HU3101: History and Philosophy of Science

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Question 1. Describe how religious orthodoxy had at various stages stood in the way of development of science in India.

Answer. Throughout history, it has been observed that new and revolutionary ideas have always been met with resistance – in the context of the development of science, this has often been a result of religious orthodoxy, the idea that the old texts are unerring and complete. Here, we focus on science in India.

Charaka was a pioneer in medical science during the 2$^{\text{nd}}$ century AD. In his texts (the *Charaka Samhita*), we find knowledge of physiology and anatomy, how to diagnose and make predictions, and how to administer various treatments, procedures, and medicines. In one instance, Charaka prescribes beef, and claims that the flesh of a cow is beneficial for treating certain conditions[1]. On the other hand, there are passages which venerate cows and brahmins, the cow being a sacred animal in the Hindu practice. Such self-contradictory views have been regarded as uncharacteristic of a person of Charaka's stature. It is now thought that the latter passages had been added later by brahmins, perhaps to confuse those reading the text.

Sushruta was a pioneer in surgery between the 4$^{\text{th}}$ and 5$^{\text{th}}$ century AD. His works reveal numerous surgical procedures, aided by sophisticated surgical instruments. One which stands out is his description of early plastic surgery, involving the grafting of skin; such mastery clearly indicates great and precise knowledge of anatomy. Sushruta advocated the dissection of corpses as a way for students to learn, thus gaining direct knowledge via experiments and observation. However, the *Manusmriti* which codified the caste system of four Varnas prohibited people of different castes from mixing/touching in any way. Thus, the practice of dissection was heavily discouraged and from the 7$^{\text{th}}$ century AD onwards, anatomy became long forgotten knowledge. Both of these examples illustrate how religious orthodoxy became detrimental to the advancement of medical science in India.

Aryabhata I, who lived during the 5$^{\text{th}}$ century AD, is the oldest Indian mathematician whose works are available today. Among his many achievements, he recognized that the earth is spherical, and that its rotation about an axis causes the apparent westward motion of the stars in the night sky. He was able to predict solar and lunar eclipses, and also realized that the luminosity of the moon and the planets is due to the sun, the only truly luminous object in our solar system. However, his work was not accepted or continued by his successors, mainly due to criticism. In particular, Varahamihira was a great astronomer of the following century in his own right. In his works, we see that he is aware of the true nature of eclipses, much like Aryabhata I. In spite of this, he continues to talk about the astrology of Rahu and Ketu, which supposedly cause eclipses according the the wisdom of the brahmins. Brahmagupta, who was perhaps the greatest scientist of his time, held exactly the same position. He too knew and acknowledged that eclipses are unrelated with Rahu, but warns that this knowledge would render the brahmanical rituals meaningless and the Vedas false. Thus, he advises astronomers like Arybhata and Varahamira not to oppose these general beliefs. This is yet another instance of self-contradiction, perhaps due to pressure to somehow justify the rituals and practices of the brahmins.

[1] Quoting from a translation of the text, "disorders caused by an excess of vayu, rhinitis, irregular fever, dry cough, fatigue, and also in cases of excessive appetite resulting from hard manual labour".

These instances, in which empirical observations have been sidelined in order to conform to and accommodate religious beliefs, show how religious orthodoxy stood in the way of scientific progress in India.

Question 2. Science is intrinsically international in nature. Discuss, citing examples.

Question 3. What do you understand by "Thales discovered nature"? Explain, citing examples.

Answer. Thales of Miletus lived during the Ionian phase of Greek Science, from approximately 600 BC onwards. The Ancient Greeks recognised an entire pantheon of gods, each responsible for some facet of nature. For example, Zeus was the god of the sky, Poseidon the god of the sea, and Hades the god of the dead. Thus, all natural phenomena were ascribed to their whims. Lightning storms represented the anger of Zeus, earthquakes the anger of Poseidon, and so on. As a result, there was no real attempt to understand these phenomena on a deeper level.

Thales was not satisfied with this state of affairs, and instead proposed that these natural phenomena could be explained in a different way: the interaction of matter, in accordance with natural laws. This was a bold step since he claimed that natural phenomena are not acts of god, but simply a result of *nature* taking its course. This is what we mean by Thales *discovering nature* – he brought nature into the forefront of thought, giving rise to what we would now call *science*. Even during the time of Newton, science was practised under the banner of *natural philosophy*.

To illustrate this point, we give a few examples of Milesian theories of nature proposed by Thales and his successors. Drawing from experience, Thales thought that the earth floated on a vast ocean, much like a boat; earthquakes are a result of disturbances in this ocean, causing the earth to shake. Anaximander though that lightning arose from clouds being split up by the wind. We may note that despite missing several crucial details (chief being the nature of electricity), this is surprisingly insightful. Presumably, he noted a correlation between the occurrence of lightning and violent storms accompanied by huge clouds and high speed winds.

In any case, both these hypotheses offer much to think about without directly invoking god, and are certainly improvements over the prevailing beliefs of the time. They are based in observation and common experience; Anaximander's hypothesis even has a certain predictive power and can be loosely verified. The Milesians entertained open debate regarding their ideas, introducing an element of competition: who can produce the best theory to explain this event? This is why we say that the Milesians were the first to do real science.

Question 4. In the light of Thomas Kuhn's paradigm theory, show how the Newtonian paradigm changed into the Einsteinian paradigm.

Answer. Thomas Kuhn's definition of a paradigm in science differs from common usage of the word. By paradigm, he refers to s set of universally recognized scientific achievements which (for a time) provide model problems and solutions for a community of practitioners (scientists within the relevant field of study). Thus, the paradigm of the present guides the direction of research done in that field, and provides a lens with which to view and interpret new discoveries. It does so by setting up questions about the unknown and making suitable predictions; it is then up to scientists to investigate these predictions. If these are verified, this strengthens or at least increases confidence in the paradigm. If contradicted, such a novel discovery may well spawn an entirely new paradigm.

In order to understand the paradigm shift from the gravitational theory of Newton to that of Einstein, we must first recognize why Newton's ideas dominated scientific thought for over two centuries. Newton's most celebrated contributions lie in mechanics: the three Laws of Motion and the Law of Universal Gravitation. The idea that the earth must attract bodies in order for them to stay on their surface, or fall, is not necessarily new[2]. What Newton realized is this: the reason why an apple falls to the ground *is exactly the same* as why the moon orbits the earth. Indeed, Newton's description of this new *gravitational force* was not merely qualitative, but quantitative, described by the formula

$$\mathbf{F}_{12} = G\frac{m_1 m_2}{r^2}\,\hat{\mathbf{r}}_{12}.$$

With this and his Laws of Motion[3], Newton could convincingly and accurately explain (and predict) the motions of *every celestial body* observed, recovering Kepler's Laws[4]. With the same set of equations, he could also explain every phenomenon pertaining to mechanics (motion) on earth. This is what we mean by the Newtonian paradigm. Over the next couple of centuries, most of Newton's predictions were verified, inspiring great confidence. When analysing any sort of motion, Newton's Laws were indispensable.

With the advancement of technology in the 19$^{\text{th}}$ century, astronomers began making measurements with astounding precision. Suddenly, an anomalous phenomenon was discovered. The orbit of Mercury, which is elliptical, isn't a static shape in space but rather rotates with time; we say that the perihelion of Mercury *precesses*. This too was predicted by Newton — the problem was that his calculations were off by a rate of 43 arcseconds per century! Yet another inexplicable phenomenon was the bending of light by the sun. These are clear indications that Newton's theories were incomplete at best, wrong at worst.

In the 20$^{\text{th}}$ century, Einstein published both the Special and General Theory of Relativity, resolving all of these problems in one stroke. The concept of gravity was refashioned from a *force* – action at a distance – to a consequence of the *geometry* of space-time[5]. A revolutionary new idea was that the passage of time is not steady and absolute, but rather subject to both relative motion as well as gravity. It turns out that in the absence of extremes of these effects, Einstein's equations reduce to those of Newton's, which explains why Newtonian mechanics stood the test of time for so long. The full predictions of Einstein's theories are far reaching, and we are exploring and verifying them even today.

Once again we emphasize how the Newtonian paradigm set up questions and predictions in physics regarding the motions of heavenly bodies. It was the failure of just a few of these predictions that lead to its demise; it was the success of the Einsteinian paradigm in resolving these same questions that cemented it in modern physics.

Question 5. Explain how Bhaskacharya defended his position on gravitational attraction vis-à-vis the believers in the Puranic myths.

Answer. Bhaskacharya, or Bhaskara II, was a great Indian mathematician of the 12$^{\text{th}}$ century. Among his many achievements are solutions to the Pell equation (using his own *Chakravala* method) and a rudimentary form of differential calculus. Within his works (the *Siddhanta-shiromani*), one finds an allusion to the concept of gravity. Here, he muses upon how falling

[2] We highlight Bhaskacharya's comments on the attractive power of the earth as early as 12$^{\text{th}}$ century AD, discussed in Answer 5.

[3] We must mention that in order to even begin formalising his ideas mathematically, Newton had to invent an entirely new branch of mathematics, namely *calculus*.

[4] Thanks to Kepler, the fact that heavenly bodies traced elliptical orbits was already known during Newton's time; what was missing was a theory explaining this phenomenon. There is a wonderful anecdote detailed in Bill Bryson's *A Short History of Nearly Everything*, in which Edmund Halley, Robert Hooke, and Christopher Wren made a wager regarding who could solve this problem first. Halley approached Newton himself, who when given the problem remarked immediately that he had already performed the necessary calculations. Upon searching his papers, he could not find them! Pressed by Halley, he redid his calculations, which he further expanded upon and published under the title *PhilosophiæNaturalis Principia Mathematica* — at Halley's expense.

[5] Again, formalising these ideas took a great deal of mathematics: *Riemannian geometry*. This time it was already available in a rudimentary form, but only as a mathematical curiosity not applied to physics. A considerable amount of time was spent by Einstein (racing against Hilbert) in expressing his ideas using this language.

bodies must attracted by the earth. After all, if this were not the case, then there ought to be no bias towards any particular direction for the body to fall; there is something special about the direction towards the earth, directly beneath a person. Using his knowledge about the spherical shape of the earth, he further notes that a person on the other side of the earth can comfortably stand and walk just like him; while this other person appears to be upside down from our perspective, the reality is that the other person has a different direction for 'beneath'. At any point on the earth, 'beneath' or the direction objects fall is always towards the earth's center.

Bhaskacharya's work implies that the earth is a body suspended in space, unsupported by anything else. This contradicted the accepted wisdom of the Puranas, which stated that the earth was supported by one of the heads of the serpent Vasuki. Thus, believers in the Puranas naturally questioned, "How can a body as large as the earth remain suspended without support?"

Bhaskacharya countered with the question, "If the earth is indeed supported by some (presumably enormous) body, how can such a body remain suspended without support?" In other words, if one accepts that every body must be supported by another, one must ask, "How is the body at the base of the chain supported?" There are two possibilities: either there is a final supporting body which is unsupported, thereby contradicting our initial assumption (every body must be supported), or there is an infinite chain of bodies each supporting the other, which is absurd. The latter fallacy is called *infinite regression*.

Thus, Bhaskacharya argued that if one is prepared to accept the fact that a final supporting body (such as Vasuki) can remain suspended on its own strength, then one must also accept that the earth itself ought to be able to remain suspended in space[6].

[6] Note that this does not explicitly rule out a finite number of supporting bodies. After this, one can argue that the earth remaining suspended on its own is a much simpler explanation than the earth supported by Vasuki which in turn is suspended on its own. Of course, the best way to decide is by direct observation; today, we have photographic evidence. Even in those days, astronomy ought to have been sufficiently advanced to make the required observations.