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Examples of Rationalism in Physics

> "What led me to my science and what fascinated me from a young age was the, by no means self-evident, fact that our laws of thought agree with the regularities found in the succession of impressions we receive from the natural world, that it is thus possible for the human being to gain enlightenment regarding these regularities by means of pure thought …"

Max Planck, *A Scientific Autobiography* (1948)

1. Introduction

As we've discussed in class, Descartes in the *Meditations* initially regarded sensory beliefs as unreliable and uncertain. They could not simply be accepted on trust. On the other hand, some other beliefs, those supported by reason, were impossible to doubt. Hence Descartes aimed to rescue empirical knowledge by giving a solid logical proof that the senses are (when properly used) reliable. Since Descartes regards reason as the ultimate source of knowledge, he is a rationalist.

In the course of this 'proof', Descartes was luckily provided with knowledge of certain principles by reason alone, the 'natural light'. For example, reason made it clear that nothing can be more perfect than its cause, that a most perfect being necessarily exists, that such a being cannot be a deceiver, and so on. Such truths provided by reason (rather than experience) are called *a priori*. The view that some human knowledge is *a priori*, known innately and independent of experience, is called 'nativism', and is part of the thesis of rationalism.

Descartes' interests included natural philosophy (now called 'science'), especially physics and astronomy. Cartesian physics, though hardly known to scientists today, was very influential in the 17th century. It was Descartes who first formulated 'laws of motion' for simple bodies, and who first attempted to write down laws governing particle collisions. Indeed, after the publication of Newton's great *Principia Mathematica* in 1687, Newtonian physics was immediately accepted in Britain, but in continental Europe some physicists remained Cartesian for a few decades.

As late as 1736, for example, Newtonians and Cartesians were arguing about the precise shape of the earth. Newton had predicted that the earth, due to its rotation, should be an oblate spheroid – slightly flattened at the poles, i.e. wider at the equator. The Cartesians used this as a point of attack, since Cassini had measured the earth to be prolate – slightly pointy at the poles, i.e. narrow at the equator. The French mathematician Pierre Louis Maupertuis went north to Lapland to measure the curvature of the earth there, and compare this to the curvature at Paris. These measurements confirmed the flattening of the poles, as Newton predicted. Voltaire quipped that Maupertuis was the 'aplatisseur du monde et de Cassini' (*flattener of the world and of Cassini*). Ha – take that, Cassini!

Voltaire also told Maupertuis that: "Vous avez confirmé dans des lieux pleins d'ennui/ Ce que Newton connut sans sortir de chez lui." (*You went to the ends of the earth to discover what Newton knew without leaving his armchair* – my rough translation.)

Part of the controversy in physics between Descartes and Newton concerned the issue of what we now call empiricism vs. rationalism. In a nutshell, Newton favoured empiricism, and sought to 'deduce' all his theories from observation, while Descartes was a rationalist, and rather like Max Planck in the quote above believed that he could infer the laws of physics by pure reason, at least to a great extent, and check that they fitted the observations later.

In reading the selection below from Descartes' *Principles of Philosophy*, you'll see that Descartes also derives physical laws from *theological* premises. If that seems rather odd, remember that Descartes thinks he has already given a sure proof of God's existence as the world's creator. As a matter of principle, is it not reasonable that some aspects of the creation should be inferable from known properties of the creator?

This theological approach to the natural world also illustrates Planck's statement that "our laws of thought agree with the regularities found in the succession of impressions we receive from the natural world". This is another standard component of rationalism, that we live in a 'rational universe', in the sense that the world is structured according to logical and mathematical principles. Rationalism is therefore contrary to materialism in making mind more fundamental than matter. For example, Plato was a rationalist, in believing the material world to be structured by eternal Forms that are accessible only to the intellect, not to the senses. Rationalists of this sort need not be theists, exactly, but historically many of them have been. Kepler and Galileo, for example, believed that God was a mathematician, and used mathematical structures to create the physical world.

2. Descartes' slingshot argument for his second law of motion.

(*Principles of Philosophy*, Part II, Article 39, Jonathan Bennett translation.)

> **39**. **The second law of nature: each moving thing if left to itself moves in a straight line; so any body moving in a circle always tends to move away from the centre of the circle.**
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> The second law is that every piece of matter . . . . tends to continue moving in a straight line. This is true despite •the fact that particles are often deflected by collisions with other bodies, and •the fact (noted in section 33) that when anything moves it does so as part of a closed loop of matter all moving together. The reason for this second rule is the same as the reason for the first rule, namely the

unchangingness and simplicity of the operation by which God preserves motion in matter.

[Bennett's commentary: *Descartes's way of linking this with the second law is harder than it needs to be, because it is so compressed. Its central thesis is the proposition P: When God preserves the motion of a particle, he preserves now the motion that it has now, without attending to how it was moving a moment ago. Actually, Descartes admits, in a single instant of time—a single now—no motion at all can occur, which means that P can't be quite what he wants. But he holds to its 'no attention to the immediate past' part of it, and contends that this has the upshot that God will always maintain, in each separate uninterfered-with particle, motion in a straight line and never in a curve. He illustrates this with the example of a stone being whirled around in a sling, using a rather complex diagram that we don't need.*]

When a stone is rotated in a sling, whirling around in a circle, at any given instant in its journey the stone is inclined to leave the circle and move along its tangent—·so that (for instance) at the bottom-most point of the circle it is inclined to shoot off straight ahead, parallel with the ground·. The suggestion that it is inclined at each instant to move in a circle is an impossible story: it involves the thought that the stone will be inclined to go on moving in a circle, but at any given instant the fact that it has been moving in a circle is a fact purely about the past; it's absurd to think that that past circular motion is somehow still with the stone, still in the stone, at this instant. And we know from experience that at the instant the stone is released from the sling, it shoots off in a straight line. So there we have it: any body that is moving in a circle constantly tends to move away from the centre of the circle that it is following. Indeed, when we are whirling the stone around in the sling, we can feel it stretching the sling and trying to move away from our hand in a straight line.

3. Descartes' collision rules.

As mentioned in the introduction, Descartes was the first to formulate the collision problem, and attempt to solve it. His solution wasn't very successful [i.e. it was almost completely useless]. Descartes broke down the problem into seven different rules, most of which he got wrong, but two of his better efforts are quoted below. Incidentally, the collision problem was first solved correctly by Huygens in the 1650s. (Huygens taught Leibniz physics at one point.) In case you want to score Descartes' failure as a victory for empiricism, you should be aware that Huygens' solution is also almost entirely *a priori*.

> **45. Rules will be given for calculating how much the motion of a given body is altered by collision with other bodies.**
> For us to use these results to work out how individual bodies speed up, slow down, or change direction as a result of collision with other bodies, all we need is •to calculate the power each body has to produce or resist motion, and •to accept as a firm principle that the stronger power always produces its effects. This would be easy to calculate for the special case of •a collision between two perfectly hard bodies isolated from other bodies that might affect the outcome. In that class of special cases the following rules would apply.
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> **46. The first rule.**
> When two perfectly hard bodies, x and y, •of the same size •moving at the same speed •in opposite directions along a single line collide head-on, they will come out of the collision still moving at the same speed with the direction of each precisely reversed. …
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> **51. The sixth rule**.
> When two perfectly hard bodies, x and y, •of the same size, •x moving and y entirely at rest collide, they will come out of the collision with •y to some extent driven forward by x and •x to some extent driven back in the opposite direction by y. [*Descartes's argument for this has at its core:*] Since x and y are equal ·in size·, so that there's no more reason for x to bounce back than there is for it

to move y, it is obvious that these two effects must be equally shared—x must transfer half of its speed to y while retaining the rest and moving in the opposite of its previous direction.

Descartes wasn't the only scientist who used *a priori* arguments believing that physical laws could (at least to some extent) be discovered by pure thought. Max Planck was another, as well as Einstein, Helmholtz, Stevin, Galileo, Kepler, Huygens, Leibniz and many others (even Newton now and again!). Here are a selection of rationalist arguments from other physicists.

4. Galileo's free fall argument

According to Aristotle a large cannon ball has a natural downward gravitation that is faster than that of a small steel shot. But Galileo argued against this natural speed difference on rational grounds, as follows.

> If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. If a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight…… but the two stones when tied together make a stone larger than that which before moved with the speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition.
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> (Galileo, *Dialogue Concerning the Two Chief World Systems*, The First Day.)

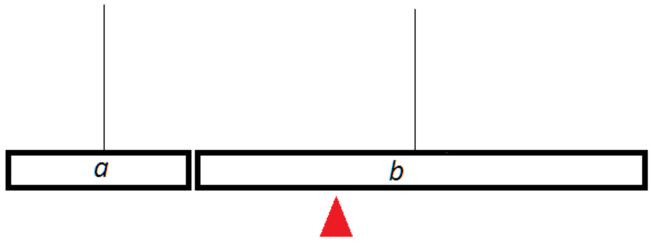
5. Stevin's argument for the principle of the lever

A lever is a rigid bar that can rotate around a fixed point called the pivot or fulcrum. Levers are useful in construction for their well-known ability to multiply forces. To raise a body weighing a ton (2000 lb), one can use a man of only (say) 200lb, and a strong enough beam. By placing the one-ton body at (say) one foot from the fulcrum, and the man just over ten feet away on the opposite side, the heavy body will be raised. In general, a small force on one side exactly balances a force that is *r* times greater on the other side, if the smaller force is applied to a point *r* times further from the fulcrum.

Archimedes (3rd century BC) is credited with first describing this magic of the lever, and in a rush of excitement apparently said, "Give me a place to stand, and I shall move the Earth with it".

In 1586 the Flemish mathematician Simon Stevin gave a rational argument for this principle of the lever, which (as far I can tell, as I couldn't locate the original text) went something like this.

Imagine two metal bars of uniform thickness and density, each suspended horizontally from a thread attached to its centre. As shown in the diagram below, their lengths are *a* and *b*, and they're arranged so that their ends are almost touching.



Since each bar is symmetrical about its thread, with an equal length on either side, the two bars are initially at equilibrium. It is clear that if the two ends (that are almost touching) are now glued together, then the bars will remain at equilibrium. (Since they weren't moving anyway, how will fixing them together make a difference?) After the glue dries, a pivot (shown as a red triangle) is raised until it just touches the new bar, length $a+b$, at its centre.

It's clear, again by symmetry, that if the strings were cut simultaneously then the bar would remain at equilibrium, being perfectly balanced around its centre. Now the left-hand string is exerting an upward force proportional to a, at a distance $b/2$ from the fulcrum. (This is easily calculated, as half the length of the combined bar, $(a+b)/2$, minus $a/2$.) Also, the larger upward force, proportional to b, from the right-hand string is applied at a smaller distance $a/2$ from the fulcrum. Multiplying each force by its distance from the fulcrum gives $ab/2$ in each case, proving that such pairs of forces do not disturb the equilibrium of a lever.

6. Archimedes' buoyancy principle.

We know that a chunk of styrofoam, if submerged in water, will be subject to a strong force of "buoyancy" pushing it back up to the surface. But how strong is this buoyancy force? Archimedes' principle states that the upthrust on any submerged body equals the weight of the water that's displaced by the body, i.e. the weight of the water that would otherwise occupy the body's space.

Archimedes' principle can of course be shown empirically, but there is also a logical argument for it, as follows.

Consider a submerged object B in a tank of water. If B were not present, then the region of space occupied by B would contain water instead. In that case, we would have a simple tank of water, and the water in a tank must be stationary (assuming the tank is not heated, stirred, etc.) since the water in each part of the tank is identical to the rest. (Note that this is another appeal to symmetry.) Let B' refer to the hypothetical chunk of water that would occupy the same volume as *B*. Now *B*' would have weight, i.e. it would feel a downward gravitational force, and yet it would not move, as stated above. Thus *B*' must also be subject to an upward force, presumably exerted by the surrounding water, that would exactly balance its weight. (This upward force is called the buoyancy.) In other words, the buoyancy on *B*' would exactly equal its weight. Now let's go back to *B*, the submerged object. The water surrounding *B* is exactly like the water that would surround *B*'. We might say that the surrounding water "doesn't know" what kind of body it surrounds; hence it will exert the same upward force no matter what that body is made of. Therefore, for any submerged body, the buoyancy on it equals the weight of the water displaced.

7. Kant's argument for Newton's Inverse Square Law

Before he became a famous philosopher, Immanuel Kant worked on some problems in physics. For example, the 'nebular hypothesis', the theory that the solar system formed by the gravitational collapse of an initial cloud of matter, was proposed by Kant in 1755 long before Laplace independently thought of it in 1796.

Kant accepted Newton's law of gravity, which states that any two bodies will each feel a force directly toward the other, with a magnitude proportional to the 'inverse square' of the distance between them. In other words, if the distance between the objects is tripled, then the force decreases by a factor of the *square* of 3, i.e. by a factor of nine. As a good rationalist, Kant regarded this inverse square aspect of gravity (and other forces) as knowable *a priori*, by the argument below. (Newton himself, by contrast, claimed to deduce the inverse-square feature from Kepler's laws, which in turn were based on observations of the planets.)

> "We find a physical law of reciprocal action applicable to all material nature, the rule of which is that it decreases inversely as the square of the distance from each attracting point—that is, as the spherical surfaces increase over which this force spreads—which law seems to be necessarily inherent in the very nature of things, and hence is usually propounded as knowable *a priori*." (Kant, *Prolegomena*)

The argument here seems to be as follows. Since a point is spherically symmetric (invariant under all rotations) it can only cause fields that are also spherically symmetric. (In general, a symmetric cause can only have a symmetric effect.) Thus the emanation from the point that produces the field will, at distance r from the particle, be evenly spread over the surface of a sphere of radius r (centred at the particle). This sphere has a surface area of $4.\pi.r^2$, so that the intensity of the field is proportional to $1/r^2$.

8. Common Rationalist Principles

I've included a number of these rationalistic arguments so you can get a good feel for how they work (or fail to work) and the kinds of principle they assume. We can now summarise a few of these principles, listed below.

1. Effects can be logically inferred from their causes, i.e. from a suitably complete descriptions of the total cause.

2. Every event has a cause. (Objects and events don't appear "from nowhere", spontaneously, all by themselves.) This is a corollary of (1), since conclusions cannot be inferred without premises.

3. Exactly similar causes always yield exactly similar effects. Also a corollary of (1), since the same premises will yield the same conclusion.

4. If a cause is symmetric (in a certain respect) then its effects must also be symmetric (in the same respect). Again a corollary of (1) as symmetrical premises yield symmetrical conclusions.

5. The parts of a system can be considered as individuals, and will behave independently of each other, unless they exert forces upon each other. (Separability principle)

6. A similar situation holds with respect to instants of time. They can be considered as separate entities, acting independently of each other.

7. Forces on a system can only be exerted by the immediate environment, not by distant objects, except indirectly via a chain of intermediaries. (Locality principle)

8. A similar situation holds with respect to instants of time. A physical system "lives in the moment", as it were, and is directly affected only by what happened immediately beforehand. It has no "memory" of what occurred before that. (Markov principle.)