THE MATTER OF MASS

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A NEW PERSPECTIVE BY K. STRANG

The Matter of Mass

Distinctions and Newton's Laws of Motion

Matter and mass are not identical. Mass is a property of matter (however you want to describe 'matter'). It can also be of two different varieties, namely gravitational mass (think of weighing something or dropping something where it accelerates towards the earth at approximately10 ms^{-2} or angular momentum as acceleration includes change in direction) and inertial mass (think of something at rest or moving at a constant velocity and as velocity includes direction the constancy means moving in a straight line).

Newton thought of inertia as an internal force of matter but admitted while he could give a mathematical account of gravity, he could not give a mechanical account. This means that although the mathematics worked, there was no ontological explanation of how the mass of one planet could effect the mass of another millions of miles distant.

Newton's three laws of motion [1] are based on the assumption of absolute space which means an unchanging backdrop to events. His great rival Leibniz criticised this idea:

'These gentlemen maintain, then, that space is a real absolute being; but this leads them into great difficulties. For it appears this being must be eternal and infinite. This is why there are some who believed that it was God himself, or else his attribute, his immensity. But as it has parts, it is not a thing which can be appropriate to God. . . . I have more than once stated that I held *space* to be something purely relative, like *time*; space being an order of co-existences as time is an order of successions.' [Leibniz's correspondence with Clarke, third paper, *Leibniz Philosophical Writings*, J. M. Dent & Sons 1973 p210-211]

This approach was adopted by Ernst Mach (1838 - 1916) and Einstein.

Newton and the bucket of water

Newton in order to demonstrate his absolute space set up an experiment by suspending a bucket of water on a rope and twisting the rope. When the rope was released the bucket spins and the surface of the water which is initially flat begins to spin in tandem with the bucket then experiences a centrifugal force causing it to rise up the sides of the bucket forming a concave shape. Then both bucket and water spin together *without* relative motion and the water reaches its greatest curvature.

'Newton asked what it was that caused the water's surface to curve. Was it the water's motion relative to the side of the bucket . . . or motion relative to absolute space? Surely the latter, since when the relative motion is greatest, at the start, there is no curvature of the water's surface, but when the relative motion has stopped (and the water and bucket spin together) the curvature is greatest. This was Newton's main argument for absolute space.' [Julian Barbour, *The End of Time* Phoenix 2000 p62-63]

This was a problem for the relativists because if the motion of the water had to be relative, what was it relative to if not the bucket or a questionable absolute space.

Mach's Principle and Einstein

Ernst Mach did not think the inertial mass was an intrinsic quality of matter but depended on the configuration and distribution of all the mass in the universe. On Newton's bucket experiment he argued that if motion was relative then it

' . . . was ridiculous to suppose that the thin wall of the bucket was of any relevance . . . Newton had used the bucket experiment to show that relative motion could not generate centrifugal force, but Mach argued that the relative motions that count are the ones relative to the bulk of the matter in the universe, not the puny bucket. And where is the bulk of the matter in the universe? In the stars.' [*ibid* p65]

Barbour points out that Bishop Berkeley (1685 – 1753) had reached similar conclusions and that Einstein had been greatly influenced by Mach in developing GTR.

The Gyroscope

There is a fascinating set of experiments filmed at The Royal Institution's Christmas Lectures by Eric Laithwaite in 1974 that was banned for a time because they seemed to undermine the idea of the equivalence of inertial and gravitational mass. In one telling experiment an extremely heavy gyroscope is fitted at the end of a short handle and a young boy from the audience is asked to try and lift it which he is unable to do. Then the boy is strapped to a pole on a revolving platform and the gyroscope is set in motion. The boy is handed the spinning gyroscope and he is able to lift it easily as his platform rotates. What conclusions can be drawn from this? Either the weight

of the gyroscope has decreased significantly or the boy has, in a trice, become incredibly strong! It seems to me to indicate that gravitational mass and inertial mass are not identical or that the centripetal force experienced by the rotating boy has enabled the gyroscope, to rise up in a gravity defying way. Laithwaite does not explicitly draw conclusions from his experiments but allows the audience a chance to figure it out. The episode can be found at https://www.rigb.org/explore-science/explore/video/engineer-through-looking-glass-jabberwock-1974. There is a transcript of the lecture with more notes included in the scientific papers section of my website but here is a quote referring to the experiment:

'*This is no experiment to try yourselves*. It is more dangerous than holding a sizeable sky rocket while it is burning. The big wheel is more dangerous than connecting apparatus to the household electricity supply. If the wheel were to be dropped and to run amok, I can tell you now that its energy is sufficient to throw it 200 feet into the air - and this theatre is less than sixty feet high !

You see, rotating mass is a very compact form of storing energy, more compact than most of us realise. In the league table of energy/weight ratio it comes a good third to those much sought and used creatures, nuclear fuel and chemical fuel. Electromagnetism, hydraulics, pneumatics, fuel cells, solar batteries and so on, are much lower down the table, with electrostatics bottom of the league, and car batteries not leading them by very much (which is why we have not got our electric cars yet). But we did have flywheel-driven buses in Switzerland, where the route is all up hills and down. The one thing a petrol engine will not do is to pour petrol back into the tank as you go downhill. But a flywheel will accept the energy back, so there is enough energy in a flywheel to drive a bus for half a day. A nice figure to remember is that a high tensile steel fly-wheel spun up to its bursting speed (oh, I forgot to tell you, sometimes they burst, too!) is equivalent in energy to the same volume of water as the volume of the flywheel raised to 100,000 feet .'

It is surprising that more technology hasn't arisen from this. But then Laithwaite was an engineer and sidelined over his views on gyroscopes. He went on to invent the Maglev (magnetic levitation) system where trains are levitated and propelled using magnets which reduces resistance and increases speed.

Centripetal and Centrifugal

Although reference has been made to 'the centrifugal force' it is not technically a force but describes the effect of inertia – the tendency to resist a change in motion.

Newton knew that a rotating body underwent acceleration towards the centre of rotation. This is a centripetal force. Is it the spinning of the mass of the earth that causes everything to be drawn towards its centre? The moon takes almost 28 days to complete one cycle whereas the Earth takes 24 hours so the reduced rate of spin is possibly why there is less gravity on the moon. The Sun also rotates as it orbits the galaxy. So given the experiments with the gyroscope is it the differential motion of the spins of the various bodies in the solar system that account for gravity rather than mass on its own.

Carl Murray in an essay 'Is the Solar System Stable' highlights the importance of resonance in orbital and spin cycles :

'Resonance pervades the Solar System. It happens when any two periods have a simple numerical ratio. The most fundamental period for an object in the Solar System is its orbital period. . . . Another common form of resonance in the Solar System is spin-orbit resonance, where the period of spin of an object . . . has a simple numerical relationship with its orbital period. For example Mercury is locked in a 3:2 spin-orbit resonance. A more obvious example is our own Moon, which is in synchronous rotation because of the 1:1 spin-orbit resonance that forces it to keep the same face towards the Earth. . . . Most natural satellites . . .are in synchronous spin states although this was not their original state: they have evolved into such configurations . . .' [The New Scientist Guide to Chaos, Penguin Books, 1992 pp 98 and 103]

The main point of the essay I think was to show how periods of order can arise from greater periods of chaos.

Conclusions

It seems to me that motion is the cause of a great deal of phenomena: heat, magnetism so why not gravity. Mass as lumps of matter on its own has nothing to recommend it unless it is viewed as a bound sum of electro-magnetic waves with vastly increased density or compression that allows it to

move in a periodic way similar to radiation but slower. Isn't this what $E=mc^2$ means?

Notes 1 Newton's Laws of Motion

An object at rest will remain at rest, and an object in motion will continue in a straight line at constant speed, unless acted upon by an external unbalanced force. This is also known as the law of inertia.

The rate of change of an object's momentum is directly proportional to the applied unbalanced force and occurs in the direction of the force. [i.e. Force equals the mass times the acceleration, ($F = ma$)]

Newton's third law states that for every action, there is an equal and opposite reaction.