Euler's Galilean Philosophy of Science

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Abstract

Here is a phrase never uttered before: "Euler's philosophy of science." Known as an extraordinary mathematician first, a mathematical physicist second, but never really a physicist — not enough empirical cred — no one has considered whether Euler had a philosophy of science. Even his famed "Letters to a Princess" is described as a somewhat naive parroting of Newton. But Euler is no Newtonian. His philosophy of science borrows from Leibniz, a little from Descartes (in spite of, nay, because of, his critiques of both), but is best seen as continuous with the tradition of a Galilean interpretation of the world as consisting of interacting mechanisms, and the practice of letting the requirements of sound mechanical description and problem solving dictate metaphysics.

1 Introduction

Euler's philosophy of science must be reconstructed from various of his writings, which as a result span a large portion of his life. But a consistent picture does arise. It's main components are a metaphysics, an epistemology, and an explanatory approach. My plan is to describe, briefly, all three, while claiming that they display similarities to Galileo's own philosophy of science.

What I have not found is a "smoking gun"; no explicit acknowledgement by Euler of a debt to Galileo or his approach. But I do think the similarities

are striking. (A supporting argument, not given here, but which I mention in passing, is that just as there are striking similarities between Euler and Galileo, there are stark differences between Euler and either of Newton or Leibniz. Thus, if we are to place Euler in any tradition, it's most plausible that it be Galilean rather than one of these other two contenders.) A brief preview of those similarities are the following:

- a commitment to mechanism and mechanical interaction as an explanatory framework
- a natural science founded equally on matter theory (particularly cohesion) and the science of motion
- seeing mathematics as descriptive of mechanisms, rather than merely motions

The last claim I think will sound most controversial, given interpretations of Galileo's law of falling bodies, for instance, as merely descriptive of the motion and not offering a causal explanation at all. I think that's a misinterpretation, that Galileo did seek a causal interpretation of both the time-squared law and the uniform acceleration law. A number of the diagrams on Galileo's working folios seem to be attempts to derive these laws from natural circular motion. Nonetheless I'm willing to concede that, although Galileo did not see math as describing mechanisms or causal relations between quantities (how could the square of time be a cause of a body's position?), Euler does see the relations that way, at least the *appropriate* relations, the *principles* of mechanics. Euler's position would then represent both an innovation and maturation of Galileo's philosophy of science.

In what follows, I will demonstrate Euler's side of the connection: the role of mechanism in his natural philosophy, his views on the essence of material bodies, and commitment to all causes of change in motion through contact.

2 The organization of Natural Science

In addition to the formal domains of mathematics and logic, Euler distinguishes three different areas when speaking about the study of nature. Natural science is his broadest category, the explanation of causes which affect material bodies.

> Natural science is a science that aims to explain the causes of change that occur to material bodies. (E847, p 1)

But within Natural Science, more specifically, are statics and mechanics, for bodies at rest or in motion, respectively, and metaphysics, which is basically an exercise in interpretation for Euler; viz. it is reasoning about the properties the world must have given the truths of statics and mechanics. (For a discussion of statics and mechanics, see the preface to Euler's *Mechanica*, E015; for the characterization of metaphysics:

> Metaphysics ... is occupied with the investigation of the nature and properties of bodies ... knowing [the truths of Mechanics] will serve as a guide in these thorny investigations. (E149, p2)

See also E200, with the title "Essay on a metaphysical demonstration of the general principle of equilibrium".)

The importance of the organization is the hierarchy implicit it in. The main activity of Natural Science is mechanics for Euler, the study of how forces affect the motion of bodies. But mechanics is embedded within a broader program, which recognizes both the aim of mechanics (demonstrating the causes of change) and the conditions necessary for the possibility of that program (the metaphysics of material bodies.)

3 Criterion of understanding

Mechanics is a mathematical discipline, but since the point of mechanics is explanation of the causes of motion, the mathematical language used within mechanics must meet a criterion of understanding. Euler describes that criterion in the Preface to his *Mechanica*.

> But in all writings which are written without analysis it happens most in Mechanics that the reader, although convinced of the truth of those things which are put forward, nevertheless does not achieve clear and distinct knowledge of them, and so can barely solve the same questions by his own devices when they are altered even a little, unless he engages in analysis and explicates the same propositions using an analytical method. This often happened to me when I began to read through Newton's *Principia* and Hermann's *Phoronomia*: although I seemed to myself to have understood the solutions to many problems, still I could not solve other problems that differed even a little.

Only the analytic approach to mechanics provides a proper understanding of mechanics, and that is a proper understanding of the causes of the various ways the motion of a body can be effected. The analytic calculus has

certain representative affordances which enable easy extrapolation from one solution to another, physically similar, situation.

The feature which makes this so is the ability, in analytic calculus, to represent and operate on functions. Those functions represent the mechanical connections between bodies, equilibrium relations among quantities and changes in quantities. This is a representation more general than merely a mathematical description of a body's motion, or a trajectory in time.

An important class of functional relations are those which describe constraints among the parts of different types of bodies. Euler has a plan for mechanics, exemplified by his plan, albeit, not completed, for his Mechanica. It beings by considering points and the effects of forces on their motions; next are rigid bodies, then fluids, and finally gasses. The nature of these bodies means that the effects of forces on those bodies is different. They are modified by the internal mechanical connections of those bodies.

Functions describe the internal mechanical connections. They also express general properties of bodies. A function describes abstract relations among variables which represent *kinds* of physical properties. An actual existing body is one fully determined, i.e. with specific values for all it's variables.

> If the essence is stipulated in its totality, there arises a single body, containing nothing indeterminate. Such a body is representative of all material bodies really existing as part of this world, since nothing can exist in reality that is not fully determined. Whilst the essence of material bodies in general is subject to few stipulations, the particular types of body, and the individual bodies belonging to each type, arise when the constraints placed on the essence are complete, so that nothing is left indeterminate. (E842, S.8)

Constraints arise through the nature of the body (whether solid, elastic, liquid or gas) and through interactions with other bodies.

There is thus, a close connection between Euler's metaphysics and his mechanics, through functions — and through functions to explanation and equilibrium expressed as mechanical connection.

4 The general properties and essence of bodies

In E847, "An Introduction to Natural Science", Euler considers four general properties of all material bodies, finally arriving at impenetrability as the essence of matter.

> Every material body must occupy in space a particular location, and it is impossible for two bodies to be at the same location at the same time. (E842, p20)

A body could not be said to occupy space unless it was impenetrable. If another body could pass through the location of a body, it could not be said to occupy that space.

The other properties Euler considers as candidates for essence all depend on impenetrability because they, too, depend on the ability of a body to occupy space. Those other properties are extension, mobility, and persistence in a state of motion.

A further distinction is made between what Euler calls coarse matter and subtle matter. The latter is the ether, which differs from coarse matter in that, while it is impenetrable, it is also elastic. Ether is the medium in which light travels, and is also responsible for gravity. Tension in the ether causes there to be a pressure on bodies. The pressure weakens the faster the ether moves, in a direction orthogonal to the motion of the ether. And, since the ether moves faster closer to massive bodies, the difference in sideways pressure causes bodies to move towards heavier ones in the required $1/\mathrm{R}^2$ relation.

The pressure of the subtle matter is also responsible for cohesion of matter, as the ether invades the pores of bodies and surrounds bodies. Again, through the elastic pressure of the ether, bodies cohere, the pressure outside of a body being greater than within. There is no void, for Euler. All of space is filled with either coarse or subtle matter.

5 Impenetrability is the cause of all change

Given that the world is a plenum, Euler can ascribe all change to change through contact. Gravitational attraction is not a property of bodies. There is no gravitational mass, there is no gravitational force.

> 140. Gravity arises from the unequal pressure of the aether, which increases with increasing distance from the earth; therefore the bodies are more strongly pushed towards the earth than

> away from it, and the net excess of these pushing forces is the weight of the body.

All change is through contact. When two bodies come in to contact it is impossible for them to persist in their current state.

> 88. A body is pushed or pressed by others when, because of its impenetrability it is in their way, so that they cannot remain in their state; and through this push or pressure the state of the body itself is altered. From these circumstances originate all forces that act on bodies. (E842, §88)

Each body, in attempting to maintain their state, acts to change the state of the other body. Only in this way is persistence, which Euler says is the proper notion of inertia, properly considered a Force. A Force is the cause of a change. No force is required, therefore, to persist in a state of motion. Persistence is a cause a change of motion in other bodies.

Equilibrium is crucial to the explanation of change through contact. A longer explanation is given in the paper where Euler considers the controversy over vis viva. That paper is E082, titled "On the force of percussion and its true measure", published in 1746. In that paper, Euler gives his account of the proper understanding of what others call the force of inertia. His idea is that when an obstacle is encountered so that a body can no longer maintain its present state there will then be inertia in excess which is no longer consumed within the first body but rather acts to change the state of the other body.

> For as long as the Body remains in the same state of movement or of rest the force of inertia is consumed by conserving its state and consequently is deployed entirely to the inside of the body, without producing anything to the outside. But when external obstacles prevent the body from persevering in its state, so that the force of inertia cannot produce its effect to the inside of the body, then it is deployed to the outside and acts on the external obstacles so that the loss that its effect suffers in the body is exactly compensated by its external action. (E082, p.26)

Any difference in mass between the two bodies will mean that the inertia results in a different amount of speed being given up to the other body, in inverse proportion to the masses. Euler's conception of inertia thus constitutes a physical explanation of the conservation laws which govern collision.

If we construe this operation as an equilibrium or balance exchange we can understand this as a mechanical explanation, relying on analogy with a

lever. [1] This allows a broader class of mechanisms, by allowing functional, equilibrium relations between new quantities such as action. But Euler's conception does not include action at a distance. It is a balanced exchange through the pressure of contact and contact only, caused by the impenetrability of bodies and the force of their attempt to persist in their state of motion.

6 Summary

Euler explains all change in Natural Science through the cause of inertia. The metaphysics required to make this explanation possible makes impenetrability the essence of material bodies. Other general properties, require impenetrability. In particular, when bodies contact, because of their impenetrability, they cannot persist in their given state of motion. The inertia of a body therefore manifests as a force which changes the state of the other body. The motion they lose in this way is equal to the change in motion of the contacted body, and vice versa. Equilibrium is maintained through a balanced exchange of motion.

[1] Machamer, McGuire and Kochiras have recently argued for this way of generalizing the mechanical philosophy as a way of making even action at a distance a mechanical operation. This I think goes a little too far, and it's hard to see why it wouldn't simply make every cause and effect explanation a mechanical one (Aristotle becomes a mechanical philosopher).