Vital instability: life and free will in physics and physiology, 1860-1880

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During the period 1860-1880, a number of physicists and mathematicians, including Maxwell, Stewart, Cournot and Boussinesq, used theories formulated in terms of physics to argue that the mind, the soul or a vital principle could have an impact on the body. This paper shows that what was primarily at stake for these authors was a concern about the irreducibility of life and the mind to physics, and that their theories can be regarded primarily as reactions to the law of conservation of energy, which was used among others by Helmholtz and Du Bois-Reymond as an argument against the possibility of vital and mental causes in physiology. In light of this development, Maxwell, Stewart, Cournot and Boussinesq showed that it was still possible to argue for the irreducibility of life and the mind to physics, through an appeal to instability or indeterminism in physics: if the body is an unstable or physically indeterministic system, an immaterial principle can act through triggering or directing motions in the body, without violating the laws of physics.

1. Introduction

In 'Nineteenth Century Cracks in the Concept of Determinism', Ian Hacking notes that around the 1870s, there was much anxiety about the issue of scientific determinism and the possibility of free will (Hacking, 1983).[1] In this period, physicists such as Maxwell and Boussinesq made attempts to save free will, and offered explanations in terms of physics of how the will could act in the body, to show that freedom of the will was compatible with physics. Hacking describes this period as a 'silly season in the

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[1] See also Hacking (1990), p. 155ff.

philosophies of freedom and necessity', and argues that the prevalence of strange ideas about determinism in this period must mean that the very concept of determinism was under pressure: 'When great minds took to a new but crazy idea, we may suspect their very thinking about a concept was undergoing a lot of stress. I contend that the stress in the concept of determinism was as widespread as could be' (Hacking, 1983, p. 465).[2] However, Hacking does not explain what exactly this stress might have consisted in, or what caused it.

In particular, Hacking's account leaves unexplained why it was during this period, roughly 1860–1880, that these explanations of free will in terms of physics appeared. It is not the case that the issue of determinism in physics was especially pressing during this period. Laplace's well-known statement of determinism already dated from half a century earlier, in *Essai philosophique sur les probabilités* (1814), and in fact, Laplacian determinism goes back even further: Laplace had already made a similar claim in 1773, and various earlier authors in eighteenth-century France had argued for determinism in terms very similar to those of Laplace (Van Strien, 2014b). Whereas Laplacian determinism is specifically associated with mechanics,[3] in the course of the nineteenth century there was a rise of other domains of physics such as thermodynamics and electromagnetism; this development had the effect of weakening the idea that all of physics was reducible to the mechanics of point particles and force laws, and if anything, this made it less obvious that all of physics was deterministic. It is thus unclear why determinism would suddenly become such a big issue around 1860–1880.

A number of authors have turned to the theological, moral and cultural contexts to explain the background of these debates about the will.[4] Illuminating though this focus on theological, moral, and cultural contexts may be, there is more to be said about the role of scientific developments in the debate. Specifically, there was a relevant scientific development which deserves more attention, namely the law of energy conservation and its claimed applicability to physiology. Whereas a number of authors, such as Porter, Smith and Wise, and Harman, have pointed out that the law of conservation of energy played a role in the debate about science and free will in the period 1860-1880, they do not give it a central place, and do not discuss how exactly the law of energy

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[2] Moreover, Hacking shows that it was in fact only during this period that the word 'determinism' received its current meaning, pointing to Renouvier and Du Bois-Reymond as early users of the term. 'Somewhere, let us say between 1854 and 1872, the concept of determinism acquired its modern sense in all the European languages'. (Hacking, 1983, p. 460). Before this period, the central term in debates about science and free will was 'necessity', which played a role that was to some degree analogous to that of the later term 'determinism'. See Harris (2005).

[3] In fact, Laplace's determinism was not a direct consequence of his mechanics: see Van Strien (2014b). However, it was nevertheless associated with mechanics, and there was a natural expectation that in mechanics, the equations of motion generally have unique solutions for given initial conditions so that there is determinism.

[4] See Stanley (2008); Cat (2012); Nye (1976); Smith (1998), p. 249.

conservation was used as an argument for reductionism in physiology and in how far the arguments for free will by Maxwell, Boussinesq and others can be understood as arguments against reductionism in physiology.[5]

In this paper, I discuss a set of related explanations of free will and life in terms of physics by James Clerk Maxwell, Balfour Stewart (and his co-authors Tait and Lockyer), Antoine Augustin Cournot and Joseph Boussinesq. They were all physicists and/ or mathematicians who published their ideas on life and the will between 1860 and 1880. I argue that what is fundamentally at stake for them is a resistance to the reducibility (in principle) of physiology to physics, and specifically to the claimed implications of the law of energy conservation for physiology. In particular, I show the following:

(1) Their explanations of life and free will can be understood as a reaction to reductionist tendencies in physiology. During this period, roughly 1860-1880 a number of scientists (notably Helmholtz and Du Bois-Reymond) claimed that the law of conservation of energy, as applied to physiology, showed that all physiological processes were completely determined by the laws of physics, and that there was no room for vital or mental agency in physiology. It was this development that the authors I discuss were reacting against.

(2) Their concern was not restricted to the possibility of free will, which they understood exclusively in terms of the possibility for an immaterial mind or soul to act on the body; they were equally concerned about the irreducibility of life to physics, and argued for an irreducible vital principle in physiology. They defended strictly dualist conceptions of life and free will. Specifically, the dualism they defended is a type of substance dualism, since it involves an immaterial entity (mind, soul, or vital principle) that intervenes in the body.

(3) They developed theories of life and free will in terms of mechanics, based on unstable and indeterministic mechanical systems. They argued that in unstable systems, vital and mental causes could intervene with only an extremely small violation of the law of conservation of energy; in indeterministic systems, this violation is reduced to zero. Thus, mechanics provided a resource for showing how there could be vital and mental causes, and for making the law of energy conservation compatible with the intervention of immaterial agency in physiology.

(4) While they were concerned with reductionism in physiology, this did not necessarily imply that they were concerned with physiology being deterministic. In particular, Cournot and Boussinesq explicitly argued that physiology must be deterministic, but emphasized that this physiological determinism was irreducible to physical determinism.

There were others in the respective circles of Maxwell, Stewart, Cournot and Boussinesq with similar ideas, such as William Thomson (Lord Kelvin), Fleeming Jenkin,

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[5] Porter (1986), p. 202; Smith and Wise (1989), p. 617; Harman (1998), p. 200.

and Adhémar Barré de Saint-Venant[6]; however, I focus on Maxwell, Stewart, Cournot and Boussinesq, because their ideas are worked out in most detail. Whereas Maxwell was well acquainted with Stewart and Boussinesq was influenced by Cournot, for the rest there is little evidence for contact between them, although Maxwell was aware on the ideas of both Cournot and Boussinesq on the will.[7] Nevertheless, there are strong similarities between their ideas and they fit in the same context, and can therefore be better understood when considered together. The paper focuses on the scientific and metaphysical dimensions of their ideas, and does not discuss moral or religious dimensions, because these have been adequately treated by others (see footnote 5).

In section 2, I provide an introduction to the law of conservation of energy and its claimed implications for physiology; in sections 3 and 4, I discuss the attempts that were made by Maxwell, Stewart, Cournot and Boussinesq to make energy conservation compatible with the intervention of mental and vital causes, through an appeal to instability and indeterminism in physics. In section 5, I show how Cournot and Boussinesq, even though they rejected determinism in physics, did argue for determinism in physiology; and in section 6 I show that the irreducibility of life to physics was as much an issue as free will.

2. The law of conservation of energy in physiology

In this section I show how the law of conservation of energy was used as an argument for the reducibility of physiology to physics. From its earliest development, the law of conservation of energy was thought to apply to living beings and to have implications for the possibility of vital and mental causes, and was used as an argument against vitalism and mind-matter interaction and for reductionism in physiology.

The law of conservation of energy is a law of physics, but it did not purely originate in the context of physics: the law was famously derived by several scientists around the same time, in several contexts, mainly physics, engineering, and physiology. One of its main developers was Hermann von Helmholtz, who was a physician and a physiologist by training, and it was his work in physiology that led him to the development of the law of conservation of energy (Lenoir, 1982, p. 195ff; Elkana, 1974, p. 97ff). In a lecture in 1861, Helmholtz discusses the application of his law of conservation of force (which later became the law of conservation of energy) to organisms, and argues that an organism can very well be compared to a steam engine: both are machines where fuel or

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[6] See Saint-Venant (1877), and Jenkin (1868). On Kelvin, see Smith and Wise (1989).

[7] He mentions them both in a letter to Galton in 1879. See Maxwell (1879a).

food and oxygen go in and mechanical work and heat come out (Helmholtz, 1861, p. 353; see also Cahan, 2012, p. 60).

Helmholtz writes that physiologists have often supposed that processes in living bodies are determined by a vital principle, which is a directive principle specific to living organisms that can produce changes in the body through suspending or releasing the physical forces in the body. He points out that such variation of the forces that act in the body is in conflict with the law of conservation of force, since this law implies that forces cannot vary independently of physical conditions. He concludes:

> There may be other agents acting in the living body, than those agents which act in the inorganic world; but those forces, as far as they cause chemical and mechanical influences in the body, must be quite of the same character as inorganic forces, in this at least, that their effects must be ruled by necessity, and must be always the same, when acting in the same conditions, and that there cannot exist any arbitrary choice in the direction of their actions (Helmholtz, 1861, p. 357).

It is not always easy to interpret Helmholtz, as he used the word 'force' ('*Kraft*') with different meanings that he did not keep strictly separated; sometimes, the word corresponds to our present notion of energy, sometimes it means Newtonian force, and sometimes it means natural power or agent (Heimann, 1974, p. 214).[8] In the above passage, he equates 'force' with 'agent', implying that all agents acting in the living body are subjected to the law of conservation of force. Helmholtz understood causation in terms of forces,[9] and he describes the law of conservation of force in causal terms:

> We may express the meaning of the law of conservation of force by saying, that every force of nature when it effects any alteration, loses and exhausts its faculty to effect the same alteration a second time. But while, by every alteration in nature, that force which has been the cause of this alteration is exhausted, there is always another force which gains as much power of producing new alterations in nature as the first has lost. Although, therefore, it is the nature of all inorganic forces to become exhausted by their own working, the power of the whole system in which these alterations take place is neither exhausted nor increased in quantity, but only changed in form (Helmholtz, 1861, p. 347-48).

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[8] Note that P. M. Heimann is the same author as P. M. Harman, referred to earlier; he changed his name from Heimann to Harman.

[9] 'Our desire to *comprehend* natural phenomena, in other words, to ascertain their *laws*, thus takes another form of expression - that is, we have to seek out the *forces* which are the *causes* of the phenomena'. Helmholtz (1869), p. 209. At the time, a widely-debated issue in philosophy of physics was whether forces have an independent ontological status and should be seen as the efficient cause of motions, or whether force is only a relational or derived concept and is not more than the product of mass and acceleration. See Jammer (1957), p. 200-240.

Thus, according to Helmholtz, the law of conservation of force implied that vital and mental agents cannot act independently of physical conditions. If there are any special vital or mental causes, or forces, they have to be subjected to the law of conservation of force; specifically, any such force has to be conservative.[10] This has the consequence that such a force cannot vary independently of physical conditions, and has to be of the same character as physical and chemical forces.

Helmholtz's main target is the possibility of vital forces: he is opposed to the view that there is a vital principle or vital force that is specific to the organic realm, directs processes within the organism, and can explain specific features of living organisms, such as their apparent teleology. He writes that the idea of such a vital principle was still popular in the early nineteenth century, but:

> The present generation, on the contrary, is hard at work to find out the real causes of the processes which go on in the living body. They do not suppose that there is any other difference between the chemical and the mechanical actions in the living body, and out of it, than can be explained by the more complicated circumstances and conditions under which these actions take place ; and we have seen that the law of the conservation of force legitimizes this supposition. This law, moreover, shows the way in which this fundamental question, which has excited so many theoretical speculations, can be really and completely solved by experiment (Helmholtz, 1861, p. 357).

Although Helmholtz's arguments are mainly aimed at vitalism, or the possibility of vital forces, they also imply that mental causes have to be subjected to the law of conservation of force. Yet, Helmholtz does argue that we have free will, but he thinks that free will cannot be comprehended scientifically (Helmholtz, 1861, p. 454).

Thus, Helmholtz used the law of conservation of energy as an argument against vital causes in physiology. This was a step towards reduction of physiology to physics. It is important to note that it was very difficult in practice to apply the law of conservation of energy to physiology, because it was often not possible to make accurate measurements of the relevant quantities, and it was not possible to completely verify experimentally that there was no intervention of vital causes in physiological processes. However, Helmholtz provided experimental support of the law of conservation of energy in physiology to some degree, and he felt confident in arguing that the law was rigorously valid in physiology, and that it excluded the intervention of vital causes.[11] The applicability of the law of conservation of energy to physiology may thus have been limited in the sense that its use in laboratory research in physiology was limited, but it

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[10] In fact, Helmholtz argued that all forces have to be central, which is a stronger requirement: central forces are conservative forces that are directed towards a point. Helmholtz argued that all occurrences were reducible to matter and central forces. See Helmholtz (1847), p. 5ff.

[11] See Elkana (1974), p. 97-111. See also Lenoir (1982), p. 200-214, for Helmholtz' work on muscle contraction and heat production in the body.

was applicable in the sense that, given the fact that there was a broad range of support for the law in different scientific domains, there were good reasons to think that it applied to all natural processes, including physiological processes. The applicability of the law of conservation of energy in this sense was also acknowledged by others, for example Maxwell wrote in 1879:

> It would be rash to assert that any experiments on living beings have as yet been conducted with such precision as to account for every foot-pound of work done by an animal in terms of the diminution of the intrinsic energy of the body and its contents; but the principle of conservation of energy has acquired so much scientific weight during the last twenty years that no physiologist would feel any confidence in an experiment which shewd a considerable difference between the work done by an animal and the balance of the amount of energy received and spent (Maxwell, 1879b).

Helmholtz was part of the famous physiology laboratory of Johannes Müller, where organic processes were as much as possible explained in physical and chemical terms. Whereas in the work of Johannes Müller himself, there is a mild vitalist element, some of the younger members of the laboratory, among whom was Helmholtz, completely rejected vitalism, and thought that physiology could be completely reduced to physics and chemistry (Lenoir, 1982, p. 195-96). Another member of this group who explicitly used the law of conservation of energy to argue against mental causes and free will was the well-known physiologist Emil Du Bois-Reymond. I will discuss his argument too because it was quite influential: it appeared in a lecture that Du Bois-Reymond gave in 1872, titled 'The limits of our knowledge of nature', which became well-known and triggered a large debate about the proper aims of science. Hacking (1983) argues that this lecture contains one of the first explicit arguments for scientific determinism.

On the basis of the law of conservation of energy, Du Bois-Reymond argues that the mind cannot intervene in the physical world: in Du Bois-Reymond's view, the only way to effect a change in nature is to exert a force; thus, if the mind were to intervene in the physical world, it would have to exert a force, and this would disturb the amount of energy in the physical world. Without the possibility of exerting forces, the mind has no causal efficacy, and it is therefore unintelligible:

> In the physical world, no more and no less can happen than this law [of conservation of energy] determines; the mechanical cause passes completely into the mechanical effect. Thus, the mental processes that are associated with the material processes in the brain are for our understanding devoid of a sufficient

> reason. They lie beyond the law of causation, and are therefore unintelligible, like a *perpetuum mobile.* (Du Bois-Reymond, 1872, p. 41).[12]

Du Bois-Reymond argues that anything that cannot be reduced to motions of atoms is fundamentally unknowable and beyond the realm of causality. The fact that the mind cannot intervene in the physical world, as the law of energy conservation shows, thus makes it non-causal and therefore places it outside of the domain of science.

One way to make mind-matter interaction compatible with the law of conservation of energy would be to argue that there is a 'mental energy' which is convertible into other types of energy and subjected to the law of conservation of energy, so that the mind is included in the system within which energy is conserved. In this way, there can be mental forces (or, by a similar argument, vital forces), that are conservative and thus do not violate the law of conservation of energy. This is an approach that was taken up at the time, for example by Bain (see Bain, 1867). However, it placed strong restrictions on mind-matter interaction and vitalism: it implied that the actions of the mind or the vital principle were determined by the laws of physics, and that vital and mental forces could not vary independently of physical conditions. Thus, the vital and the mental domain would come under the dominion of the laws of physics and would lose their independence.[13]

Thus, Helmholtz and Du Bois-Reymond used the law of conservation of energy as an argument against irregular vital and mental causes, and argued on the basis of this law that all occurrences in the living body were regulated by the laws of physics. In other words, they used the law of conservation of energy as an argument for the completeness of physics, as Papineau defines it in his article "The rise of physicalism": 'All physical effects are fully determined by law by prior physical occurrences' (Papineau, 2001, p. 8).

In his article, Papineau points to the development of the law of conservation of energy as an important step in the acceptance of the idea that physics is complete. He argues that the law of conservation of energy excludes indeterministic forces (Papineau, 2001, p. 25-26). This fits with the use that Helmholtz and Du Bois-Reymond made of the law of conservation of energy. However, as we will see in the next sections, an argument was available and used against this implication; irreducible vital and mental causes could be made compatible with energy conservation if one allowed for unstable and indeterministic mechanical systems.

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[12] 'Mehr als dies Gesetz bestimmt, kann in der Körperwelt nicht geschehen, auch nicht weniger; die mechanische Ursache geht rein auf in der mechanischen Wirkung. Die neben den materiellen Vorgängen im Gehirn einhergehenden geistigen Vorgänge entbehren also für unseren Verstand des zureichenden Grundes. Sie stehen ausserhalb des Causalgesetzes, und schon darum sind sie nicht zu verstehen, so wenig, wie ein Mobile perpetuum es wäre'.

[13] In addition, both Helmholtz and Du Bois-Reymond rejected this possibility because they thought that forces always had to be bound up with matter, and that matter and forces could not be understood separately: they both argued that all natural phenomena were reducible to atoms and central forces connected with these atoms. See Helmholtz (1847), p. 5ff; Du Bois-Reymond (1848), p. xxxvi.

3. Causation without forces

Whereas Helmholtz and Du Bois-Reymond used the law of conservation of energy as an argument against vital and mental causes and for reductionism in physiology, this argument met with resistance from a group of physicists and mathematicians including Maxwell, Stewart, Cournot and Boussinesq. They thought that the domain of physics should be restricted and that the living realm should have some degree of autonomy from the laws of physics. They sought ways to argue for the possibility of genuine vital and/or mental causes which were not determined by the laws of physics, but at the same time did not violate the law of conservation of energy. In this section I show that they could make this argument through an appeal to unstable mechanical systems, on which an immaterial principle can act without exerting a physical force.

Maxwell was well acquainted with Helmholtz (Cahan, 2012), and he discussed Helmholtz's ideas on energy conservation in a letter to Campbell in 1862 (this was probably in reaction to Helmholtz's lecture from 1861, cited above[14]):

> We see also that the soul is not the direct moving force of the body. If it were, it would only last till it had done a certain amount of work, like the spring of a watch, which works till it is run down. The soul is not the mere mover. Food is the mover, and perishes in the using, which the soul does not. There is action and reaction between body and soul, but it is not of a kind in which energy passes from the one to the other, - as when a man pulls the trigger it is the gunpowder that projects the bullet, or when a pointsman shunts a train it is the rails that bear the trust (Maxwell, 1862).

Harman writes that Maxwell agreed with Helmholtz's anti-vitalism, referring to exactly this paragraph (Harman, 1998, p. 203). Indeed, this statement goes against the idea that there are vital forces which act as the 'motive power of the body' – this would be a clear violation of the law of conservation of energy. However, it seems from the above passage that, according to Maxwell, there are other ways in which a soul may have an effect on the body: it can cause or direct motions without being the motive power. The same idea comes up in an essay in 1873, in which Maxwell writes:

> As the doctrine of the conservation of matter gave a definiteness to statements regarding the immateriality of the soul, so the doctrine of the conservation of energy, when applied to living beings, leads to the conclusion that the soul of an animal is not, like the mainspring of a watch, the motive power of the body, but that its function is rather that of a steersman of a vessel – not to produce, but to regulate and direct the animal powers (Maxwell, 1873, p. 817).

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[14] According to Harman (1998), p. 202, Maxwell was almost certainly present at Helmholtz's lecture; the letter was written shortly after its publication.

The basic idea we find in Maxwell is that the soul is not a moving force but that it can trigger or direct motions. This possibility of triggering or directing motions depends on instability in the system that is acted upon: there must be certain unstable or singular points in the system 'at which a strictly infinitesimal force may determine the course of the system to any one of a finite number of equally possible paths' (Maxwell, 1879b). In the analogies of pulling a trigger or switching railway tracks, it is the mechanism of the gun or the points lever which makes it possible to act on a large scale through exerting only a very small force.

The analogies Maxwell employs are intended to show that not all change in nature is effected through a direct exertion of energy (pushing and pulling) but that it is also possible to act through triggering or directing motions. Because this involves only a tiny, and possibly infinitely small, amount of energy, it is a big step towards making vital and mental agency compatible with energy conservation. Maxwell argued that the violation could be small enough to be beyond our epistemic reach. Therefore, he claimed, science cannot exclude the possibility of such a directive principle:

> Every existence above a certain rank has its singular points: the higher the rank, the more of them. At these points, influences whose physical magnitude is too small to be taken account of by any finite being, may produce results of the greatest importance. (Maxwell, 1873, p. 822).

Here, with 'singular point', Maxwell means a point at which there is strong instability; systems in which there are singular points are unpredictable to such a degree that we can't exclude the possibility that an immaterial directive principle intervenes at such points.

The idea that processes can be caused by an agency acting on a small scale also comes up in Maxwell's work on statistical mechanics, in the form of "Maxwell's demon", a hypothetical entity who can cause entropy decrease by acting on individual molecules. The demon was invented by Maxwell in order to show that violations of the second law of thermodynamics (the law of increase of entropy) are possible in principle. The demon operates through moving a slide to open and close a hole in a wall, and it is assumed that this can be done without friction, so that the demon does not have to exert any force; whereas the complete absence of friction is not a realistic assumption, it approximates a situation in which there is a slide which can move with a very small amount of friction, and this can also be regarded as an unstable mechanical system (see Harman, 1998, p. 134ff).

The physicist Balfour Stewart used the term 'delicacy of construction': he argued that certain machines are delicately constructed, which means that only very little force is needed to operate them.[15] As an example of such a delicately-constructed machine,

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[15] His ideas on the issue can be found mainly in Stewart (1875); Stewart and Lockyer (1868); Stewart and Tait (1875).

Stewart mentions a gun or rifle, which can go off through 'the expenditure of a very small amount of energy upon the trigger', and this can have a large effect: 'if well pointed, it may explode a magazine, – nay, even win an empire' (Stewart and Lockyer, 1868, p. 324). However, the gun will not go off spontaneously; the application of a small amount of 'directive energy' to the trigger is required. It is therefore a machine of '*finite* delicacy of construction' – unstable, but deterministic. We only get complete unpredictability in a combined system of man and gun:

> The rifle is delicately constructed, but not surpassingly so; but sportsman and rifle, together, form a machine of surpassing delicacy, ergo the sportsman himself is such a machine. We thus begin to perceive that a human being, or indeed an animal of any kind, is in truth a machine of a delicacy that is practically infinite, the condition or motions of which we are utterly unable to predict. (Stewart, 1875, p. 160-61).

Thus, living beings are machines of infinite delicacy of construction. To argue that a living being is no more and no less than a delicately constructed machine would mean that life can be explained in mechanistic terms. But Stewart and his co-author Lockyer explicitly distinguish this materialist conception of life from the view that there is a 'principle in its essence distinct from matter' which can bring about effects by exerting an infinitely small amount of force on the delicate machine that is the organism (Stewart and Lockyer, 1868, p. 326). Stewart and Lockyer claim that no decision between these two options can be made, but at the same time clearly suggest that it is the second that is most attractive to them. Thus they suggest that the difference between animate and inanimate machines lies in the presence of an immaterial vital principle that operates the machine.

Stewart was not concerned with free will; rather, his concern had to do with life's being irreducible to physical processes. Stewart's ideas about a directive principle in living beings were part of a spiritual worldview based on physics. For him, the notion of 'delicacy of construction' and the possibility of directing motions without exerting a force opened up a way to argue that God could operate in the universe without violating the laws of nature. In this way, God could affect the physical world in a way similar to that in which the vital principle ('life') can operate in the body.[16] Also for Maxwell, there was a spiritual element in his ideas about life and the will, although it was less explicit.[17]

With the exception of the spiritual side, Stewart's and Maxwell's ideas about the irreducibility of life to physics are very similar to those of Antoine Augustin Cournot. Cournot was primarily a mathematician, working among others on analysis and

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[16] This view was most explicitly articulated in *The Unseen Universe*, a book published in 1875 by Stewart and Tait of which the stated purpose was 'to endeavour to show that the presumed incompatibility of Science and Religion does not exist' (Stewart and Tait, 1875, p. vii).

[17] See Maxwell (1879b), his review of a book by Stewart and Tait.

probabilities, but he is mainly remembered for his work in mathematical economics and his philosophical writings.[18] To understand how the vital principle can act in a world that is ruled by the laws of physics and chemistry, Cournot proposes starting with the experience that we have of acting in the physical world. He pictures someone rowing a canoe, who has to use his own muscular force to overcome the resistance of the water, wind and stream and tide. But this is not the only way in which we can act: someone who has learned to sail can make use of the force of the wind to overcome the resistance of the water (Cournot, 1875, p. 100). To do this, he needs only a small amount of muscular work to set the sails, but this amount is massively disproportionate to the actual force that is needed to displace the ship. With the invention of steam ships, it became possible to set a ship in motion with even less muscular effort, and future developments may further reduce the required amount of muscular effort. Cournot argues that machines may be invented which can be operated with an infinitely small amount of force:

> Nothing prevents us from imagining (at least in theory) that the physical work that the currently most perfected machine always requires on the part of man, is borrowed from the blind forces of nature by means of an even more perfect machine, so as to infinitely reduce the part of physical work imposed on man, and to increase his power as the master and director of the natural forces. (Cournot, 1861, p. 369-70).[19]

In the same way that man operates a machine, the vital principle can operate the body, which is in fact a superior machine.

The basic principle of approaches such as those of Maxwell, Cournot and Stewart goes back to Descartes, who argued that the mind could change the direction of motion with the quantity of motion being conserved.[20] What is new about the ideas of Maxwell, Cournot and Stewart, however, is that they are developed explicitly as a reaction to the law of conservation of energy and its claimed implications. We can divide the analogies they employed into two groups. Some, such as Maxwell's railway pointsman and Cournot's sailing ship, are directly based on the possibility to direct motions or forces (Cournot, 1861, p. 371). But in the analogy of pulling the trigger of a gun, something else

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[18] On his influence, see Martin (ed.) (2005).

[19] 'Rien n'empêche de concevoir (en théorie du moins) que le travail physique qu'exige toujours, de la part de l'homme, la machine actuellement la plus perfectionnée, soit emprunté aux forces aveugles de la Nature à l'aide d'un mécanisme plus parfait encore, de manière à atténuer indéfiniment la part du travail physique imposé à l'homme, et à accroître sa puissance comme maître et directeur des forces naturelles.' (As an aside, Cournot remarks that, through modern technological developments and the emergence of factories, physical labour is more and more being replaced by the operation of machines, for which forces merely have to be directed.)

[20] Or at least that is the standard view; for a discussion and defense of this standard view, see McLaughlin (1993).

is going on: pulling the trigger causes a transformation of potential energy into kinetic energy. Thus, there are two types of unstable systems on which a change can be effected through exerting a very small force: systems in which a small force suffices to change the direction of motion, and systems in which a small force suffices to cause a transformation of energy.

The concept of energy in particular plays a central role in the ideas of the French physicist Saint-Venant, whose arguments for the possibility of an immaterial directive principle were closely related to those of Maxwell and Boussinesq, and were based explicitly on the possibility of triggering energy transformations.[21] Saint-Venant argues that when we act in the world it is often through causing a transformation of energy:

> I transform, in the external world, potential energy into actual [kinetic] energy when I open the outlet of a water reservoir, when I pull the trigger of a loaded gun, when I let go of the trigger that releases a pile driver from several meters' height. These effects can be considerable; each of them can constitute a good or bad action, as abundantly spilled water can either fertilize or devastate an area, or as a gunshot can either rid us of a dangerous animal or turn a society upside down by hitting a highly-valued head. To produce these effects, however, takes no more than the barely perceptible effort of one of my fingers. (Saint-Venant, 1877, p. 420).[22]

This is, according to Saint-Venant, comparable to how the will acts in the brain. To cause a transformation of energy, a small force needs to be exerted, but 'this force may be infinitely diminished'.[23] And except for this small force needed to trigger the transformation, the total amount of energy remains constant in such a transformation of energy; thus, it is in almost complete accordance with the law of conservation of energy.

In conclusion: in reaction to the law of conservation of energy and its claimed implications for vitalism and free will, it was argued that a vital or mental agency could cause a transformation of energy or a change in the direction of motion by performing an extremely small switching or triggering act on a mechanical system. However, in the analogies provided, the force needed for pulling the switch or the trigger could be made very small or even infinitely small, but it did not become zero; so although this was a big

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[21] Saint-Venant was also one of the earliest people to work on energy conservation; Darrigol (2001) has shown how Saint-Venant anticipated the law of energy conservation in the 1830s.

[22] 'Je change, hors de moi, de l'énergie potentielle en actuelle si j'ouvre la bonde d'un réservoir d'eau, si je presse la détente d'une arme chargée, si je lâche le déclic retenant élevé de plusieurs mètres un mouton à enfoncer les pieux. Ces effets peuvent être considérables; chacun d'eux peut constituer une bonne ou une mauvaise action, car l'eau abondamment répandue peut ou fertiliser ou dévaster un canton, le coup de feu peut, ou le débarrasser d'une bête nuisible, ou bouleverser la société en frappant une tête précieuse. Il n'a fallu pourtant, pour les produire, que l'effort à peine sensible d'un de mes doigts'.

[23] 'cette force peut être indéfiniment atténuée'.

step towards making vital and mental causes compatible with energy conservation, it did not succeed entirely, as a small violation of the law of conservation of energy was still needed.

4. The appeal to indeterminism

As we've seen, there was an obvious problem with the attempt to save the possibility of vital and mental causes through an appeal to unstable mechanical systems: in the mechanical systems that we are familiar with, such as a gun or a steam ship, it is possible to cause changes through exerting a very small force, but this does not explain how it is possible to cause changes without exerting any force at all.

Both Cournot and Stewart argued that while man-made machines such as guns always require some triggering work in order to operate them, the case may be different for the body: the body could be regarded as an infinitely perfected machine (or, in the words of Stewart and Lockyer (1868, p. 325-26), a machine of 'infinite delicacy of construction'). In *Matérialisme, Vitalisme, Rationalisme* (1875), Cournot argues that while man can invent sailing boats and steam engines, nature is a far better inventor, and it is conceivable that nature might be able to diminish the work needed further, to the point of 'suppressing this auxiliary or additional expense of mechanical force that we can only reduce'.[24] Thus, it may be possible for a vital principle to act in the body because the body is a perfect machine, whereas man-made machines are always imperfect. However, it remained unclear how such a perfect machine could be possible. In *Traité de l'Enchaînement des Idées Fondamentales dans les Sciences et dans l'Histoire* (1861), Cournot argues that the required force could be made infinitely small, and that a force that is infinitely small according to the mathematics may not correspond to anything at all in reality; however, he did not have a convincing argument for this claim (Cournot, 1861, p. 373-75).

An ingenious solution to this problem was found by the French physicist and mathematician Joseph Boussinesq, in his 'Conciliation du véritable déterminisme mécanique avec l'existence de la vie et de la liberté morale' (1879). Boussinesq, a physicists and mathematician, is mainly known for his work in hydrodynamics. His theory about life and the will was widely discussed by both scientists and philosophers, among others Maxwell, Du Bois-Reymond and Renouvier. The solution he proposed was based on a mathematical theory of singular solutions to differential equations. The

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[24] 'supprimer cette dépense auxiliaire ou accessoire de force mécanique que nous ne pouvons qu'atténuer'. Cournot (1875), p. 53.

equations of motion for a physical system may, at certain points, not have a unique solution, which means that at these so-called singular points, the equations of physics leave the future course of the system undecided. This is a genuine form of indeterminism in classical mechanics: the examples Boussinesq gives of such (physically) indeterministic systems are equivalent to the Norton dome, which was described by John Norton in (2003), and which subsequently raised quite some discussion in philosophy of physics about the question whether there can be indeterminism in classical mechanics.[25] Boussinesq was not the first to point out this type of indeterminism in classical mechanics: Poisson and Duhamel pointed out similar cases of indeterminism before him. However, Boussinesq worked out the case in most detail and was the first to use it as an argument for the possibility of vital and mental causes (Van Strien, 2014a).

Boussinesq argues that if the laws of physics do not uniquely determine the future course of a system, there must be a directive principle to determine what will happen. This directive principle can be either free will or a vital principle. At singular points, the directive principle can act on the system and change the future course of the system without exerting any force at all: not even an infinitely small force is needed. The equations of motion are never changed or violated by the directive principle, but merely supplemented by it in cases in which the equations themselves leave the future course of the system undecided. Thus, the possibility of genuinely indeterministic systems in physics opens the way for vitalism and free will.

Boussinesq could allow that the laws of physics are universally valid and hold without restriction for living organisms, and at the same time resist a materialist conception of life. These two positions could be reconciled through singular points, at which changes in the system could be effected by a non-physical principle, without a violation of the laws of physics.

The main practical challenge for Boussinesq was to make plausible that singular solutions to equations of motion occur specifically in the equations describing organic systems and that they can occur sufficiently regularly to form a basis for a theory of life and free will. Boussinesq proves mathematically that singular solutions are theoretically possible in a system of two atoms acting on each other, but it also turns out that the probability of their occurrence in such a system is infinitely small (Boussinesq, 1879, p. 109, 113). He argues that for there to be a finite chance that singularities occur, specially prepared circumstances are required which accommodate them (Boussinesq, 1879, p. 109), and that there are such prepared circumstances in living organisms. Life depends on the maintenance of a special interior environment, through the organization of the organs and the availability of nutrition, which is ultimately characterized by a physico-chemical instability beyond which 'there is only death, that is to say, the reign of

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[25] On the similarities between Norton's dome and Boussinesq's dome, see Van Strien (2014a).

mechanical laws only'.[26] It is probably the action of the directive principle itself which causes these special interior conditions to be maintained; thus, the directive principle makes the conditions for its enduring influence possible (Boussinesq, 1879, p. 116).

For Boussinesq, the connection between singular points and life was so strong that he defined life mathematically. According to his definition, a living being is a system for which the equations of motion allow for singular points, at which the intervention of a directive principle, that is, an extra-physical cause, is necessary (Boussinesq, 1879, p. 40, 113). Boussinesq thought that it was desirable to have such an exact definition of the word *life*, which he thought to be 'a bit vague' (Boussinesq, 1879, p. 112).

Boussinesq's approach to the problem of the will was taken up by Maxwell, who thought that this approach was interesting, even if it was also problematic. In a letter to Galton, he wrote:

> In most of the former methods Dr Balfour Stewart's &c. there was a certain small but finite amount of travail decrochant or trigger-work for the Will to do. Boussinesq has managed to reduce this to mathematical zero, but at the expense of having to restrict certain of the arbitrary constants of the motion to mathematically definite values, and this I think will be found in the long run, very expensive. But I think Boussinesq's method is a very powerful one against metaphysical arguments about cause and effect and much better than the insinuation that there is something loose about the laws of nature, not of sensible magnitude but enough to bring her round in time (Maxwell, 1879a).

Maxwell did realize that a central problem for Boussinesq's theory is that singular solutions, although possible in theory, are extremely unlikely to occur in actual systems. This is because they will only occur if certain quantities (such as forces and particle positions) have a specific value, and the effect disappears if the value is only slightly different. Nevertheless, he thought it was a promising approach, especially because it avoids any need for the mind to exert even a small force that is not regulated by the laws of physics; there is therefore no violation of the laws of physics involved at any scale.

This was an improvement over Maxwell's own approach, a couple of years earlier: in his essay from 1873 on science and free will, Maxwell had suggested that there could be an immaterial directive principle capable of triggering or directing motions in unstable mechanical systems. This would involve indeterminism through a violation of the laws of physics on a small scale, small enough to be beyond our epistemic reach. Maxwell explicitly rejected the view that the principle of determinism should be taken to be absolutely valid to the exclusion of any possible influence of the mind. For us as human beings, with our limited capacities of observation, determinism cannot be confirmed by observation: Maxwell argues that there are many cases in which we are not able to make

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[26] 'il n'y a que la mort, c'est-à-dire le règne des lois mécaniques seules'. Boussinesq (1879), p. 65.

predictions. This is especially the case in those processes which involve instabilities. He concludes:

> If, therefore, those cultivators of physical science from whom the intelligent public deduce their conception of the physicist, and whose style is recognised as marking with a scientific stamp the doctrines they promulgate, are led in pursuit of the arcana of science to the study of the singularities and instabilities, rather than the continuities and stabilities of things, the promotion of natural knowledge may tend to remove that prejudice in favour of determinism which seems to arise from assuming that the physical science of the future is a mere magnified image of that of the past (Maxwell, 1873, p. 823).

As the occurrence of singularities and instabilities is, according to Maxwell, a characteristic of living beings, we should not expect to find determinism when studying living beings.

In the analogies that Maxwell gave of unstable mechanical systems, there could be physical indeterminism through violations of the laws of physics on a small scale, through the exertion of a very small force by an immaterial principle, without there ever being any possibility of observing these violations. One reason why Maxwell might think that the laws of physics could be violated on a small scale is his work in statistical mechanics, which led him to argue that violations of the second law of thermodynamics were theoretically possible (e.g. through Maxwell's demon). According to Maxwell, the second law of thermodynamics is a statistical law of nature, that holds on average on a macroscopic scale, but does not hold rigorously on a small scale. The same might hold for other laws of physics as well: they may also be statistical laws of which violations are possible in principle. Nevertheless, Maxwell apparently thought that this assumption of there being 'something loose' about the laws was not the most elegant approach to the problem of free will, and he therefore approved of Boussinesq's approach in which there is indeterminism in the mechanical system itself and in which there is no violation of the laws of physics involved at any level.

We have seen that if one wants to argue that an immaterial principle can act through directing motions or triggering energy transformations, there are two possibilities: one can argue either that this directive principle can act through exerting a very small (possibly infinitely small) force, or that it can act without exerting any force. The first possibility requires physical systems that are unstable, and involves a small violation of the laws of physics, in particular the law of conservation of energy; moreover, there is the metaphysical problem of how an immaterial principle can exert a physical force, however small. The second possibility requires genuine indeterminism in the equations of physics. Arguing for indeterminism in physics was thus a way to make vital and mental causes compatible with the law of energy conservation.

5. Physical determinism versus physiological determinism

The explanations of life and free will by Maxwell, Stewart, Cournot and Boussinesq were primarily an attempt to make vital and mental causes in physiology compatible with the law of conservation of energy. While indeterminism in mechanics provided a resource to make their arguments work, the debate was not primarily triggered by a general concern over determinism in science, but rather by the claimed applicability of the law of conservation of energy to physiology. This can also be seen by the fact that although Maxwell, Stewart, Cournot and Boussinesq were all concerned about the implications of the law of energy conservation in physiology, not all of them were concerned about determinism in the physiological realm. In particular, Cournot as well as Boussinesq accepted physiology as a deterministic science, as long as it was not reducible to physics and as long as there was a role for genuine vital causes in physiology.

One can make a distinction between physical determinism and physiological determinism:

(1) *Physical* determinism says that the future course of a system is uniquely determined by the laws of physics. Laplacian determinism, according to which perfect prediction of the future states of the universe is possible on the basis of perfect knowledge of the positions, velocities, and forces on all the particles in the universe at an instant, can be counted as a type of physical determinism.[27]

(2) *Physiological* determinism says that the future course of a system is uniquely determined by laws of physiology, which may involve an irreducible vital principle or be otherwise irreducible to physics. A well-known proponent of physiological determinism is Claude Bernard, who argued for determinism in physiology in his *Introduction à l'étude de la médecine expérimentale* (1865), while also arguing that physiological processes are irreducible to physical and chemical processes.[28]

In these terms, Cournot and Boussinesq specifically argue against physical determinism, because they fear that it would lead to an exclusion of non-physical causes and to physical reductionism. Despite their objections against physical determinism, Cournot and Boussinesq do argue for determinism in the physiological realm. Both Cournot and Boussinesq argue that, as long as no free will is involved, physiological processes take place according to deterministic laws. However, this is a physiological determinism that is irreducible to physical determinism, and compatible with the intervention of non-physical causes. In this way they can argue, like Claude Bernard, for lawfulness of

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[27] In Van Strien (2014b), I argue that Laplace's determinism was not directly derived from his physics; nevertheless it is closely related to physics and can be formulated in terms of laws of mechanics.

[28] Bernard argues that there is a kind of vital principle involved in organic processes that directs processes without producing them, but he does not give a detailed account of how this could work. See Bernard (1865), p. 51. On the contrast between Bernard's determinism and Laplacian determinism, see Gayon (2009); Israel (1992).

physiological processes, so that physiology can be a proper science even though it is not reducible to physics.

Both Cournot and Boussinesq specify that physiological processes are deterministic in a non-Laplacian way. According to Laplacian determinism, all future (and past) states of a closed system are fully determined by a specification of the state of the system at the present instant. But both Cournot and Boussinesq argue that in physiology, perfect knowledge of the present state of a system does not suffice to determine the future states; in order to determine the future states of the system, one needs knowledge of past states as well. The difference has to do with heredity: Cournot and Boussinesq do not think that all the information needed for the future development of an organism is present in the seed or embryo. Cournot argues that to determine what will come of a seed, one has to study not only its present state but the past as well:

> That which we lack for predicting the fate of the future plant, when taking into account the actual data of the surrounding environment and hence the variations that it will undergo under the influence of physical forces, is not so much a descriptive anatomy of the germ, pushed far enough, than a genealogy, a history of ancestors, sufficiently detailed and going back far enough. (Cournot, 1875, p. 115-16).[29]

Boussinesq thinks that heredity must be explained through the assumption of a direct influence of the past states, or 'anterior evolutions', on current physiological processes (Boussinesq, 1879, p. 134). Such influence is possible, in his theory, through the directive principle which acts in living beings at singular points. In processes in which no free will is involved, this principle acts according to deterministic laws of physiology. There is thus a 'special', irreducible explanation of heredity, and this explanation depends on the possibility of vital causes that act at unstable or singular points in the system.

However, both Cournot and Boussinesq did think that although processes in physiology are typically deterministic, indeterminism had a limited role to play in the organic world. Cournot argues that occasionally the laws of physiology can allow for indeterminism (just as the laws of physics can allow for physical indeterminism at certain points) (Cournot, 1875, p. 118ff), and that this occasional indeterminism in physiology is needed to account for novelty in the organic realm, such as the development of new species. Boussinesq limits pure indeterminism to the realm of free will (that is to say, the acts of the will are determined in the sense that there is an

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[29] 'Ce qui nous manque pour prédire les destinées de la future plante, en tenant compte comme de raison des données actuelles du milieu ambiant et par suite des variations qu'il subira sous l'influence des forces physiques, c'est bien moins une anatomie descriptive du germe, poussée assez loin, qu'une généalogie, une histoire des ancêtres, suffisamment détaillée et remontant assez haut'.

agency that determines what will happen, but undetermined in the sense that they are not predictable in any way) (Boussinesq, 1879, p. 57).

Thus, although both Cournot and Boussinesq left some room for indeterminism, they both argued that, usually, physiological processes are completely deterministic. Their concern was thus not with determinism in the physiological realm; what they wanted to ensure was that the law of conservation of energy was not taken to lead to a reduction of physiology to physics, and that there could be genuine vital causes.

6. Free will and life

When Maxwell and Boussinesq wrote about free will, they understood it strictly in terms of mind–matter interaction. They argued for an immaterial mind or soul that could cause changes in the body (where the body is treated as a mechanical system), and thus regarded an antimaterialist and dualistic metaphysics as essential for free will. As we've seen, these ideas about the will were very much connected to ideas about life, and about the possibility of non-materialistic explanations of organic processes. These special explanations of life could account e.g. for holistic and teleological features of organisms. For Boussinesq, the problem of how to account for organic processes was just as important as that of free will: he was quite critical of materialist physiology that fully reduced organic processes to the laws of physics and chemistry (Boussinesq, 1879, p. 38-39). Maxwell's primary concern was with free will, but his ideas about the possibility of free will are also connected to the issue of whether life can be explained in a materialist way. This becomes clear in the following passage from 1879 about the very definition of life:

> Science has thus compelled us to admit that that which distinguishes a living body from a dead one is neither a material thing, nor that more refined entity, a 'form of energy'. There are methods, however, by which the application of energy may be directed without interfering with its amount. Is the soul like the engine-driver, who does not draw the train himself, but, by means of certain valves, directs the course of the steam so as to drive the engine forward or backward, or to stop it? (Maxwell, 1879b).

Thus, according to Maxwell, there is no vital matter or vital energy, but there can be a soul which directs motions in living beings.

Finally, Cournot and Stewart were not at all concerned with the issue of free will, with Cournot going so far as to deny free will. According to Cournot, an act is always determined by something, by physical circumstances, physiological or psychological factors, reason, superstition, or by past experiences (Cournot, 1875, p. 239). The French philosopher Renouvier argued that Cournot's ideas could provide a basis for a theory of free will, even if Cournot himself was not interested in the problem of free will but only in the problem of life. But, as Renouvier remarked, 'the question is the same, as it concerns finding a conciliation between a mechanical order and actions that are exerted on this order without belonging to it'.[30]

Cournot and Boussinesq can both be counted as vitalists; although neither held the position that there are vital 'forces' of the same order as physical forces, they did have a dualistic conception of life, and their ideas seem to fit under the label of ontological vitalism or substance vitalism, with an immaterial principle directing motions at the microlevel.[31] The authors discussed in this paper were thus primarily interested in the possibility for a non-physical cause to intervene in living beings, whether the mind or the soul or a vital principle (or even God). They argued for a strict dualism between the body as machine and an immaterial entity that operates the machine. However, they did not go into details about the nature of this immaterial entity or exactly how it was to relate to the body.[32]

Conclusion

The debate discussed in this paper about the possibility of free will or a vital principle that is not regulated by the laws of physics, is very much about the same issue with which Descartes wrestled (notably in the correspondence with Princess Elisabeth; see Shapiro, 1999), of how the mind could act on the body, or, more generally, how a non-

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[30] 'la question est la même, en tant qu'elle a trait à une conciliation à trouver entre un ordre mécanique et des actions qui s'exercent sur lui sans lui appartenir'. Renouvier (1882).

[31] On types of vitalism, see Wolfe (2011). On vitalism in Cournot, see Martin (2011), and Vatin (2007).

[32] The argument that the possibility of vital and mental causes could be saved through an appeal to instability or indeterminism in physics had a kind of afterlife in Bergson, who, in a lecture in 1911, explained how vitalism could work in terms that are very reminiscent of Maxwell, Stewart and Cournot: 'When we investigate the way in which a living body goes to execute movements, we find that the method it employs is always the same. This consists in utilizing certain unstable substances which, like gunpowder, need only a spark to explode them. I refer to foodstuff, especially to ternary substances, carbohydrates and fat. A considerable sum of potential energy, accumulated in them, is ready to be converted into movement. That energy has been slowly and gradually borrowed from the sun by plants; and the animal which feeds on a plant, or on an animal which has been fed on a plant, and so on, simply receives into its body an explosive which life has fabricated by storing solar energy. To execute a movement, the imprisoned energy is liberated. All that is required is, as it were, to press a button, touch a hair trigger, apply a spark; the explosion occurs, and the movement in the chosen direction is accomplished.' (Bergson (1911), p. 18). But Bergson did not think there was an immaterial directive principle that could pull the trigger; instead there was indeterminacy originating in a difference in temporal span between the mental and the physical.

physical cause could have an impact in the physical world. Around the 1870s, this issue was again brought to the foreground through the development of the law of conservation of energy, which Helmholtz and Du Bois-Reymond applied to physiology in order to exclude the intervention of non-physical causes. In response, a number of physicists and mathematicians such as Maxwell, Boussinesq, Cournot and Stewart made attempts to defend strictly dualist conceptions of life and the will, through an appeal to unstable and indeterministic systems in mechanics. The law of conservation of energy thus posed a problem for dualism with regard to life and the will, but did not bring an end to dualist theories.

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