HU3101: History and Philosophy of Science

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Question 6. Copernicus ushered in the heliocentric model of the solar system. And yet, there were many objections to his theory. Why?

Answer. Copernicus advocated a heliocentric model of the solar system, contrary to the traditional Ptolemaic picture of a geocentric 'universe'. He proposed that the planets (including the Earth) orbit the Sun in fixed circular paths.

Following are some objections to this theory.

1. *Lack of observational support*: Copernicus offers very little observational evidence to support his hypothesis. As a result, the idea that the planets obey *uniform circular motion* does not hold up (Mercury in particular has a fairly high orbital eccentricity of ≈ 0.2). This is a fairly serious deficiency in his model.

   Later, the observations of Tycho Brahe became invaluable for future astronomers. Kepler used these to establish a more refined heliocentric model.

2. *'Mystical arguments'*: Copernicus based many of his arguments on the works of Greek and Islamic scholars; for instance Aristarchus of Samos and Philolaus postulated that the Earth is in motion. He also tried to justify his model as superior on the grounds that it is simpler and more elegant. This is not sufficient to choose one model over the other.

3. *The motion of the Earth*: Aristotelian physics demands that the fast moving planets be made of a different, lighter material than that of the Earth. This is because Aristotle believed that in order for a body to stay in motion, a persistent 'force' of sorts must be applied; the planets must thus be made of some 'Aether' whose natural state is that of motion. For instance, Tycho Brahe praised the Copernican model for its mathematical brilliance (it dispenses with epicycles, and provides a simple explanation of the retrograde motion of the planets), but critiques it upon this very point.

   > This innovation expertly and completely circumvents all that is superfluous or discordant in the system of Ptolemy. On no point does it offend the principle of mathematics. Yet it ascribes to the Earth, that hulking, lazy body, unfit for motion, a motion as quick as that of the aethereal torches, and a triple motion at that.

   Tycho Brahe devised his own model of the solar system, identical to the Copernican one in every way except that the Sun orbits the Earth, while the other planets orbit the Sun.

   Thus, the known physical/mechanical principles of the time were insufficient to support the Copernican model.

4. *The vastness of space*: Tycho Brahe used measurements of the parallax of stars to note that if the Copernican model was correct, the stars would have to be extremely far away and huge (larger than the Sun), which seemed to be an absurdity (contradicting the Ptolemaic model) at the time. Copernicus defended this position on religious grounds, saying that the Bible does not forbid such a hypothesis; after all, such a majestic universe would be even more fitting for an all-powerful Creator.

   Today, we may recognize this as a success of the Copernican model.

5. *Missed insights*: In the absence of a universal theory of motion, there was little need for a 'better' model than the existing geocentric ones, since both were able to explain the (then known) observations with comparable accuracy. While the Copernican model is mathematically simpler, the real value in this model is the shift in perspective if offers by placing all heavenly bodies at par with each other. This hints at a deeper driving force behind this configuration, later discovered and explained by Newton.

6. *Religious/theological objections*: The Copernican model offends many religious principles of the time, most of which regard the Earth as the center of the universe (due to its apparent 'importance'). For instance, the Bible seems to treat the Earth as immobile and fixed in space, a direct contradiction to the heliocentric model. This is a hurdle which Copernicus' successors, most notably Galileo, had to face.

In short, the Ptolemaic model, Aristotelian principles, and the religious views of the time all settled upon a geocentric model; challenging this system would require an entirely new kind of physics to be discovered.

Question 1. Kepler and Galileo consolidated the Copernican Revolution, aided by Tycho Brahe. Discuss.

Answer. The Copernican Revolution is chiefly concerned with the deprecation of the Ptolemaic geocentric model of the solar system, and the acceptance of the Copernican heliocentric model. In the process, the notion of the centrality of the Earth was discarded, and the grand scale of the cosmos gained some more appreciation.

In the context of physics, there were two challenges to be solved. First, the orbits of the planets had to be precisely (and simply) described. Second, their motion, most importantly that of the Earth (even though we don't feel it), had to be explained. The former was accomplished by Brahe (through observation), Kepler (through his mathematical interpretation), and Galileo (through his telescopic observations and his experiments with mechanics).

1. *Tycho Brahe*: He collected an incredible amount of astronomical data before the advent of telescopes, upon which future astronomers like Kepler worked. He was also a great instrument maker. By discovering a new star in the Cassiopeia constellation, he refuted the Aristotelian idea that the sphere of stars is fixed. By discovering a comet whose trajectory passed through the 'solid spheres of the planets', he showed that these Aristotelian objects do not exist; the orbits of the planets must be explained in some other way. However, we have seen that he objected to the Copernican model on the grounds that the Earth cannot move.

2. *Johannes Kepler*: He worked on Brahe's data, and through his calculations of the orbit of Mars, he realized that the planet traced an ellipse (with the Sun at one of the foci). This culminated in Kepler's Three Laws of Planetary Motion, which accurately and quantitatively described the orbits of all planets.

3. *Galileo Galilei*: He advanced the technology of telescopes substantially, and through his observations of Jupiter, he discovered four orbiting moons. This again contradicts the Aristotelian view that all heavenly bodies orbit the Earth. Furthermore, this Jupiter-moon system formed a small Copernican system of its own, supporting the idea that smaller bodies orbit larger ones, the Earth being no more special than the other planets in this regard. Further observations of the phases of Venus brought the Ptolemaic model into greater suspicion.

   Galileo is perhaps remembered mostly for his conflict with the Church: he championed heliocentricism which contradicted the Holy Scripture. As a result, he was forced to recant and live under house arrest for the rest of his life. His book *Two New Sciences* is regarded as one of the greatest works of physics before Newton.

Question 2. What are the three basic principles of Dialectical Materialism? Cite at least one modern scientist's interpretation of Dialectical Materialism.

Answer. Dialectical Materialism is part of the Marxist philosophy, dialectics being discourse between two or more parties via reasoned argumentation. Friedrich Engels postulated the following three basic principles in *Dialectics of Nature*. These principles have been used as a heuristic by Richard Lewontin and Stephen Jay Gould in their work on evolutionary biology.

1. *The Law of Unity and Conflict of Opposites*: According to Gould, this represents the idea that the components of a biological system are often inextricably interdependent.

2. *The Law of Transformation of Quantity to Quality*: According to Gould, this is the idea that by applying many small inputs to a system, one can change its state.

3. *The Law of the Negation of the Negation*: According to Gould, this is the idea that complex systems cannot revert to previous states, this giving a direction of time (the negation of the negation need not always be as simple as the original).

Thus, Gould uses these principles to talk about complete systems and the interactions of their components (which are inputs/outputs to the system) in a holistic way.

Lewontin interprets the principles as the ideas that

1. Creation and destruction are dual parts of Nature.
2. A process influences the conditions around it, such as those leading to its creation/destruction.
3. History often leaves an important trace.

He uses dialectical materialism not as a method, but rather as a thumb-rule for avoiding dogmatism in science.

Question 3. Karl Popper was a staunch anti-Marxist. Yet, much of Popper's ideas were anticipated by Engels. Discuss.

Answer. The idea of dialectics – conflict of opposites – is integral to the Marxist philosophy detailed by Engels. In *Dialectics of Nature*, Engels observes that everything in Nature seems to arise out of struggle between opposites; what is left is often a more refined version of the 'inputs'. In science, different hypotheses play the same role. The discoveries of new facts introduces a pressure by which the number of satisfactory hypotheses is whittled down (a hypothesis which incorrectly describes known facts must be discarded, or at least corrected). In this manner, given sufficiently many data points, once can reach a distilled law or theory. Often, existing hypotheses are not enough to explain the facts; thus, we begin anew with a new set of hypotheses.

We note that similar to Popper's falsification principle, attention is shifted away from facts which *support* a hypothesis to facts which *contradict* it. A hypothesis should be open to criticism and attempted falsification; thus, dialectics is compatible with Popper's ideas of avoiding dogmatism in science. Furthermore, the dialectic 'evolution' of theories is practically identical to Popper's formula for the advancement of scientific knowledge,

$$\mathrm{PS}_1 \to \mathrm{TT}_1 \to \mathrm{EE}_1 \to \mathrm{PS}_2,$$

i.e. a Problem Statement gives rise to a set of Tentative Theories, which pass through Error Elimination. At the end, we have new and potentially more interesting Problem Statements, and the cycle repeats. At each cycle, science really begins with conjecture, not with observation.

We recall that Popper's method of conjecture and refutation was a response to the Problem of Induction. However, in *Dialectics of Nature*, Engels too confronts this 'Baconian superciliousness' of induction (forming hypotheses based on supporting observations). While inductive reasoning worked out very well for Newton, Engels criticises how the same principles of induction often lead to contradictory results in science in more recent times[1]. He further illustrates how induction was not the only line of reasoning in use, by putting forward Carnot's work on thermodynamics – this involves mentally constructing an ideal engine (not a physical, observable one), and drawing conclusions from this thought experiment. He notes how this system resembles the old 'Greek intuition'.

Engels does not however claim that inductive reasoning is completely unsuitable for science, rather that induction and deduction belong together and 'supplement each other'. Popper also acknowledges a quasi-inductive trend in science; while the individual steps in scientific discovery may be deductive in nature, the global picture often reveals that scientific theories progress from specific to generic.

There is another aspect of Popper's philosophy anticipated by Engels – his stance on indeterminacy. Regarding the problem of free will, Popper says that "freedom is not just chance but, rather, the result of a subtle interplay between something almost random or haphazard, and something like a restrictive or selective control." On may find in Engel's writings that he too denies determinism, which 'disposes of chance'. To show that this is not how Nature works, he cites the work of Darwin and his theory of evolution in which species are not unchangeable. Rather, individuals accrue 'infinite, accidental differences' over time. Thus, while the basic physical processes in an organism may be obey strict natural laws, chance plays an important role on a larger scale.

Question 4. What do you make of the debate between Newton and Leibniz regarding the priority of inventing calculus?

Answer. We state at the outset that it is very likely that Newton and Leibniz developed their ideas on calculus independently – the greatest source of complications seem to be Newton's reluctance to actually publish his ideas at the appropriate time.

On one hand, we have Newton who employed the notion of *fluxions* (essentially time derivatives, using infinitesimals) as early as 1665; we only know this by perusing his manuscripts, which came to light only after his death. Over time, Newton revised the use of infinitesimals to something resembling the modern notion of a limit, thus defending against criticisms of the awkwardness of 'division by zero'. This same method of fluxions can be found in a geometric form in Newton's *Principia* of 1687, used in service of calculating tangents, extrema, and centers of gravity of curves.

Interestingly, Newton corresponded with Leibniz in 1676 (in reply to a query on his work on infinite series, something that Leibniz was also working on) and briefly mentions his method of fluxions: albeit in cipher. Even up to this point, Leibniz was oblivious to Newton's actual work on calculus.

Leibniz was working on his own *differential calculus* by 1675. He visited London in 1676 and John Collins, who saw that Leibniz was interested in series, prepared a compendium of work including (what little that had been published) of Newton's fluxional calculus. This is perhaps the weakest link in the case for Leibniz; he says that these notes contained nothing new to him. Continuing his correspondence with Newton, he explained his method of differential calculus in a letter in 1677 (this is the source of allegations that Newton plagiarized Leibniz). His full work on calculus was published in a treatise in 1684.

[1] "By induction it was discovered 100 years ago that crayfish and spiders were insects and all lower animals were worms. By induction it has now been found that this is nonsense ... Wherein then lies the advantage of the so-called inductive conclusion ... ?"

We note that Leibniz visited Paris in 1673 and 1675 which was when he was exposed to the works of British mathematicians including Gregory (on series) and Newton. However, these may be put aside on the grounds that he was far too young at the time to properly appreciate or absorb those ideas.

The dispute seems to have only begun proper after Newton's publication of his *Principia*, where he explicitly claims to have developed fluxions decades ago. Various mathematicians began taking sides and accusing the other party of plagiarism; however, up to 1700, neither Newton nor Leibniz were directly involved.

It is likely that Leibniz only became fully aware of the power of Newton's fluxional calculus when the latter published two treatises in 1704; this made him realize that Newton's methods were practically identical to his own. On the other side, supporters of Newton saw this as further evidence that Leibniz's work was an imitation of Newton. This culminates in 1712, by which time Newton was very much involved in the accusations against Leibniz. The Royal Society (of which Newton was the president) began set up a committee to look into these accusations and settle this debate. Their report in favour of Newton was published as the *Commercium Epistolicum* in 1713.

Today, with the advantage of being able to go through their early manuscripts, we give both Newton and Leibniz credit for independent discovery. Perhaps the most banal place where they left their mark is in notation, both of which are in common use even today.

$$\dot{f} \cong \frac{df}{dt}, \qquad y' \cong \frac{dy}{dx}.$$

Question 5. Show how the centre of science gradually shifted from Eastern Europe to Western Europe.