On Aristotelian, Classical and Quantum Physics

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Numbers in brackets refer to selections from the accompanying list of 70 quotations from the history of philosophy and science.

Preface

The boundary between wishing and choosing is defined by the limits of our power. As Aristotle says, we can wish "for impossible things, like [bodily] immortality," but we actively choose what we judge to be within our power [1].

Differing accounts of physical nature, specifically, differing accounts of the relation between the sensible and the intelligible, convey different implications concerning what is within our power, thus different implications for our pattern of choices in life and related dispositions of will and appetite [2, 3, 4]. Here lies the significance of early modern philosophy, and its offspring, classical physics. In Bacon and Descartes, culminating in Newton, *laws of nature* replace natural forms and ends as the fundamental intelligibles of physical science, and imply a vast expansion of human power to predict, control, transform natural processes—for the prolongation of life and "the relief of the human estate."[1] The latest phase of this project is genetic science and its apparently radical possibilities for the transformation of human life. There is even talk of achieving bodily immortality[2]—something impossible on grounds of Aristotle's

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[1] Bacon, *New Organon* II.52; see also I.88, I.129, II.1-6, also *Wisdom of the Ancients* XIII, on Proteus. In *The Advancement of Learning*, Bacon refers to "the dignity and excellency of knowledge and learning in that whereunto man's nature doth most aspire, which is immortality or continuance" (*The Works of Francis Bacon*, ed. Spedding, Ellis, and Heath, Vol. III, p. 318). See also Descartes, *Discourse on the Method*, Part 6, AT VI 61-62, CSM I 142-43, and *Principles* (French) III.44, AT IXB 155, CSM I 255.
[2] Stanley Shostak, *Becoming Immortal: Combining Cloning and Stem-Cell Therapy* (Albany: SUNY Press, 2002).

biological science of organic form, or soul, and its correlative, necessarily corruptible matter.

Because of these connections, between types of physics and their implications—real or imaginary [5]—for the limits of our power, our patterns of choice, corresponding dispositions of will, appetite and imagination, and resulting conceptions of the world, I doubt that it is possible to separate completely natural philosophy and metaphysics from ethics.[3] This is especially problematic today due to the difficulty of discerning the essential limitations of modern natural science.

Introduction

The bookstores contain quite a few books on the weirdness of quantum physics. To my knowledge, there are no books on the weirdness of classical physics, which is even described by physicists as common sense sharpened up. I don't think this is right, and so the most basic theme and more accurate title of this lecture is "Classical Weirdness."

My intention is to discuss classical physics before an audience that is familiar with the Aristotelian background, an audience that is thereby equipped to see the remarkable contrast between early modern philosophy and classical physics, on the one hand, and Aristotelian physics, on the other. I will note, in particular, a paradoxical and immoderate disposition and view of the world associated with classical physics, a

[3] What I have in mind here is more subtle (reflect on quotations 1-5) than the common tendency to derive immorality from physics by bad analogies. Here are two great examples from the physics of the last century: "Einstein showed that all values are relative to the frame of reference and that there's no absolute frame. Therefore, nothing's absolutely wrong and so I can do whatever I want." "Quantum mechanics shows that nothing has any properties before we observe it, so nothing has any meaning before we make it. Therefore, freedom is sovereign and I can do whatever I want."

disposition that continues on into genetic science today, despite great differences between biology and classical physics.

The worldview of classical physics is exemplified by the Newtonian forces-and-particles model of the universe. But certain basic features of the Newtonian forces-and-particles model are found more generally throughout all of prequantum physics, including the physics of Einstein, who is the most articulate opponent of quantum physics. Thus, by the term 'classical physics', I mean all prequantum, post-Aristotelian, mathematical physics, including relativity. I will treat quantum physics mainly indirectly, by means of brief and inadequate comparisons to Aristotelian and classical physics. Against the background of classical physics, quantum physics appears indeed to be a radical departure. But, as noted, I argue that classical physics is itself a radical break from the preceding, Aristotelian physics. This is not to say that Aristotelian natural philosophy can simply provide the adequate philosophical comprehension of quantum physics. The quantum phenomenon of non-locality or entanglement [62] is a challenge for any philosophy of nature. But I believe that the Aristotelian background is valuable, maybe indispensable, for the eventual understanding of what quantum mechanics really means.

On Classical Physics

Basic points about classical physics are nicely made by Louis de Broglie in a 1955 collection of his essays titled *Physics and Microphysics*. The lengthy excerpt that I am about to read describes characteristics common to the three great theories of classical physics—mechanics, electromagnetism, and thermodynamics—as well as Einsteinian relativity. Indeed, the points we'll distill out of this passage will be essential to Einstein's conception of what physics must be. Einstein's conception, based on classical physics, stands opposed, on the one side, to Aristotelian physics, and, on the other, to quantum physics. Here is de Broglie's description of classical physics [58]:

> With [Cartesian] coordinates of space and time, classical mathematical physics was in a condition to represent in a precise way the succession of phenomena which our senses allow us to verify around us.
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> From that moment a way opened quite naturally before theoretical physics and it boldly entered upon it. It was thought that all evolution of the physical world must be represented by quantities [like, for example, the position and momentum of a particle] localized in space and varying in the course of time. These quantities must render it possible to describe completely the state of the physical world at every instant, and the description of the whole of nature could thus be given by figures and by motions in accordance with Descartes's programme. This description would be entirely carried out with the aid of differential equations . . . enabling us to follow the localization and the evolution in the course of time of all the quantities defining the state of the physical world. A magnificent conception for its simplicity and confirmed by the successes which it has achieved for a long time! [We must ask if there were ever successes in biology.] It sustained and orientated all the efforts of the great schools of mathematical physics of the nineteenth century.
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> Assuredly not all scientists agreed to this description of the world by figures and movements exactly in the same way. Some with lively and concrete imagination sought to picture the elements of the material world so as to make the phenomena observed by our senses flow from the existence and movements of atoms or of corpuscles too small to be directly observed; they wanted to dismantle the machine to see all the wheels functioning. Others, more cautious and above all endowed with a more abstract mind, wanted to content themselves by uniquely representing phenomena by means of directly measurable quantities, and mistrusted the hypotheses—in their eyes too speculative and useless—of the atomists. And whereas the atomists were thus boldly advancing, opening new ways and allowing science to make astonishing progress, the energeti[ci]sts, impeded by their more formal and timid methods, retained a certain advantage from the conceptional point of view when they denounced what was simple and a little naïve in the pictures invoked by their bold rivals. But, without being aware of it, both [the atomists and the energeticists] admitted a . . . number of common postulates of which the future was to prove the frailty.
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> They were, in fact, agreed in admitting the validity of the abstract framework of space and time, the possibility of following the evolution of the physical world with the aid of quantities well located in space and varying continuously in the course of time, and the legitimacy of describing all phenomena by groups of differential equations. If the energeti[ci]sts, like Pierre Duhem, refused to allow the intervention everywhere of the 'local movement' which could be represented by a displacement of parts, they fully admitted the consideration of 'general

movements' defined more abstractly by the variations of quantities in the course of time. In spite of their differences of view on the manner of carrying out this program, all theorists were then in agreement in representing the physical universe by well-defined quantities in the framework of space and time and subject to differential equations.

The differential equations . . . of classical mathematical physics have the common character of allowing us to follow rigorously the whole evolution of the phenomena which they describe, if we suppose that there are certain known data relative to an initial state corresponding to a particular value of time. From this there was deduced the possibility of establishing a kind of inevitable interconnexion of all the phenomena, and thus was reached the conception of a universal determinism of physical phenomena. It is not my purpose to examine from the philosophical point of view the idea of universal determinism, and I have not to ask myself, for example, if the mind, which, after all is said and done, is the creator of mathematical physics, could recover its place in a nature conceived of in such a rigid manner. What is certain is that physical phenomena, in so far as they were exactly represented by the differential equations of classical physics, were submitted to a very precisely defined determinism.

Classical physics thus represented the whole physical universe as projected with absolute precision into the framework of space and time, evolving from it according to the laws of an inexorable necessity. It completely set aside the means used to arrive at a knowledge of the different parts of this vast mechanism for, if it recognized the existence of experimental errors, it only saw in them a result of the lack of precision of our senses and of the imperfection of our [experimental] techniques, and accepted the possibility of reducing them indefinitely, at least in principle, by an adequate improvement in our methods. All these representations rested essentially on the classical ideas of space and time; for a long time they appeared sufficient for a description of the evolution of the material world. *Physics and Microphysics*, 116-18

From this long passage, I distill three characteristics of all classical physics, which also imply a notion of the relation between mind and world, or intellect and nature. The three characteristics are:

Continuity of space, time, and motion

Spatio-temporal imageability of fundamental processes

Deterministic causality

First, by continuity of space, time, and motion we mean, for example, that it would be absurd for a planet to change its distance from the sun by suddenly disappearing from its present position and instantaneously reappearing at a new position on an orbit with a different radius. The orbits of planets are continuous; there are no jumps. Second, by spatio-temporal imageability of fundamental processes we mean that we can always put up in our mathematical imagination Cartesian spatial coordinates, x, y, z, and then picture the relevant physical quantities varying in that space with time. Imagine, for example, a particle with a precise position, x(t), and momentum, p(t), moving on its trajectory. This way of using the mind is assumed to be fully adequate to the nature of things. Third, by deterministic causality we mean that, through the equations of motion, the numerical values of the relevant quantities at one instant of time enable us to calculate the values of those quantities at the next instant, and the next, on into the future. No other type of causality, beyond initial data (or boundary conditions) and equations of motion, is needed to account for all natural phenomena.

Accompanying this grand conception is an idea of scientific realism that Einstein expressed very simply: "The belief in an external world independent of the perceiving subject is the basis of all natural science" [60]. At one level, this is immensely plausible: Is the moon there when nobody looks? Of course it is. But at another, more philosophically precise level, Einstein's assertion is seriously problematic; just consider his use of the terms 'science', 'perceiving', 'natural', and, especially, 'external', in light of Aristotle's understanding of these terms.[4] Nevertheless, in this classical conception of the physical world and its accessibility to human mind, it is assumed that the physical quantities (such as position, momentum, energy, field intensity) that we discover in the performance of our physics are in no way brought into being or actualized by our acts of

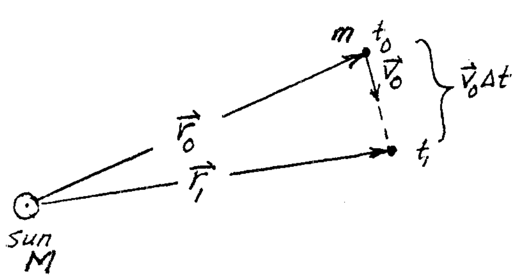
[4] For openers, is the organ of perception external to the perceiving subject?

measurement, any more than the position of the moon or the intensity of the earth's magnetic field are brought into being by our observing or measuring them.

Let me illustrate the classical conception of the world by reviewing the basic logic of the Newtonian calculation of the trajectory of a body moved under gravitational force. This will exemplify de Broglie's account, and will get us, as well, to the Newtonian forces-and-particles model of the universe—a worldview which has remarkable implications.

Basic logic of the Newtonian trajectory calculation

We begin the calculation with Newton's second law of motion, F = mdv/dt, and his law of universal gravitational force, $F = -GMm/r^2$. The problem to be solved is this: given by empirical observation the position, $\mathbf{r}_o$, and velocity, $\mathbf{v}_o$, of a planet or comet relative to the sun at a given time, t_o, to derive the position and velocity, $\mathbf{r}_1$, $\mathbf{v}_1$, at a later time, t_1, without recourse to observation. (I am basically following the account of Einstein and Infeld, *The Evolution of Physics*, p. 30.) So we take a large sheet of plotting paper and represent on it the sun, of mass, M, and the planet or comet, of mass, m, at time t_o:

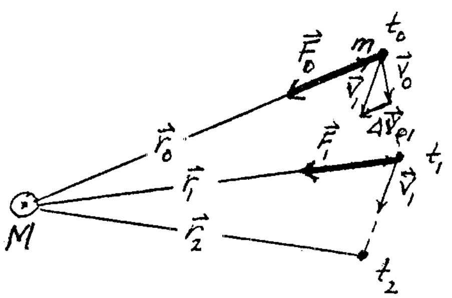


Shown as arrows or vectors are the initial data, $\mathbf{r}_o$, $\mathbf{v}_o$. Knowing $\mathbf{v}_o$, we can *estimate* the position of the planet or comet a short time later at time t_1 by taking its motion as rectilinear (even though it's curvilinear). This is erroneous, but we can make the error as small as we like by making the time interval $\Delta t = t_1 - t_o$, smaller and smaller.

So we move the planet or comet in the direction of $\mathbf{v}_o$ a distance $\mathbf{v}_o\Delta t$. We have now derived from initial data, $\mathbf{r}_o$, $\mathbf{v}_o$, the approximate position of the body at time t_1.

But what is the new velocity, $\mathbf{v}_1$? Obviously, a planet or comet under the gravitational attraction of the sun moves on a curved path (it must, by Newton's first law). Thus the direction of the velocity vector is constantly changing. To estimate the new velocity, $\mathbf{v}_1$, at time t_1, we must find the change in velocity of the body, $\Delta\mathbf{v}_{01}$, that occurred during the first time interval, Δt, from t_o to t_1. Then we can construct, by vector addition, $\mathbf{v}_1 = \mathbf{v}_o + \Delta\mathbf{v}_{01}$. This would complete our prediction of the new position and velocity of the planet or comet a short time, Δt, into the into future. This may seem like a small step, because Δt is small, but if we can repeat it for the next time interval, from t_1 to t_2, deriving $\mathbf{r}_2$ and $\mathbf{v}_2$ from $\mathbf{r}_1$ and $\mathbf{v}_1$, and so on *ad infinitum*, then we will have made a world-historic revolution in human thought. And here is where Newton's law of universal gravitation comes into play; it is the crucial link in the logic of the trajectory calculation, without which our procedure would stop dead after the estimate of $\mathbf{r}_1$.

Combining the law of gravitation with the second law of motion enables the (approximate) calculation of the change in velocity, $\Delta\mathbf{v}_{01}$:



$-GMm/r_o^2 = m\Delta v_{01}/\Delta t$,

thus $\Delta v_{01} = -GM\Delta t/r_o^2$, as shown.

And thus we have $\mathbf{v}_1 = \mathbf{v}_o + \Delta\mathbf{v}_{01}$.

Now we have predicted both $\mathbf{r}_1$ and $\mathbf{v}_1$ from $\mathbf{r}_o$ and $\mathbf{v}_o$.

We can repeat this algorithm: From $F_1 = -GMm/r_1^2$ derive $\Delta\mathbf{v}_{12}$, and then construct

$\mathbf{v}_2 = \mathbf{v}_1 + \Delta\mathbf{v}_{12}$, plotting $\mathbf{r}_2$, $\mathbf{v}_2$, at time t_2, etc. *Thereby we trace out the orbit or trajectory of the body* moving under the gravitational force of the sun, without further recourse to observational data. After performing the calculations, we ask, does the prediction match future observation? For example, does Halley's comet in fact appear where we predicted it would? Within the limits of observational precision, yes, it does.

In this account of the concept of *trajectory*, I have suppressed technical details (non-linearity, the many-body problem, energy considerations) involved in actual trajectory analysis in order to display what is essential to the kind of thinking characteristic of classical physics. I would like to bring out two features of this Newtonian account that are not explicitly discussed by de Broglie, and that are of great importance from the side of the philosophy of nature, namely, (1) species-neutrality and (2) what I call physico-mathematical "secularism" for lack of a better term.[5]

Species-neutrality, a new type of relation between the sensible and the intelligible

It is important to appreciate the remarkable character of Newton's law of gravitational force [51]. Normally, the way a body moves or behaves is intimately related to what kind or species of body it is, as known through ordinary sense perception. Pigs don't fly, sparrows don't oink. The old-fashioned name for this is hylomorphism: "a different form requires different matter" [18]. But Newton's law of gravitation isn't like that; it is not of the Aristotelian, species-specific type of relation between sensible and

[5] I take the term "species-neutrality" from Richard Kennington, an extraordinary teacher of early modern philosophy. I take the term "secularism" from Francois De Gandt: "Newton claimed to treat forces in a purely mathematical mode; by deferral, which in a sense turned out to be final, he left in suspense the properly philosophical or physical questions concerning the causes of gravitation and the ontological reality of force. This neutrality (or 'secularism') of centripetal force in face of the controversies on the cause of gravitation is the essential characteristic of the new science." *Force and Geometry in Newton's* Principia, trans. Curtis Wilson (Princeton University Press, 1995), x-xi.

intelligible. The equation, $F = -GMm/r^2$, expresses an intelligible principle of local motion in nature that is indifferent or neutral to the kind, size, shape, internal structure and function of the two interacting bodies. And that is why, as long as the spatially extended bodies in a gravitational system don't bump into each other, they can be represented mathematically as unextended points: mass points. Recall that, according to Aristotle, in *Physics* 6.4, mobile being, the *per se* movable, is necessarily divisible [8]. An unextended, indivisible point, therefore, could be moved only *per accidens* by being in or on something that is itself *per se* movable and is thus extended. But for the solution of many problems in the physics of gravitational systems, this piece of natural philosophy is not needed. The spatial extendedness, the shapes and sizes of bodies don't matter. As Newton says, "Nature is exceedingly simple and conformable to herself. Whatever reasoning holds for greater motions [e.g., of the solar system] should hold for lesser ones [of particles] as well" [52].

The peculiar, species- or structure-neutrality of the law of gravitational force facilitates Newton's grand analogy—that every body is like a solar system writ small—whereby he generalizes from his particular gravitational theory to the universal forces-and-particles model, a mental image of everything physical in the whole universe. Newton proposes this in the preface to the *Principia* [53]:

> I derive from the celestial phenomena the forces of gravity with which bodies tend to the sun and the several planets. Then from these forces . . . I deduce the motions of the planets, the comets, the moon, and the sea. I wish we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles, for I am induced by many reasons to suspect that they may all [!] depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards one another, and cohere . . . or are repelled and recede. . . . These forces being unknown, philosophers have hitherto attempted the search of Nature in vain.

Here, all the sensible, composite bodies are mentally conceived as clouds of subsensible particles, which move in space on in-principle calculable trajectories. The central assumption here is that all the principles of natural phenomena will be like the gravitational force law: expressible in species-neutral terms like mass, and the spatial relations of point-like centers of attraction and repulsion. Needless to say, the discovery of electric charge and Coulomb's law, similar in its algebraic form to Newton's, gave the Newtonian program great impetus. Thus in 1847 Helmholtz proclaimed the goal of physical science as the complete intellectual penetration of nature by human mind [57]:

> [N]atural phenomena are to be related to the motions of matter possessing unchanging forces of motion, which forces depend only on spatial relations. . . . The force, however, which two whole masses exert on each other must be resolved into the forces of all their parts on one another; thereby mechanics goes back to the forces of material points, that is, to the points of space filled with matter. . . . Finally, then, the task of the physical natural sciences is specified thus: to reduce natural phenomena to unchanging attractive and repulsive forces, whose strength depends on the distance. The realizability of this task is, at the same time, the condition of the complete comprehensibility of nature.
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> "On the Conservation of Force," *Wissenschaftliche Abhandlungen*, Vol. I, pp. 15-16

According to this world-conception, all the wholes in nature consist of particles that obey mathematically expressible force laws analogous to Newton's law of gravitation. All the properties and activities of all the wholes in nature are derivable from, or somehow entailed by the local motions and quantitative properties of their constituent particles. Thus mass, charge, associated force laws, particle position, velocity, momentum, energy, associated densities and flows, etc., are the terms adequate for the explanation of all natural phenomena.

What does the forces-and-particles model of the universe imply, according to its own inner logic, about nature as we ordinarily, prescientifically encounter it? Here is a list of twelve paradoxical implications—implications that clash with our ordinary sense-perception-based experience of, and belief about natural things, especially living things:

- Wholes are reducible to sufficiently simple parts or particles.
- There is no sense in which parts are potential in the whole.
- The only real motion in nature is the local motion of particles.
- There is no true genesis, no real novelty in nature, no substantial change.
- Secondary qualities, like colors, have as such no extramental reality.
- There is no intrinsic unity to natural compounds, which are only aggregates.
- There is no intrinsic stability of the visible, natural kinds of bodies.
- There is no intrinsic scale of size in nature.
- There are no privileged moments or states, no ends in nature.
- The temporal irreversibility that we see is not a fundamental aspect of nature.
- Nature is in principle completely comprehensible to human mind.
- Nature is completely malleable: one kind of body can be transformed into another [54].

All of these implications are at odds with the Aristotelian understanding of nature, as can be seen partly from quotations, 7-30, and partly from any course on Aristotle. I want to focus on the last item on the list, above: *transformism*. How does it follow from the universal forces-and-particles model? It follows quite simply. For, if the intelligible principles are species-neutral, then the heterogeneity of species, so evident to our senses, e.g., pig and sparrow, must not result *per se* from those intelligible principles, but must rather be, somehow, accidental. That is: the sensible species are not the effects of causes aimed *per se* at those effects, and so their heterogeneity is not rooted in the essential nature of things, and, furthermore, might not be a barrier to our operation.

For example: In light of Newton's law of universal gravitation, we learn that there is no essential difference or heterogeneity of celestial and terrestrial bodies. In fact, in light of Newton's laws of motion and gravitational force, humanly controlled space flight is discovered to be possible, to be within our power, so that we can choose to do it. By launching a body from earth, namely, a rocket, with enough velocity, engineers can make it go up into the heavens and, metaphorically speaking, transform a terrestrial body into a celestial body. This is in fact shown at the end of Newton's *Principia*. Moreover, by means of rocket stages and appropriate midcourse burns, following the same physics, the engineers can control the trajectory of the rocket and make it go wherever we desire. Now this is a wonderful but particular piece of physics and engineering; we have not mastered all physical phenomena but only one type, gravitational systems. But look what happens to this particular case when, in our imagination, we apply to it Newton's universalizing analogy: "Whatever reasoning holds for greater motions [the earth, the rocket, the solar system] should hold for lesser ones [the tiny particles of a body] as well" [52]. Therefore, one imagines, just as engineers can shape the trajectory of a rocket in the solar system, so also they should be able in the future to control the trajectories of the particles in a cloud that we have traditionally called "a cat" and thereby shape that cloud into one that we have traditionally called "a dog." This may be *practically* difficult today, due to the smallness of the particles and their large number, but there is nothing in the *nature of things* to prevent this—nothing about material being and its principles, or the process of sense perception, or (as de Broglie describes) the use of experimental apparatus that might limit our knowledge and control of the phenomena. Therefore, as Newton himself astonishingly says, "Every body can be transformed into another, of whatever kind, and all the intermediary degrees of qualities can be successively induced in it" [54].

Here is that paradoxical and immoderate disposition and view of the world arising from early modern philosophy and classical physics. Newton is not unique, not an exception for this outlook; see quotations 32-50, from Bacon, Descartes, and Spinoza.

Note how Newton states explicitly that the transformations we can produce will be continuous: he says, "all the intermediary degrees of qualities can be successively induced." It is not clear why Newton asserts this, but it seems that, in the changes we can induce in bodies, there are to be no quantum jumps from one quality or state to another, nor any substantial changes.

I have presented all of this under the heading of species-neutrality, a new type of relation between sensible and intelligible. Newton's forces and particles model is not only species-neutral but, obviously, reductionist: wholes are reducible to parts. Mysteriously holistic principles, like Aristotelian soul or Hegel's concept of life [56], are excluded from nature. This absolute priority of parts to wholes is necessary for Newton's thesis of universal transformism. Note that Darwinism, as it currently understands itself, is also species-neutral [65], although it is not reductionist; Darwinism does not claim that an animal is simply an aggregate of fully actual, elementary parts. Thus, in Darwinian biology, species evolve and transmute according to random variation and natural selection, but not in a way that can be humanly controlled by manipulation of the particles of animals. Human control of evolution, including our own, is a belief in the minds of certain genetic scientists based on their alleged understanding of their power to manipulate DNA [66, 67]. But not all molecular biologists share this belief [68, 69].

The species-neutral reductionism of classical physics is so radical that it directly contributes to one of the great scientific revolutions of the twentieth century, quantum physics. Rutherford's scattering experiments of 1911 led to the nuclear or "planetary" conception of the atom: a dense, positively charged nucleus surrounded by electrons in a much larger environing space. It seems, at first glance, like the solar system, and thus like a vindication of Newton's universal forces and particles model. But the two-part problem of the stability of matter is now posed in the particular terms of the nuclear atom, as follows.

The problem internal stability: Considering a single isolated atom, what keeps the negative electrons in place around the positive nucleus—either at fixed positions or, if we conceive them to circulate like planets, in orbits of fixed radii—in view of the electrical force that strongly attracts them to the nucleus? The external stability problem: Considering the many atoms of liquids and solids—atoms so closely packed that the materials they compose resist compression—what enables each atom to maintain its shape and integrity against the strong external disturbances ("crunching" against the other atoms) to which it must be continually exposed?

Classical physical theory cannot provide answers to these questions. Classical theory makes unintelligible the stability of atoms, and therewith the properties of the chemical species consisting or composed of atoms. We prescientifically experience these properties all the time, e.g., the solidity of our bones and of the chair we are sitting on, and we observe them in sophisticated laboratory experiments, e.g., the color spectra of light emitted from gases under electrical stimulation. This is the world-historic failure of classical physics, and one of the well known doorsteps to quantum physics.[6]

The failure of classical physics on the internal atomic stability problem is described in standard textbooks. There is no stable equilibrium configuration of static, electrically charged particles, a theorem originally attributed to Samuel Earnshaw and immediately derivable from Laplace's equation, $\nabla^2\phi = 0$, for the electric potential in free space. There is no stable configuration of orbits for electrons circulating around the nucleus due to radiative energy loss (accelerating charges produce electromagnetic radiation, and this uses up their mechanical energy, so that the electron would spiral into the nucleus in a tiny fraction of a second).[7]

The failure of classical physics on the external stability problem is succinctly described by Niels Bohr as paraphrased by Heisenberg [59]. The following passage is especially relevant because it situates the difficulty in the very notion of deterministic particle trajectory or, more generally, deterministic system evolution, as described by de Broglie:

> My starting point was not at all the idea that an atom is a small-scale planetary system and as such governed by the laws [like those] of astronomy. I never took things as literally as that. My starting point was rather the stability of matter, a pure miracle when considered from the standpoint of classical physics.

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[6] For about two centuries, classical physics solved all sorts of engineering problems in which the stable properties of liquids and solids were taken for granted and incorporated in the equations as boundary conditions or empirically determined constants. For example, water is incompressible and has a given viscosity, while cement is solid, unlike butter, and will contain the water in a swimming pool, whose surface will be horizontal in equilibrium in the earth's gravitational field. If disturbed, the water will propagate surface waves and eventually return to its stable equilibrium state with a flat surface. This does not, however, explain the respective characteristics of water and concrete in terms of their atomic and molecular constituents, or nuclei and electrons. For this, quantum physics is required.

[7] See William Thomson and P. G. Tait, *Treatise on Natural Philosophy* (Oxford: Clarendon Press, 1857), 372-73; L. D. Landau and E. M. Lifshitz, *The Classical Theory of Fields* (Reading, MA: Addison-Wesley, 1962), 100; R. M. Eisberg, *Fundamentals of Modern Physics* (New York: John Wiley & Sons, 1961), 108-109, also 366-69 on the great importance of the Pauli exclusion principle.

By 'stability' I mean that the same substances always have the same properties, that the same crystals recur, the same chemical compounds, etc. In other words, even after a host of changes due to external influences, an iron atom will always remain an iron atom, with exactly the same properties as before. This cannot be explained by the principles of classical mechanics [or classical electromagnetism], certainly not if the atom resembles a planetary system. Nature clearly has a tendency to produce certain forms . . . and to recreate these forms even when they are disturbed or destroyed. You may even think of biology: the stability of living organisms, the propagation of the most complicated forms which, after all, can exist only in their entirety. But in biology we are dealing with highly complex structures, subject to characteristic, temporary transformations of a kind that need not detain us here. Let us rather stick to the simpler forms we study in physics and chemistry. The existence of uniform substances, of solid bodies, depends on the stability of atoms; that is precisely why an electron tube filled with a certain gas will always emit light of the same color, a spectrum with exactly the same lines. All this, far from being self-evident, is quite inexplicable in terms of the basic principles of Newtonian [and Maxwellian] physics, according to which all effects have precisely determined causes, *and according to which the present state of a phenomenon or process is fully determined by the one that immediately preceded it.* This fact used to disturb me a great deal when I first began to look into atomic physics.

Heisenberg, *Physics and Beyond*, trans. A. J. Pomerans, 39; emphasis added.

On grounds of classical theory, then, there is no way in which a future state—such as the *ground state* characteristic of a given species of atom—could be a cause of present motion.[8]

We can see exactly what Bohr is getting at by means of our trajectory calculation, above: Imagine that a typical classical system, the solar system, suffers a strong external disturbance. Say a large comet or asteroid passes through the solar system, not colliding with any planets, but pulling them off of their previous orbits through its own gravitational force. Is there anything in the fundamental principles of Newtonian physics—the principles that we just used to calculate a trajectory from given initial conditions—that would cause the planets to recover their previous orbits? The answer is, no, for the effect of the comet or asteroid is to "reset" the initial conditions, the positions and velocities of

[8] This is an imprecise but didactically useful formulation of final causality.

the planets, which then *fully* determine the future trajectories under the laws of motion and force (the dynamics). There is no room in this "kind of reasoning" [53] for the solar system somehow to remember, as it were, its past configuration and get back to it. The species-neutrality and reductionism of the classical world view make nature hopelessly mushy.

It is therefore not surprising that the kind of theory required for the phenomena of atomic and molecular stability does not possess those three fundamental characteristics of all classical physics: (1) continuity of space, time and motion, (2) in-principle spatio-temporal imageability of elementary processes, and (3) deterministic causality. Specifically, it is not surprising that "particle trajectory" and "field magnitude"—the central concepts of classical physics—are discovered to be false to nature on the atomic scale.

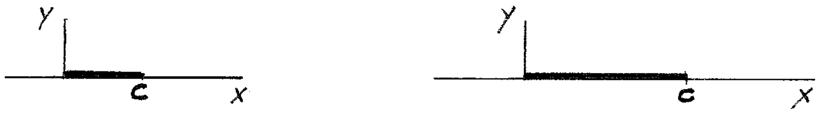
Physico-mathematical "secularism": working around the question of the difference between mathematical objects and physical objects

Are mathematical objects different in some fundamental way from physical objects? Plato says, yes. Aristotle says, yes, but not in the way that Plato thinks. Descartes says, no, the object of physics, matter in motion, is the object of geometry. Newton says, let's set aside this philosophical dispute, and *assume that any difference between mathematicals and physicals makes no difference for the conduct of our mathematical physics.* Henceforth, one can have one's private beliefs about the modes of being of mathematical and physical objects, such as central forces, but no scientific attention will be paid to the question. (You see the analogy to secularism in early modern political theory: one's religious beliefs will be a private matter; the differences between, say, Catholics and Protestants will not be allowed to affect the conduct of government.)

Needless to say, since mathematical objects are not subject *per se* to motion, which is actualization of potentiality [7], physico-mathematical secularism entails the banishment from physics of the seminal Aristotelian notion of potentiality, and of grades of being in function of act and potency.

Physico-mathematical secularism is embedded in the use of Cartesian coordinates and magnitudes to represent *physical* space and time, and physical properties of bodies, particles, and fields, as de Broglie described. Consider the particle trajectory that we calculated and represented on paper, above: At each instant of time, t, the particle possesses a real-numerically precise value of position, x, y, z, and a real-numerically precise value of momentum, mv_x, mv_y, mv_z, as well as energy, E. In general, we assume that such variable magnitudes can faithfully represent anything measurable in the physical world. We thus presume that physical objects have properties with real-numerically precise values. Our measurements and calculations are then supposed to reveal, predict, and finally control the physical quantities objectively existing in space and time. Or are we confusing mathematical objects with physical objects? No matter (pun intended); it's not a problem: unwitting reification of mathematical objects can do no harm to physics—this follows from the original assumption of physico-mathematical secularism.

This assumption, set down in the 17th Century, is dubious, the more so in view of the highly constructed character of the Cartesian, numerical magnitudes that we use in our physics. To see what I mean by "highly constructed character," look at the two magnitudes shown in boldface:



Are the two magnitudes equal or unequal? The answer is, yes. As Euclidean, first-intentional magnitudes, they are obviously unequal, since I can lay the left one adjacent to the right one, cut off a part of the right one equal to the left one, and see the remainder. But as Cartesian, symbolic magnitudes, taken in our minds as possessing numerical value, point by point, based on our choice of a unit length, they are obviously equal, since they both have the same real-numerical value, c.[9] We, unlike premodern mathematicians, have two different concepts of magnitude in our mental toolbox. The Cartesian magnitude is a very sophisticated mental artifact or construct. The idea that Cartesian magnitudes can be mentally substituted for physical space and time, and for the properties of genuinely physical entities without detriment to our knowledge of nature is very questionable.

For example, physico-mathematical secularism leaves classical physics unprepared for anything like the Heisenberg uncertainty principle, e.g., $\Delta x \Delta p \geq h/2\pi$, $\Delta E \Delta t \geq h/2\pi$. This principle means, among other things, that the being and knowability of spatio-temporal properties, like particle position, x, at time, t, are intertwined with the being and knowability of dynamical properties, like momentum, p, and energy, E. Here, again, is Louis de Broglie [62]:

> What is now [e]specially important for us to understand is the profound meaning of this rather mysterious idea of the quantum of action [Planck's constant, $h = 6.62 \times 10^{-27}$ erg-sec]. Up till [the early 20th Century] the space and time of classical physics, or its successor—the space-time of the relativity physics—had

[9] Jacob Klein, *Greek Mathematics and the Origin of Algebra* (Cambridge, MA: M.I.T. Press, 1968), 117-25, 197-211.

appeared to us as a framework given *a priori* and [being] quite independent of what one could put into it, [being] quite independent particularly of the movements and evolution of the bodies which were localized in it. . . .

The real significance of the quantum of action [Planck's constant, h] has been disclosed to us notably by the discovery of Heisenberg's uncertainties. . . . It seems certain today that the existence of the quantum of action expresses a formerly totally unsuspected union between the framework of space and time and the dynamical phenomena which take place in it. The picture of space and time [in classical physics] is essentially static; a body, a physical entity, which has an exact location in space and in time is, by this very fact, deprived of all evolutionary property; [but] on the contrary, a body which is developing, which is endowed with dynamic properties, cannot really be attached to any point of space and time. These are philosophical remarks which go back to Zeno [and so to Aristotle]. . . . Heisenberg's uncertainty relations appear akin to these remarks; they teach us, in effect, that it is impossible to attribute simultaneously to a body a well-defined motion and a well-determined place in space and time.

Physics and Microphysics, 120-22

There is no way in the classical conception of mind and world, space and time, mathematics and physics, measurement and calculation, in which our knowledge of one physical quantity, say, position or time, could affect or interfere with, or limit our knowledge of another such quantity, say, momentum or energy. They are all just Cartesian magnitudes. But, as de Broglie reminds us, pointing back to Aristotle, a moving body—as opposed to a mathematical point "moving" in our imagination—is not *actually* in a place or at a fixed position; if it were, it would not be in motion. Aristotle, of course, did not quantify the indeterminacy in the position of a body moving with a given speed; he did not discover Planck's constant. But Aristotle does prepare us for the idea of indeterminacy—of some things having less being than others—and thus of limits to the intelligibility of the potentially being.

Conclusion

On the other hand, quantum physics reveals something unanticipated by anyone prior to Einstein and his famous debate with Bohr, 1927 to 1935. This new thing is non-locality or entanglement, the Einstein-Podolsky-Rosen (EPR) correlations that Einstein called "spooky actions at a distance."[10] Here is the metaphor used by Einstein to illustrate the effect and to convey his sense of frustration with, and rejection of, quantum physics.

Imagine a ball in one of two boxes. Each box has a hinged lid that we can lift in order to observe whether the ball is in that box or not. We begin in the situation in which we do not know which box the ball is in. We can characterize the state of our knowledge by saying that there is a 50 percent probability that the ball is in either box. We then open one box and thereby discover which box the ball was in. By discovering which box the ball was in, we reduce our ignorance to certainty. It would be absurd to think that our act of observation created the presence or absence of the ball in the box we opened. But this is what the Copenhagen Interpretation of quantum physics says. The 50 percent probability was not just a feature of our knowledge, but (somehow) of the being of the ball. Very well, says Einstein, how much time does it take for the information that, say, box 1 is empty (because we looked in box 1) to propagate through space over to box 2 where the ball is then produced? The Copenhagen Interpretation says, no time at all; it's instantaneous. Einstein then asks his final question: how far apart can the two boxes be? And the answer is, arbitrarily far apart; quantum physics places no upper limit on the spatial separation of the boxes. For Einstein—the committed believer in classical

[10] Einstein to Max Born (1947), in Max Born, *The Born-Einstein Letters* (New York: Walker and Co., 1971), 158.

physics—nature simply cannot be this way.

The metaphor of the ball and boxes is, of course, an analogy, and every analogy is lame. The boxes and box-states (occupied, unoccupied) stand for pairs of photons or particles in states of polarization (vertical, horizontal) or spin (up, down). Unlike the boxes, these quantum systems are accessible only in extraordinarily artfully arranged, multi-stage experiments that prepare the photons or particles in pair-states possessing the quantum property of *coherence*. As I recall, EPR correlations have been observed over laboratory distances of about 20 to 40 feet, beginning with the experiments of Aspect in 1982.[11] The large question is, what philosophical understanding might be adequate to this unusual phenomenon?

[11] See Tim Maudlin, *Quantum Non-Locality and Relativity* (Malden, MA: Blackwell, 2002).

Quotations from the History of Philosophy and Science
Richard F. Hassing, TAC, March 7, 2003
Updated June 18, 2008

Aristotelian Ethics: wish, power, choice, disposition, appearance.

1 [Choice] is not wish, although it seems near to it; for choice cannot relate to impossibles . . . but there can be wish for impossibles, like immortality (deathlessness). . . . But no one chooses such things, but only what he thinks can be brought about through his own efforts. . . . in general, choice seems to be concerned with the things that are within our power. *NE* 3.2, 1111b20-30

2 'Good' and 'bad' signify a quality most of all in things having a soul, and of these most of all in those that have choice. *Meta.* 5.14, 1020b23-25

3 The origin of action . . . is choice, and that of choice is desire and reasoning with a view to an end. This is why choice cannot exist either without intellect and thinking, or without an ethical disposition; for good action and its opposite cannot exist without a combination of thinking and character. *NE* 6.2, 1139a31-35

4 [E]ach state of character has its own ideas of the noble and the pleasant. *NE* 3.4, 1113a32

5 Every desire (*orexis*) . . . is for the object of desire (*orekton*), which is the starting point of the practical intellect. . . . [T]he intellect does not appear to cause motion without desire (*orexis*); for wish (*boulêsis*) is a species of desire (*orexis*), and whenever a man is moved according to judgment, he is moved according to wish (*boulêsis*) also [see *NE* 3.3, 1113a11-13]. But desire (*orexis*) may cause motion in violation of judgment [also]; for desire (*epithumia*) is a [species of] desire (*orexis*). Now the intellect [is] in every case right; but desire (*orexis*) or imagination [may be] right and [may be] wrong. In view of these facts, what always causes motion is the object of desire (*orekton*); but this object may be either the good or the apparent good. . . . *De Anima* 3.10, 433a16-29

6 'He that is ignorant (says the proverb) receives not the words of knowledge, unless thou first tell him that which is in his own heart.'
Bacon, "The Plan of the Great Instauration," para. 2

Aristotelian Physics: wholes and parts, actual and potential.
(Wholes are prior to parts; parts can be potentially in the whole; motion is only partly actual.)

7 [M]otion is the actuality of the potentially being as such. . . . [M]otion is thought to be an actuality of a sort, yet it is incomplete; and the cause of this is the fact that the potential, of which this is the actuality, is incomplete. . . . [M]otion is . . . difficult to grasp but capable of existing. . . .
Physics 3.1, 201a11, 3.2, 201b32-33, 202a2

8 [N]o thing is in motion in an [indivisible] moment. . . . Everything that is changing is of necessity divisible. *Physics* 6.3, 234a25, 6.4, 234b10

9 And what is continuous and limited is said to be a whole when it is some one thing consisting of many constituents, especially when these exist potentially. . . . *Meta.* V.26, 1023b33-34

10 [Material parts] cannot exist if separated from the whole; for it is a finger of an animal not in any manner whatsoever, since it is equivocally called 'a finger' if it is dead. *Meta.* VII.10, 1035b23-25

11 For it is not in any manner whatsoever that a hand is a part of the body, but only when it can perform its function, so it must be alive; if not, it is not a part. *Meta.* VII.11, 1036b31-32

12 For the whole must of necessity be prior to the part; for if the whole [body] is destroyed there will not be a foot or a hand, unless in the sense that the term is similar (as when one speaks of a hand made of stone), but the thing itself will be defective. . . . *Pol.*I.2, 1253a19-24

13 [W]hen the animal is one and is continuous by nature. . . . every part exists potentially. *Meta.* VII.16, 1040b15-16

14 If the eye were an animal, its vision would be its soul . . . and if vision departs, there is no eye any longer, except equivocally, as in the case of the eye in a statue or a painting. . . . just as the eye is its vision with its pupil, so the animal is its soul with its body. *De An.* II.1, 412b19-22, 413a3

15 [I]f a soul were in only one part as a form, it would not be the act of an organic body, but the act of only one organ, for example, of the heart or of some other organ; and the other parts of the body would be actuated by other forms. And thus the whole body would not be a natural unit, but merely something made up of parts [the parts not being potentially in the whole, but actually in the whole, as in an artifact]. Therefore it follows that a soul is in the whole body and in each of its parts. Aquinas, *Questions on the Soul*, q 10

Aristotelian Physics: the relation between sensible and intelligible.
(It's *species-specific*: what the different natural kinds have in common is not as fundamental as what differentiates and specifies them.)

16 Ought w e . . . to begin by discussing each separate species—man, lion, ox, and the like—taking each kind in hand independently of the rest, or ought we rather to deal first with the attributes which they have in common in virtue of some common element of their nature . . . ? Now it is plain that if we deal with each species independently of the rest, we shall frequently be obliged to repeat the same statements over and over again. . . . The causes concerned in the generation

of the works of nature are, as we see, more than one. There is the final cause and there is the motor cause. Now we must decide which of these two causes comes first, which second. Plainly, however, that cause is the first which we call the final one. *Parts of Animals*, 639a15-25, b12-15

17 The principles and elements cannot be the same for all things, except by analogy, that is, in the sense in which one might say that there are three principles, form, privation, and matter; but each of these is distinct for each genus.
Meta. 1070b18-20

18 [M]at ter is among the relative things: for a different form, a different matter.
Phys. 194b9

19 [A]ll things that change have matter, but there is distinct matter in distinct things.
Meta. 1069b25

20 For e ach motion it is the subject capable of that motion which has that motion.
Phys. 251a14

21 [T]he soul is no t a body but something of a body, and, because of this, it exists in a body. But it exists in such and such a body and not as the earlier thinkers thought; they fitted it to a body without further specifying what that body is or what kind of a body it is, although there is no evidence that any chance body can receive any chance soul. According to reason, too, the case is such as the following: each thing's actuality by its nature can exist [only] with the potentiality which belongs to that thing or with its appropriate matter. *De An.* II.2, 414a20-28

22 [W]hat each thing is—for example, a human being, a horse, or a household—when its coming into being is complete (*tês geneseôs telestheisês*) is, we assert, the nature of that thing. *Pol.* 1252b32-34

23 [T]hat for the sake of wh ich, or the end, is what is best. *Pol.* 1253a1

24 [W]hat is by nature proper to each thing will be at once the best and the most pleasant for it. *Nic. Ethics* 1178a5

25 What then can this [hum an] function (*ergon*) be? Mere life appears to be common to the plants, whereas we are looking for the distinctive[ly human].
Nic. Ethics 1097b33-1098a1

26 [N]ature does nothing in vain . . . man alone amon g the animals possesses speech.
Pol. 1253a8-9

27 [I]t is peculiar to man as compared to the other animals that he alone has a perception of good and bad, just and unjust. *Pol.* 1253a15-17

28 [T]he soul and other natural forms are not *per se* subject to motion . . . they are, moreover, the perfections of mutable things.

Aquinas, *In de trinitate*, Q 5, A 2, ad 6

Aristotelian Physics: form as both source and limit of knowledge.

29 Limit means . . . the substance of each thing, or the essence (*to ti en einai*) of each thing, for this is said to be the limit of knowledge, and if of knowledge then of the thing also. *Meta*. V.17, 1022a5, 9-10

30 [E]ssence will belong to nothing which is not a species (*eidos*) of a genus, but only to a species of a genus. . . . [B]y form (*eidos*) I mean the essence of each thing. *Meta*. VII.4, 1030a12-13, VII.7, 1032b2

Early Modern Philosophy and Classical Physics: the relation between sensible and intelligible, reductionism, transformism.

(The relation between sensible and intelligible is *species-neutral*: what different natural kinds have in common is more fundamental than what specifically differentiates them.)

An ancient precursor:

31 STREPSIAD ES: You know the house next door?
PHEIDIPPIDES: Yes. What is it?
STREPSIADES: That, my son, is the Thinkery. For clever brains only, they say. It's where the scientists live, the ones who try to prove that the sky is like one of those round things you use to bake bread. They say it's all around us and we're—
PHEIDIPPIDES: And we're the lumps of coal, I suppose?
STREPSIADES: Exactly—you've got the idea.

Aristophanes, *The Clouds*, 92-96

Bacon:

32 When man contemplates nature working freely, he meets with different species of things, of animals, of plants, of minerals; whence he readily passes into the opinion that there are in nature certain primary forms which nature endeavors to educe. . . . *New Organon*, I.66

33 [I]n nature nothing really exists besides individual bodies [true particles, II.8; thus no forms], performing pure individual acts [thus no parts potentially in the whole] according to law. *New Organon*, II.2

34 [F]orms are figm ents of the human mind, unless you call those laws of action forms. *New Organon*, I.51

35 [T]he philosoph y which is now in vogue embraces and cherishes certain tenets . . .

as with respect to the doctrine that the heat of the sun and of fire differ in kind [because celestial bodies and terrestrial bodies are essentially distinct; 198a30-32] . . . . Which things, if they be noted accurately, tend wholly to the unfair circumscription of human power. . . . Whereas it is most unskillful to investigate the nature of anything [e.g., heat or gravitation] in the thing itself [fire; a stone], seeing that the same nature [heat; gravitation] which appears in some things [spirit of wine; celestial motions] to be latent and hidden is in others [fire; a stone] manifest and palpable. . . . *New Org.*, I.88

36 On a given body to generate and superinduce a new nature or new natures is the work and aim of human power. . . . *New Org.*, II.1

37 I f a man be acquainted with the cause of any nature (as whiteness or heat) in certain subjects only, his knowledge is imperfect. . . . But whosoever is acquainted with [laws of nature] embraces the unity of nature in materials the most unlike [e.g., a magnet and living flesh], and is able therefore to detect and bring to light things never yet done [magnetic resonance imaging in medical diagnostics], and such as neither the vicissitudes of nature, nor industry in experimenting, nor accident itself, would ever have brought into act . . . *New Org.*, II.3

38 We are told . . . that there are three kinds of heat: the heat of heavenly bodies, the heat of animals, and the heat of fire; and that these heats . . . are in their very essence and species—that is to say, in their specific nature—distinct and heterogeneous. . . . [But] the [Baconian] understanding, rejecting the notion of essential heterogeneity, easily rises [by Method] to inquire what are in reality [as opposed to our erroneous opinions about form] those points of difference between the heat of the sun and of fire . . . however they may themselves partake of a common [Baconian] nature. *New Org.*, II.35

Descartes:

39 there are but few pure and simple natures which either our experience or some light innate in us enable to intuit as primary and per se . . . Figure, extension, motion, etc. are of this sort. . . . If we have even the slightest grasp of [a simple nature, e.g., a line] . . . [then] we know it completely. *Regulae*, VI, XII

40 [B]y 'nature' I do not here mean some goddess or other sort of imaginary power. Rather, I use that word to signify matter itself. . . . *Le Monde*, Chap. 7

41 I suppose that the quantity of the matter I have described does not differ from its substance . . .[and] I conceive of its extension . . . not as an accident, but as its true form and its essence. *Le Monde*, Chap. 6

42 The nature of body consists not in weight, hardness, colour, or the like, but simply in extension. *Principles*, II.4

43 [W]e understand this nature [of corporeal substance or extension] to be exactly the same in any part of space as in the whole space. *Principles*, II.8

44 All the variety in matter, all the diversity of its forms, depends on [local] motion [of patches of extension]. *Principles*, II.23

45 The only principles which I accept, or require, in physics are those of geometry and pure mathematics; these principles explain all natural phenomena . . . *Principles*, II.64

46 I took pains to make everything belonging to the nature of fire very clearly understandable. . . . Thus I made clear how it is formed and fueled, how sometimes it possesses only heat without light, and sometimes light without heat; how it can produce different colors and various other qualities in different bodies; how it melts some bodies and hardens others; how it can consume almost all bodies, or turn them into ashes and smoke; and finally how it can, by the mere violence of its action, form glass from these ashes—something I took particular pleasure in describing since it seems to me as wonderful a transmutation as any that takes place in nature. *Discourse on Method*, Part V, AT VI 44-45

47 [The] nature [of all purely material things, which includes animals] is much easier to conceive if we see them develop gradually (*peu à peu*) in this way than if we consider them only as entirely completed (*toutes faites*). *Discourse on Method*, Part V, AT VI 45

48 It is only the will, or freedom of choice, which I experience within me to be so great that the idea of any greater faculty is beyond my grasp; so much so that it is above all in virtue of the will that I understand myself to bear in some way the image and likeness of God. *Fourth Meditation*, AT VII 57

Spinoza:

49 That which is common to all [bodies] . . . and which is equally in a part and in the whole [e.g., Cartesian extension, Newtonian mass], does not constitute the essence [the Aristotelian natural form; *Meta.* 1030a12] of any particular thing. . . . Those things which are common to all . . . cannot be conceived except adequately. *Ethics*, II.37, 38

50 Nothing comes to pass in nature, which can be set down to a flaw therein [cf. Phys. 199b4]; for nature is always the same, and everywhere one and the same in her efficacy and power of action; that is, nature's laws and ordinances, whereby all things come to pass and change from one form to another, are everywhere and always the same; so that there should be one and the same understanding of the nature of all things whatsoever, namely, through nature's universal laws and rules. *Ethics*, III, Introduction

Newton:

51 [T]here is a power of gravity pertaining to all bodies, proportional to the several quantities of matter which they contain . . . [and] inversely as the square of the distance. . . [$F = -GMm/R^2$]. *Principia*, III, Prop. 7 and Cor. 2

52 Nature is exceedingly simple and conformable to herself. Whatever reasoning holds for greater motions [e.g., of the solar system] should hold for lesser ones [of atoms] as well. "Unpublished Conclusion of the *Principia*," in A. R. and M. B. Hall, *Unpublished Scientific Papers of Isaac Newton*, 333

53 I derive from the celestial phenomena the forces of gravity with which bodies tend to the sun and the several planets. Then from these forces . . . I deduce the motions of the planets, the comets, the moon, and the sea. I wish we could derive the rest of the phenomena of Nature by the same kind of reasoning from mechanical principles, for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards one another, and cohere . . . or are repelled and recede. . . . These forces being unknown, philosophers have hitherto attempted the search of Nature in vain. *Principia*, 1686 Preface

54 Ever y body can be transformed into another, of whatever kind, and all the intermediary degrees of qualities can be successively induced in it.
Principia, First Edition, Hypothesis III

Leibniz:

55 I believe that monads always have full existence and that we cannot conceive of parts being said to be potentially in the whole.
Leibniz, Letter to Des Bosses, 16 June 1712

Hegel (a post-Newtonian holist):

56 The notion of the whole is to contain parts: but if the whole is taken and made what its notion implies, i.e., if it is divided, it at once ceases to be a whole. Things there are, no doubt, which correspond to this relation: but for that very reason they are low existences. . . . The relation of whole and parts comes very easy to reflective understanding; and for that reason it often satisfies when the question really turns on profounder ties. The limbs and organs, for instance, of an organic body are not merely parts of it: it is only in their unity that they are what they are, and they are unquestionably affected by that unity, as they also in turn affect it. These limbs and organs become [mere] parts, only when they pass under the hands of the anatomist, whose occupation, be it remembered, is not with the living body but with the corpse. Not that such analysis is illegitimate: we only mean that the external and mechanical relation of whole and parts is not sufficient for us, if we want to study organic life in its truth.
Hegel, *Encyclopedia Logic*, sec. 135, note; see also sec. 38, note

Helmholtz:

57 [N]atural phenomena are to be related to the motions of matter possessing unchanging forces of motion, which forces depend only on spatial relations. . . . The force, however, which two whole masses exert on each other must be resolved into the forces of all their parts on one another; thereby mechanics goes back to the forces of material points, that is, to the points of space filled with matter. . . . Finally, then, the task of the physical natural sciences is specified thus: to reduce natural phenomena to unchanging attractive and repulsive forces, whose strength depends on the distance. The realizability of this task is, at the same time, the condition of the complete comprehensibility of nature.

"On the Conservation of Force," *Wissenschaftliche Abhandlungen*, Vol. I, pp. 15-16

De Broglie: the conception of the world according to classical physics

58 With [Cartesian] coordinates of space and time, classical mathematical physics was in a condition to represent in a precise way the succession of phenomena which our senses allow us to verify around us.

From that moment a way opened quite naturally before theoretical physics and it boldly entered upon it. It was thought that all evolution of the physical world must be represented by quantities [like, for example, the position and momentum of a particle] localized in space and varying in the course of time. These quantities must render it possible to describe completely the state of the physical world at every instant, and the description of the whole of nature could thus be given by figures and by motions in accordance with Descartes's programme. This description would be entirely carried out with the aid of differential equations . . . enabling us to follow the localization and the evolution in the course of time of all the quantities defining the state of the physical world. A magnificent conception for its simplicity and confirmed by the successes which it has achieved for a long time! It sustained and orientated all the efforts of the great schools of mathematical physics of the nineteenth century.

Assuredly not all scientists agreed to this description of the world by figures and movements exactly in the same way. Some with lively and concrete imagination sought to picture the elements of the material world so as to make the phenomena observed by our senses flow from the existence and movements of atoms or of corpuscles too small to be directly observed; they wanted to dismantle the machine to see all the wheels functioning. Others, more cautious and above all endowed with a more abstract mind, wanted to content themselves by uniquely representing phenomena by means of directly measurable quantities, and mistrusted the hypotheses—in their eyes too speculative and useless—of the atomists. And whereas the atomists were thus boldly advancing, opening new ways and allowing science to make astonishing progress, the energeti[ci]sts, impeded by their more formal and timid methods, retained a certain advantage from the conceptional point of view when they denounced what was simple and a little naïve in the pictures invoked by their bold rivals. But, without being aware of it, both [the atomists and the energeticists] admitted a . . . number of common postulates of which the future was to prove the frailty.

They were, in fact, agreed in admitting the validity of the abstract framework of space and time, the possibility of following the evolution of the physical world with the aid of quantities well located in space and varying continuously in the course of time, and the legitimacy of describing all phenomena by groups of differential equations. If the energeti[ci]sts, like Pierre Duhem, refused to allow the intervention everywhere of the 'local movement' which could be represented by a displacement of parts, they fully admitted the consideration of 'general movements' defined more abstractly by the variations of quantities in the course of time. In spite of their differences of view on the manner of carrying out this program, all theorists were then in agreement in representing the physical universe by well-defined quantities in the framework of space and time and subject to differential equations.

The differential equations . . . of classical mathematical physics have the common character of allowing us to follow rigorously the whole evolution of the phenomena which they describe, if we suppose that there are certain known data relative to an initial state corresponding to a particular value of time. From this there was deduced the possibility of establishing a kind of inevitable interconnexion of all the phenomena, and thus was reached the conception of a universal determinism of physical phenomena. It is not my purpose to examine from the philosophical point of view the idea of universal determinism, and I have not to ask myself, for example, if the mind, which, after all is said and done, is the creator of mathematical physics, could recover its place in a nature conceived of in such a rigid manner. What is certain is that physical phenomena, in so far as they were exactly represented by the differential equations of classical physics, were submitted to a very precisely defined determinism.

Classical physics thus represented the whole physical universe as projected with absolute precision into the framework of space and time, evolving from it according to the laws of an inexorable necessity. It completely set aside the means used to arrive at a knowledge of the different parts of this vast mechanism for, if it recognized the existence of experimental errors, it only saw in them a result of the lack of precision of our senses and of the imperfection of our [experimental] techniques, and accepted the possibility of reducing them indefinitely, at least in principle, by an adequate improvement in our methods. All these representations rested essentially on the classical ideas of space and time; for a long time they appeared sufficient for a description of the evolution of the material world. *Physics and Microphysics*, 116-18

Quantum Physics:

59 My starting point was not at all the idea that an atom is a small-scale planetary system and as such governed by the laws [like those] of astronomy. I never took things as literally as that. My starting point was rather the stability of matter, a pure miracle when considered from the standpoint of classical physics.

By ‘stability’ I mean that the same substances always have the same properties, that the same crystals recur, the same chemical compounds, etc. In other words, even after a host of changes due to external influences, an iron atom will always remain an iron atom, with exactly the same properties as before. This cannot be explained by the principles of classical mechanics [or classical electromagnetism], certainly not if the atom resembles a planetary system. Nature clearly has a tendency to produce certain forms . . . and to recreate these forms even when they are disturbed or destroyed. You may even think of biology: the stability of living organisms, the propagation of the most complicated forms which, after all, can exist only in their entirety. But in biology we are dealing with highly complex structures, subject to characteristic, temporary transformations of a kind that need not detain us here. Let us rather stick to the simpler forms we study in physics and chemistry. The existence of uniform substances, of solid bodies, depends on the stability of atoms; that is precisely why an electron tube filled with a certain gas will always emit light of the same color, a spectrum with exactly the same lines. All this, far from being self-evident, is quite inexplicable in terms of the basic principles of Newtonian [and Maxwellian] physics, according to which all effects have precisely determined causes, and according to which the present state of a phenomenon or process is fully determined by the one that immediately preceded it. This fact used to disturb me a great deal when I first began to look into atomic physics.

Heisenberg, *Physics and Beyond*, trans. A. J. Pomerans, 39

60 The belief in an external world independent of the perceiving subject is the basis of all natural science. Einstein, *Ideas and Opinions*, 266, also 270

61 [I] cannot believe that we must abandon, actually and forever, the idea of direct representation of physical reality in space and time.

Einstein, *Ideas and Opinions*, 334

62 What is now [e]specially important for us to understand is the profound meaning of this rather mysterious idea of the quantum of action [Planck’s constant, h = 6.62×10^{-27} erg-sec]. Up till [the early 20^{th} Century] the space and time of classical physics, or its successor—the space-time of the relativity physics—had appeared to us as a framework given *a priori* and [being] quite independent of what one could put into it, [being] quite independent particularly of the movements and evolution of the bodies which were localized in it. . . .

The real significance of the quantum of action has been disclosed to us notably by the discovery of Heisenberg’s uncertainties. . . . It seems certain today that the existence of the quantum of action expresses a formerly totally unsuspected union between the framework of space and time and the dynamical phenomena which take place in it. The picture of space and time [in classical physics] is essentially static; a body, a physical entity, which has an exact location in space and in time is, by this very fact, deprived of all evolutionary property; [but] on the contrary, a body which is developing, which is endowed with dynamic properties, cannot really be attached to any point of space and time. These are philosophical remarks which go back to Zeno. . . . Heisenberg's uncertainty relations appear akin to these remarks; they teach us, in effect, that it is impossible to attribute simultaneously to a body a well-defined motion and a well-determined place in space and time. De Broglie, *Physics and Microphysics*, 120-22

63 When two systems, of which we know the states by the respective representatives, enter into temporary physical interaction due to known forces between them, and when after a time of mutual influence the systems separate again, then they can no longer be described in the same way as before, viz. by endowing each of them with a representative of its own [independent of the other]. I would not call that *one* but rather *the* characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought. By the interaction, the two representatives (or ψ-functions) have become entangled. To disentangle them we must gather further information by experiment. . . . After reestablishing one representative by observation, the other one can be inferred simultaneously. In what follows the whole of this procedure will be called *the disentanglement*. Its sinister importance is due to its being involved in every measuring process. . . .

Another way of expressing the peculiar situation is: the best possible knowledge of a *whole* does not necessarily include the best possible knowledge of all its *parts*, even though they may be entirely separated [in space] and therefore virtually capable of being "best possibly known", i.e. of possessing, each of them, a representative of its own. The lack of knowledge is by no means due to the interaction being insufficiently known—at least not in the way that it could possibly be known more completely—it is due to the interaction itself.

Attention has recently been called [Einstein, Podolsky and Rosen, *Phys. Rev.* 47 (1935), 777] to the obvious but very disconcerting fact that even though we restrict the disentangling measurements to *one* system, the representative obtained for the *other* system is by no means independent of the particular choice of observations which we select for that purpose and which by the way are *entirely* arbitrary. It is rather discomforting that the theory should allow a system to be steered or piloted into one or the other type of state at the experimenter's mercy in spite of his having no access to it. This paper does not aim at a solution of the paradox, it rather adds to it, if possible.

Schroedinger, "Discussion of Probability Relations Between Separated Systems," *Proc. Cambridge Philosophical Society* 31.1 (Jan. 1935): 555-56

64 We should doubtless kill an animal if we tried to carry the investigation of its organs so far that we could describe the role played by single atoms in vital functions. . . . the idea suggests itself that the minimal freedom we must allow the organism in this respect is just large enough to permit it, so to say, to hide its ultimate secrets from us. On this view, the existence of life must be considered as an elementary fact that cannot be explained, but must be taken as a starting point in biology, in a similar way as the quantum of action, which appears as an irrational element from the point of view of classical mechanical physics, taken together with the existence of elementary particles, forms the foundation of atomic physics. Niels Bohr, "Of Light and Life," *Nature* 131 (1933): 421-23 and 457-59

Biology: Darwin and DNA

Darwin:

65 [W]e shall have to treat species in the same manner as those naturalists treat genera, who admit that genera are merely artificial combinations made for convenience. This may not be a cheering prospect; but we shall at least be free from the vain search for the undiscovered and undiscoverable essence of the term species. *The Origin of Spcies*, 447

Francis Crick (a colloquial paraphrase of his "central dogma" of molecular biology):

66 DNA makes RNA, RNA makes proteins, and proteins make us.
Quoted in Evelyn Fox Keller, *The Century of the Gene*, 54

Jacob and Monod:

67 The g enome contains not only a series of blue-prints, but a coordinated program of protein synthesis and the means of controlling its execution.
Francois Jacob and Jacque Monod, "Genetic regulatory mechanisms in the synthesis of proteins," *J. Molec. Biol.* **3** (1961), 354

Evelyn Fox Keller:

68 In many cases, experimental markers of the kind discussed above can serve as actual handles—that is, they can be manipulated in such a way as to induce definite and reproducible effects. . . . Today, with the techniques for inducing modifications in the DNA of plants and animals that reliably result in a new or enhanced production of particular proteins, genetic engineering has become a reality. . . . But *cause* in such a conspicuously pragmatic sense makes no claim either on generality or on long-term consequences. . . .
The Century of the Gene, 141-42

R. G. Collingwood:

69 In this sense, the cause of an event in nature is the handle . . . by which human beings can manipulate it. . . . The question, 'What is the cause of an event *y*?' means in this case 'How can we produce or prevent *y* at will?' . . . A cause in [this pragmatic] sense . . . is conditional. . . . [N]o one ever tries to enumerate [the conditions] completely. Why should he? If I find that I can get a result by certain means I may be sure that I should not be getting it unless a great many conditions were fulfilled; but so long as I get it I do not mind what these conditions are. If owing to a change in one of them I fail to get it, I still do not want to know what they all are; I only want to know what the one is that has changed.
An Essay on Metaphysics, ed. Rex Martin, 296, 301, 303

Leon Kass:

70 Everything is in principle open to intervention; because all is alterable, nothing is deemed either respectably natural or unwelcomely unnatural. . . . The notion of the distinctively human has been seriously challenged by modern scientists. . . . The spectacular advances in genetics and molecular biology . . . seem to force upon man . . . at least a serious reconsideration . . . of his place in the whole. . . . [T]he underlying scientific notions and discoveries call into question the very foundations of our ethics and the principles of our political way of life.

Toward a More Natural Science, 11, 37, 3-4