeper story of the emergence of scientificity about hydrostatical phenomena. Chalmers holds that Pascal began to provide an account of the causal mechanism involved in hydrostatics, and so moved toward the modern concept of pressure which was to more fully emerge in Boyle and Newton. The key was Pascal's insight that any force applied to a liquid is transmitted through it such that a force per unit area applied at any given location appears as the same force per unit area on any other bounding surface of the liquid, regardless of orientation and distance from the point of original force application. A body of water, by virtue of its defining liquidity, is in Pascal's words 'a mechanical machine for multiplying force' (p. 91). This, along with Pascal's correlative mastery of the hydrostatic press, marks the first break with a weight-centric hydrostatics. Chalmers sees that many experiments described but not performed by Pascal were just modifications of situations presented in Stevin's work as practical applications of his own theory. Then, in approaching Boyle, Chalmers first deals with developments by Torricelli and Pecquet regarding aero-statics, arguing that Boyle's achievements in hydrostatics depended

[2] Cartesian scholars will be aware that Stephen Gaukroger and I have examined Descartes's tactics here, linking them to both the later emergence of his conception of a 'dynamics of corpuscles', and the tenor of some of his detailed explanatory strategies in corpuscular-mechanical philosophy. (Stephen Gaukroger and John Schuster, 'The Hydrostatic Paradox and the Origins of Cartesian Dynamics', *Studies in History and Philosophy of Science*, 33 (2002), pp. 535–72.) Chalmers, our colleague in the School of HPS, University of Sydney, takes issue with our interpretation of how Descartes was proceeding in his early 'hydrostatics manuscript'. Chalmers offers a 'more charitable' reading of the young Descartes (pp. 64–5). (We had called Descartes's procedure 'tendentious' and '*ad hoc*' [p. 563].) However, I have also shown that the tactics we termed tendentious occur endemically inside Descartes's later natural philosophy, so that in a sense one might say that a better charitable interpretation is one that makes sense of more of Descartes's scattered natural philosophical texts. (John Schuster, *Descartes-Agonistes: Physico-mathematics, Method and Corpuscular-mechanism, 1618–33* (Dordrecht, 2013), pp. 119, 382–384; 499–514.)

crucially on what he had already learned about pneumatics. Again, the most important step is the forging of a middle level causal category, 'the spring of the air', which did not require further corpuscular reduction and which is a kind of exemplar for the new concept of 'pressure' for [non-elastic] fluids. Boyle then breaks through to begin to grasp the isotropy of hydrostatic pressure by means of thought experiments dealing with the forces on opposing sides of imaginary planes inserted at various angles into an incompressible fluid. Moreover, Boyle performed his own versions of some of the experiments mentioned by Pascal. We thus get a picture of the long-term evolutionary dynamics of hydrostatics from Stevin through Pascal to Boyle.

Chalmers then very carefully explicates how Newton achieved (what is for almost all intents and purposes) our modern conception of hydrostatic pressure. This involves Chalmers in a careful examination of Newton's well-known manuscript *de Gravitatione*, which is usually interrogated for Newton's emerging metaphysics of space and body, beginning to be forged in a critical analysis of Cartesian vortex and matter theory. Newton then polished and finalized his hydrostatics in less than ten pages of Book II of the *Principia*. Chalmers puts to excellent use Alan Shapiro's classic analysis of Descartes's and Newton's conceptions of the action of light and of fluidity to explain how Newton arrived at a productive definition of an ideal liquid, by considering at first only its incompressibility and radical continuity but not its weight.[3] From this intellectual construct a well-formed concept of hydrostatic pressure could finally be derived and thence the known hydrostatic phenomena. (Newton provides no new experimental evidence.) Along the way, Chalmers convincingly comes down on the side of those who hold *de Gravitatione* to be an early work of Newton, most likely circa 1668.

Alan Chalmers often talks about scientific theories that are 'fruitful, productive and meritorious'. This book, too, is fruitful, productive and meritorious as a work of history of science and historical epistemology. And it is so, even in the one area where readers might have some concerns. Let us call this 'the problem of natural philosophy in the Scientific Revolution'. Chalmers has preferred to study domains of natural inquiry — hydrostatics and early chemistry — where natural philosophy, mainly in the form of 'the mechanical philosophy' formed clear obstacles to mature discipline emergence. In the present book Chalmers repeatedly insists that natural philosophy (i.e. the mechanical philosophy) was nothing but an obstacle to the early modern advances of the sciences. But, can we safely induce from Chalmers's cases to such an historiographical principle? The two topping and three tailing chapters, mentioned earlier, are not there by accident. On the basis of the case of hydrostatics, we are meant to draw wider conclusions about the Scientific Revolution and the nature of modern sciences *per se*. But surely it is obvious that in the Scientific Revolution some disciplines — such as physical optics, realist Copernicanism and celestial mechanics — did emerge from fruitful entanglement with the concerns of natural philosophizing, whilst some other disciplines, including hydrostatics, did not. At one point (p. 135) Chalmers does trace the main contents of Newtonian physics, his 'billiard ball' mechanics, back to sources and problems in Descartes's *Principia*, the *locus classicus* of corpuscular-mechanical natural philosophy. But this point is not linked to a revised, wider vision of the problem of natural philosophy in the Scientific Revolution.

In the end it is not necessary to agree with Chalmers's totalizing, anti-natural philosophy stance, because his exemplary recursive history has the richer net result of permanently inflecting how we debate what the *longue durée* explication of the Scientific Revolution will look like. If you wish to show natural philosophical entanglements in disciplinary formations, your internal history of such formations had better be up to Chalmers's neo-Bachelardian standards, and your larger conclusions had better be grounded in awareness of his now-unavoidable big

3 Alan Shapiro, 'Light, Pressure and Rectilinear Propagation: Descartes' Celestial Optics and Newton's Hydrostatics', *Studies in History and Philosophy of Science*, 5 (1974), pp. 239–96.

historiographical claims. In short Chalmers has, unwittingly perhaps, upped the ante on the problem of the role[s] of natural philosophy in the process of the Scientific Revolution.