22 Newton's Post-Mechanical Philosophy of Nature and his Path to the Law of Universal Gravitation

We left our study of Newton with two related questions: (1) Why does he have a post-mechanical natural philosophy? And (2) the related problem, over the course of his career, how did he work within that natural philosophical framework to arrive at the conception of universal gravitation? (I do not say how did he discover it, but how did he work towards and construct it within that intellectual context.)

Newton was born on Christmas Day in 1642 in the old style calendar which they used in England until the 18th century. 1642 is the year that Galileo died and 99 years after the death of Copernicus so you can begin to understand the kind of time frame we are looking at here. Newton did not come from aristocratic or gentry stock, he came from what social historians call the 'yeoman' class--the substantial landholding peasants -- from a village called Woolsthorpe, which is near the Lincolnshire market town of Grantham. You can visit Newton's cottage in England, which has been restored. There are diagrams drawn in the plaster which are supposedly the young Newton's mechanical mathematical drawings. There is an apple tree in the garden where Newton was supposedly hit on the head by a falling apple and thus 'discovered' universal gravitation.

Newton had an interesting childhood, for his father died several months before he was born; three years later Newton's mother remarried and moved to a nearby village, so Newton did not regularly see her. He was raised by his maternal grandmother and later was sent to Trinity College, Cambridge in 1661. You can visit his room at Trinity College where he closed the shutters of the window and poked a hole in the shutters to let the light through into his prism to perform his experiments discovering the 'true nature' of light as made up of light of many different colours.

Newton was not noted as an outstanding student at Trinity College Cambridge. Towards the end of his undergraduate career in 1665 the plague, (which used to break out periodically in a localised fashion), struck in Cambridge and Southern England. The University was closed and Newton returned to Woolsthorpe for a year and a half of private study. There, at the age of 22, during his eighteen months in Woolsthorpe he invented differential and integral calculus. He performed optical experiments; and he made some insights into mechanics and physics. However, it is wrong to believe that he 'discovered' universal gravitation at this time. Newton blossomed into this great mathematical and physics talent during this eighteen months, but there is nothing that he did during this time that gives us a clue to where universal gravitation came from--at least that is how we would look at it today in terms of historical analysis. But, to set up a contrast between what I think we should do when we look for the construction of a key concept like universal gravitation, and what people used to do, let's look at an attempt to make sense of universal gravitation based on the facts I have stated about his early life.

About 30 years ago a very eminent American intellectual historian named Frank Manuel, wrote a book about Isaac Newton, called *A Portrait of Isaac Newton* in a style of the history of science, that was then very much avant garde, called psycho-biography. It was a Freudian biography of Newton which attempted to psycho-analyse Newton and

discover the subconscious origins of his wonderful concept of universal gravitation. There was an initial attraction in this because universal gravitation is so odd.

Manuel said that universal gravitation is the conscious, sophisticated expression of Newton's subconscious makeup. This 'subconscious makeup' was conditioned by two things: his mother was in his sphere of influence, but not actually physically present--recall that she lived nearby while Newton was raised by relatives. The other thing was that Newton was born on Christmas Day and we know from his later overt behaviour as an adult that he was always pleased with himself as a scientist and a thinker. He always rated himself above his collegues and contemporaries and peers--in fact treated them with contempt and quite brutally for he would brook no competition as the leading mathematician and natural philosopher of his day. Manuel read into Newton's behaviour the idea that Newton was very ego-centric and that Newton felt perhaps that he had been specially gifted by God. Because he was born on Christmas Day--an echo of Christ's birth perhaps--and had not known his human father, Newton subconsciously thought he was the specially gifted son of God. Newton had things revealed to him that he thought were the absolute keys to reality. And the key gift, universal gravitation, is interpreted by Manuel as the sublimated, conscious expression of someone with that peculiar unconscious makeup--universal attraction as the ultimate psychic product of his odd relation to his mother--she was (almost) there, but not 'in touch'.

This is an interesting way of viewing Newton's concepts, but it is not in the style of explanation that we do in the history of science these days. Manuel makes tremendous leaps from theories about Newton's childhood to technical work of Newton's adulthood as a professional practitioner of institutionalized, shared skills. These days we want to trace very carefully how a person such as Newton works technically on problems (a kind of Kuhnian approach to the history of science). We also want to look very carefully at what shapes how he sees and judges and approaches those problems. Those factors can be biographical, institutional or social of a broad kind. They are not likely to be just his infant or childhood experiences interpreted in a Freudian way. We have looked at Manuel to highlight yet another possible analysis of Newton's discoveries. I think you would already know what the naive, Whiggish empiricist explanation of Newton would be: "Newton was a great person who helped perfect the scientific method, which he then used, generalising facts and discovering universal gravitation". Finally, there is the kind of explanation we are trying to work with here.

Let us see if we can put a more biographical, institutional and social 'meat' on this story, telling it through time, not jumping from his childhood to his supreme adult achievements. Obviously, our explanation here will be simplistic and selective, but it is meant to give you the flavour of two things: Why was he, a post-mechanical philosopher of Nature in general, **and** how did he work towards universal gravitation within that framework.

If I were telling the story I would start with the point that when Newton went to University, in the 1660s, he was typical of what we can call the first generation of students in Europe who were consumers of the mechanical philosophy. In other words, they were presented with the mechanical philosophy as an already existing option. They did not have to struggle to invent it or present it, as Descartes, Boyle and Hobbes had had to do (although Newton's education at Cambridge was still fundamentally Scholastic and Aristotelian). This was not to change until the late 18th century in fact, when it became Newtonian. But, Newton and other students of his generation came into contact with the mechanical philosophy at University because any reasonably

informed tutor or lecturer would be familiar (although not necessarily agreeing with) the writings and publications of such people as Galileo, Descartes, Hobbes and Boyle.

The ideas of these people circulated informally in the university context. So Newton was in the position of a consumer, and this is an important thing, for rather than being an inventor of the mechanical philosopher, who would be an enthusiast, he was a cool and critical consumer. We can tell what Newton was thinking during his undergratuate years and during the plague, because of the reams of his manuscripts and notes that are available (which have been analysed by various scholars). What becomes apparent from the analysis is that he had both technical and scientific reservations about mechanism and that he was also exposed to reservations about mechanism on a natural philosophical and theological level, which implies political reservations also. Religion and natural philosophy were political issues in the 17th century. Remember that this was a mere ten years after the death of Cromwell and the restoration of the Stuart monarchy, which had ended twenty years of civil war and political-religious turmoil in England.

I cannot assign priority, and I do not think we should, to the technical, scientific reservations or to the theological, political, religious reservations. We just have to take them for granted and understand that this is the beginning of his *not* being a believer in the mechanist philosophy.

Here is an example of the type of technical reservation he had at this point. It is one example, amongst many, of Newton finding anomalies or difficulties in the mechanical natural philosophy (fig. 1). We have here the surface of a mirror; and a geometric line representing an incoming light ray. The light ray bounces off the mirror so that its angle of incidence equals its angle of reflection. This is the Law of Reflection, an example of what everyone at the time called geometric optics--the study of the behaviour of light as the light is a simplified series of geometric lines. (The Greeks invented this, just as they invented astronomy and geometry.) This was a major area of concern. People such as Descartes said that geometric optics was not sufficient, not the deep physical explanation of such phenomena. What is really there is particles in motion, colliding and interacting with one another. A typical Mechanistic explanation would go as in figure 2. The light ray is really a stream of corpuscles which hit the surface particles of the mirror and they bounce off, like tennis balls hitting the tennis court.

Newton, even as a student, saw big problems in this mechanistic theory of light, for is not the surface of the mirror alsop made out of corpuscles and therefore 'rough' on the scale of these micro-particles? So we know that the mirror is not a mathematical line on a micro level, but if it is rough, the so called light rays will not bounce off at at one angle, but would scatter in all directions, unpredictably. (fig. 3) But, empirically, this does not happen to the reflection from the mirror, the reflection is coherent and not scattered, at least that is the accepted report or 'fact'.

Newton states (in his student notebooks) that he has the answer to this problem. The light particles never physically touch the surface particles of the mirror, but interact through short-range fields of repulsive force! Each corpuscle of light gives off a little field of repulsive force *at a distance* . As for the surface of the mirror, it is a whole aggregate of particles of matter. Imagine each particle is giving off a little repulsive force through a very short distance, so that according to Newton they would set up a very thin but perfectly flat mathematical plane where the force of resistance starts above the jagged physical plane of the actual mirror particles. The sum total of having these force line up above the mirror is to create an invisible force shield. So, Newton is

talking about an invisible shield of repulsion that the aggregate of the mirrors particles set up.

Now you can see what happens. (fig. 4) Each light particle does not hit the mirror, because the fields interact with each other--the repulsive force of each light particle interacts with the flat repulsive force shield just above the physical mirror, and of course, there is no physical interaction but a kind of spiritual interaction, and you end up with a coherent beam.

Newton restores the mathematical simplicity of the phenomenon by adding something to the mechanical picture: in this case short-range forces of repulsion. This is interesting because in gravity he talks about long-range forces of attraction. This is how Newton's view of nature works. There are lots of kinds of forces of which some are attractive some are repulsive and they cause different phenomena such as gravity, light, chemistry, electricity and magnetism. Newton's view is mechanical but it is mechanical 'plus', because he worries about technicalities of the mechanical philosophy.

Where does he get his broad impetus from--his natural philosophical, theological and political background for this approach? At Cambridge in the 1660s Newton came into contact with two people: Henry More (1614-1687) and Ralph Cudworth (1617-1688) who were both representatives of a tradition of thought in England and Cambridge that historians call Cambridge Neo-Platonism, which goes back to the turn of the 17th century. It was primarily a theological viewpoint that had grown up in England and had found an institutional hold at Cambridge University. The theological viewpoint was to be calm and tolerant and rational; to try to dissuade extreme Puritans, Anglicans and Catholics from being at each others throats, for if we are rational with each other we will understand that there are a few simple rational truths that all good Christians can agree upon. Everything else is unimportant and everything else is what people argue about. So if we can all agree, for example, that you have an immortal soul; that God created the Universe; that there is maybe some Divine Providence, then that is good enough for every rational (Christian) man in the world. This is a theological standpoint that feeds into the larger movement towards tolerance because you cannot kill everyone you disagree with.

Where did these Cambridge Platonist theologians stand on natural philosophy? By the 1650s and 60s, people like More and Cudworth had taken a definite position upon natural philosophy. They did not and never did believe in Aristotelianism. Magic and the more enthusiastic and wild forms of natural magic are also dismissed because they again seem related to forms of religious enthusiasm and sectarianism. They see the relationship between natural magic being asserted along with claims to personal knowledge and revelation. They move to a position of being mechanists because it is up to date, it is non-magical, non Aristotelian, and it appears to go along with their theological viewpoints. In many ways they were typical of the people who became mechanists.

But, because they living in England in the 1650s and 1660s (where you had had civil wars, revolution, execution of the King, and a change of government, sectarian outcroppings, and, finally, the in 1660 Restoration of the Stuart monarchy); they also had a slight mistrust in mechanism in its pure state. They knew, for example, of Thomas Hobbes' version of mechanism which many people thought was atheistical because God seemed to be absent from his system. So people like More and Cudworth said 'let us be mechanists but let us also say that God has, in his benevolence, put

certain non-mechanical, spiritual powers in nature to cause those phenomena that cannot be caused purely mechanically', and to show His power and benevolence.

Organic phenomena were one case in point: according to More and Cudworth, living beings cannot be explained purely mechanically, as Descartes had claimed, there is too much organisation and purposeful direction of their development to be caused just by matter in motion. The growth of a seed cannot just be atoms and particles moving around. They used the example of the human eye: How does the human eye develop in the embryo? There must be some directive biological power in the process of biological development that produces the eye. This is the beginning of the great tradition of the Anglican and British natural theology where you defend the existence and nature of God by looking at the wonderful design and intricacy of things in nature especially in organic nature. So, in a sense that picture of Newton's natural philosophy (Chapter 21 fig. 2) where we have those active principles and powers between God and corpuscles is exactly the view of More and Cudworth.

Clear political implications are involved in these theological and philosophical. In England if you are worried about Catholic and Puritan agitations, and you wanted to ensure that society remains calm after the Restoration of the monarchy in 1660, then you were going to choose a philosophical viewpoint that cuts off both Catholic and Puritan views. Therefore, you cut off Aristotelianism and cut off magic and personal illumination, but you must cut off atheism too and extreme mechanism which can lead to atheism. Newton is impressed by this philosophical position and that is the kind of framework and metaphysical background that he works within when constructing his views in natural philosophy.

Now we will look at a few stages in Newton's movement towards Universal Gravitation. First I must mention a point in physics. Figure 5a is a body moving inertially in a straight line at a constant speed. Figure 5b is a body moving around the centre of a circle. It is perfectly obvious to the young Newton, because he is good at physics, that if something moves in a circle it is because it is being pulled toward the centre. That is why the stone in a sling moves around in a circle, it is constantly pulling towards the centre. Most people concentrate on the fact that at each moment the stone seems to tend to move away from the center--centrifugally. Newton saw that the stone is tending inertially off on a tangent and that it remains in circular motion only because we constantly pull it back toward the center of rotation with the sling. Newton called this centripetal force or impulse (centre seeking). This is difficult to conceptualise and Newton is the first person in the 17th century to see that--and he could even write the equation for centripetal. Now we will look at a few stages and phases towards universal gravitation.

Now we come to the story of Newton and the apple hitting him on the head. Newton himself told this story of the discovery of gravity when he was old and President of the Royal Society when everyone was bowing at his feet in adoration. Newton's story was that as a young man, sitting in his garden, he saw an apple fall and made him think that the same **force** that pulls the apple down towards the Earth's surface also pulls the Moon into its circular orbit (where force, is not a mechanical thing, but a attractive force). From this hypothesis he gains universal gravitation!

Well, this story from his old age has a tiny grain of truth, for when he was a young man, around 1666, he did have a terrific idea which began to open up the problem for him: In the late 1660s, having worked out circular motion, he did have an insight that the fall of bodies has to be attributed to attractive force, because of the problems with

mechanical explanations by whirlpools and vortices. (cf previous Chapter) He further saw that since the Moon is moving in a circle around us, then the Moon must be attracted by us, so that the Earth is exerting an attractive force, and maybe that force is the same one that causes local bodied to fall toward the Earth.

Now, this is not universal gravitation but it is pretty near to it. Newton works on this theory and realises that the attractive force must weaken as the inverse square of the distance. In the late 1660s he tries to verify his ideas by working on some data about the Moon's orbit and the Earth's size, but he does not have accurate data and so he gets the result that is off, in his view. Newton did not realise that his standard geography book had a rather inaccurate estimate for the diameter of the earth, which no-one found out until twelve years later. So Newton decided that his calculations and his theory of an attractrive force falling off as the inverse square of the distance does not work: the gravitation at the surface of the Earth is not what pulls the Moon into its orbit.

Newton spent the next decade working on optics, matter theory and alchemy, leaving physics and celestial mechanics speculations largely aside. Then something happened quite out of the blue. In 1679 he was brought back to the topic by his enemy, Robert Hooke. These two detested one another, because they had argued about optics in 1672 (Hooke had had the temerity to suggest that Newton's theory was not absolutely true.) Hooke and his circle of friends in London that included Sir Christopher Wren and other people of the Royal Society had been speculating about planetary motion in the Copernican system, which, of course they all accepted. (Remember that Newton was in Cambridge as Professor of Mathematics) Well, Hooke had an excellent idea that the Cartesian whirlpools that pushed the planets around did not really make sense, therefore, maybe what was needed was some non-mechanical force to pull the planets into their orbits. This sounds a lot like the young Newton in the 1660s. Hooke had been claiming (along with many of his friends) that the planets are held in their orbits by an attractive force from the Sun and Hooke guessed that this force would fall off from the Sun as the inverse square of the distance. But he could not elaborate this hypothesis mathematically, it was an intuitive guess maybe modelled on the behaviour of light.

Hooke was seemingly desperate for support for he even wrote to Newton about this problem and Newton became interested. Newton was only interested in astronomy about three times in his life: a little bit in the 1660s, in 1679 and about five years later. Newton spent most of his life doing other things, such as alchemy, theology, mathematics and optics. Hooke wrote to Newton and he worked on this problem, making some fundamental breakthroughs by revising his ideas of the late 1660s.

Newton in 1679 showed that if a body obeys Kepler's Second Law: the Areas Law, it must be undergoing a centripetal impulse towards the centre of its motion. He also showed that the body moves in an ellipse around one focus of the ellipse (Kepler's First Law) it will be undergoing centrifical impulse and this would fall off as the inverse square of the distance from the focus. This is the beginning of Newton's universal gravitation. So, Newton articulates Hooke's theory but does not publish his findings for the next five years and does not give an explanation to Hooke in London.

To make a long story short, this debate continued around Hooke and the Royal Society and in 1684 Edmund Halley, a young astronomer, later a protege of Newton, was involved in these debates and finally thought that Newton may be able to answer the question. Halley went to see Newton who resurrected his original calculations. Over the next three years he then worked from the simple case of Hooke's hypothesis to the more complex case of multiple planets' movements and not just planets as points but the

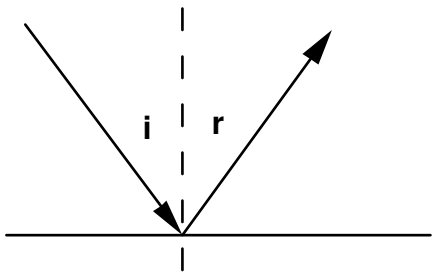
planets as spheres. Newton worked it all out in the *Principia* which appeared in 1687. In the course of that work on the *Principia,* the principle of universal gravitation as it were, emerges into clarity because as soon as you start asserting that a planet, any planet, attracts the Sun and the Sun attracts the planet according an inverse square law of force, and in particular that every point in the planet attracts every point in the Sun and vice versa (and Newton does this mathematically) as soon as you have asserted all this you have essentially asserted the universal law of gravitation. So, the Law of Universal Gravitation falls out as the crystallisation of all this work. It falls out the bottom it is not there at the top--not the origin but the outcome of this course of work.

Now what is the morale of the story in terms of scientific change and scientific development?

> (a) Something like universal gravitation is not discovered in nature, for you cannot observe it and generalise about it from nuggety fact. Universal gravitation is a theoertical construct which evolves through a long course of technical work.
>
> (b) But, this technical work and problem solving is conditioned by Newton's natural philosophy, his metaphysical framework, otherwise he would have never moved in that direction. He is conditioned by his post-mechanist natural philosophy.
>
> (c) And what conditions his acceptance of post-mechanist natural philosophy: the larger circumstances of his biography; the institutional location of his education and ultimately the members of his society who he comes into contact with and is influenced by. So, something like the Law of Universal Gravitation is not a fact of nature but is a human construct embedded in a natural philosophical background, technical work and the whole biographical, social background of the particular person or group who manufacture that construct.

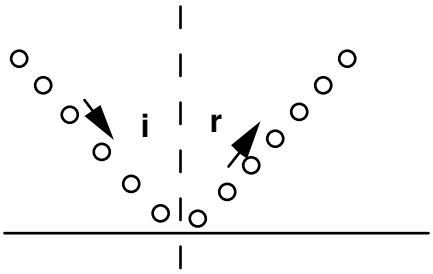
Universal gravitation is a completely historical construction, which is embedded in complicated patterns of historical work and historical conditioning: that is the basic lesson we should learn from this as with every major piece of science. We should demystify it and show that it is all open to historical, sociological and political analysis, it being a complex piece of 'culture' not a mirror image cast by 'nature'.

Figure 1



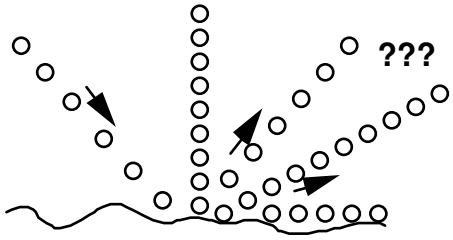
Light ray
geometrical optics

Figure 2



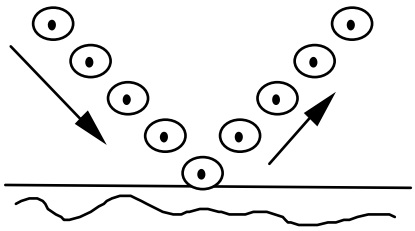
Mechanistic explanation

Figure 3



Newton's Objections

Figure 4



Newton's answer short-range force fields interact

Figure 5a

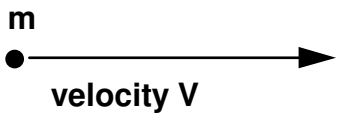
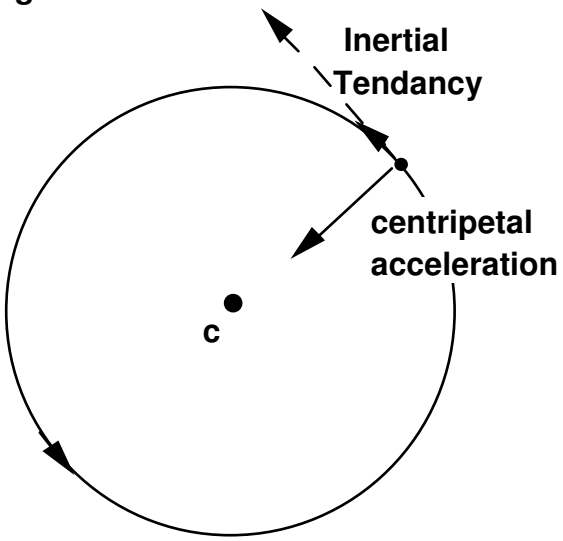


Figure 5b



Circular motion demands centripetal acceleration