Chapter 11

CLOCK CONFUSION IN THE 20TH CENTURY

The connection between inertia and timekeeping

The theory of General Relativity was published in 1915. A casual reader of the history of science may gain the impression that twenty years later Einstein's work was fully integrated into the teaching and thinking of physics. Teaching – yes; thinking – no. The backbone of the profession, that is experimental physicists in universities, government organizations, and industry, thought it hardly worthwhile to grapple with the complex mathematics of relativity, because the theory was of little or no help to the solving of their problems. It seemed to be more of a philosophical adornment, a conversation piece with which to boast one's intellectual prowess.

Cosmologists were an exception to this trend. They had the luxury of being able to let their imagination roam without accountability to controllable laboratory experiments. In 1919, Einstein became an overnight international celebrity when it was announced that photographs taken during a full solar eclipse revealed deflection of light from stars near the sun by just the amount predicted by General Relativity. Within a decade however, it had become clear that the Cambridge astronomer Arthur Eddington, who had performed the measurements, had ignored 85% of his data including stars that were apparently shifted in the wrong direction [11.1]. Unfortunately. this misuse of data was not only held up to promote Einstein's theory, but also to discredit Newtonian gravity. This was even more remarkable since Newton had never described a relationship between light and gravity.

It seems that nothing could prevent the rise of Einstein's reputation and his theories fully entered the accepted folk lore of the entire world. Claims are still made that only General Relativity can explain certain astronomical observations, but this cannot be true when rival theories are not being seriously considered. In the middle of the 20th century, the intellectual elevation of Einstein's theories had still made no impression on the armies of scientists, engineers and technicians who invented, developed, and produced the machines of our modern world. Instead, they were completely satisfied with the Newtonian mechanics with which they were utterly familiar and which is so much easier to apply.

At the same time the Einstein model of the universe had become the accepted way of describing nature. Newtonian physics was demoted to a useful approximation and any thought that the distant universe had an instantaneous effect on earth was entirely ruled out. This is why Mach's principle and the force of inertia are no longer discussed. Physics undergraduates are now presented with a large body of experiments which they are told demonstrate that Einstein's theories of relativity are proved beyond all doubt. Most of these attempt to investigate Einstein's prediction of the dilation of time itself. This involves the observation of some very clever clocks in highly unusual situations. The understanding of these tests is the primary subject of this chapter.

As well as enthusiastic supporters of Einstein's ideas, there have always been capable and respectable physicists around who spoke up against them. They have published many papers and books in spite of fierce opposition from other professors and editors of major physics journals. The scientists and journalists, who form the visible core of the physics profession, are apt to tell such dissident authors that the overwhelming majority of their peers are completely convinced that Einstein's world view is unshakeable. Consequently any criticism represents bad science. How can this attitude rest easily alongside Einstein's letters which he wrote in the middle of the twentieth century to his old friends in Switzerland towards the end of his life [11.2], in which he claimed to be unsure of the validity of his theories?

Einstein's failure to find a unified theory of electromagnetism and gravity, his protracted disagreement with Niels Bohr about the probabilistic nature of quantum mechanics and not least the growing realization that Newtonian action at a distance was no spookier than an energy filled spacetime vacuum field, were major factors behind his self doubt. Since the early 1970's, experiments have been performed that demonstrate that quantum detectors interact with each other instantaneously irrespective of their distance of separation [11.3]. Einstein and later physicists in the 1960's such as the Irishman John Bell working at CERN had deduced that if quantum mechanics were true, it required such non-local connections between all of the objects in the universe. There is now a growing body of empirical evidence which goes under the banner of "quantum entanglement" which demonstrates instantaneous non-local interactions. These results have been steadily eroding the foundation on which the field and Einstein's local action relativity theories stand. In 1949 Einstein predicted that none of his concepts were likely to survive and he was not even on the right track to penetrate the secrets of nature. Therefore in the latter half of the twentieth century, it seemed the die was cast for a major paradigm change in physics. But this revolution has still not occurred presumably as a result of a lack of consensus on an alternative outlook.

London Rebels

Without reference to Einstein's disillusionment, three prominent English physicists based in London launched a strong campaign against Einstein's theory of special relativity (SR) during the 1950-70's. This particular section of Einstein's theorizing makes predictions of physical changes to objects as a consequence of their "inertial" velocity relative to an "inertial" observer. Here the adjective "inertial" must be clearly defined as a description of an object if it is not being acted on by any external force. The consequence is that this object is not accelerating nor feeling the force of inertia. The names of the rebels were Guy Burniston-Brown, Louis Essen, and Herbert Dingle. Burniston-Brown produced several papers questioning the philosophical integrity of SR [11.4] as well as developing a Machian theory of inertia, based on the retarded action at a distance model which was discussed in chapter 10.

Louis Essen was a British government experimentalist who distinguished himself in the National Physical Laboratory (NPL) as a pioneer of atomic clocks. One suspects that all clock makers are not entirely happy with Einstein's concept of time dilation and Essen became their spokesman. His cesium clocks were highly valued developments to both sides of the cold war. He was the first foreign recipient of the Popov medal, the top Russian physics prize in 1959 as well as receiving a British OBE in the same year. Despite subsequently becoming a Fellow of the Royal Society, he was shunned for his criticism of SR. His primary concern was that Einstein had made a fundamental error with his units in the assumptions of the SR theory. He argued that Einstein had assumed that the speed of light was a fundamental constant, and his formulae constantly adjusted the unit of time to keep it so. To Essen, this was illogical and defied the basic understanding of the process of physical measurement. Essen sacrificed the good will of many of his colleagues to take this radical stance and even now the NPL web page which highlights many of Essen's discoveries, admits that he was actively encouraged by his employers and the government to suppress his dissident views just prior to his retirement. In 1978 he published an article entitled, *Relativity and Time Signals*, in the journal, Wireless World, [11.5] in which he wrote:

> "No one has attempted to refute my arguments, but I was warned that if I persisted I was likely to spoil my career prospects. … the continued acceptance and teaching of relativity hinders the development of a rational extension of electromagnetic theory."

Best remembered amongst the three Londoners was Herbert Dingle who was a professor of physics at Imperial College and later held the Chair of History and

Philosophy of Science at University College, both part of London University. He also rose to the position of President of the Royal Astronomical Society.

Dingle had lectured on relativity at the University of London and published books with titles like *Relativity for All (1922), The Special Theory of Relativity (1940),* and *Mechanical Physics (1941).* He was an excellent communicator and when he adopted an anti-SR stance in the latter part of his career he caused great trouble to the editors of respectable physics journals, including 'The Proceedings of the Royal Society', 'The Philosophical Magazine', and 'Nature'. His early battles are recounted in *A Threefold Cord: Philosophy, Science, Religion* [11.6]. This book recounts a dialogue with Viscount Samuel, the distinguished British liberal politician who sat in the Asquith Cabinet at the outbreak of the first world war. After the war he became the first High Commissioner of Palestine. At the age of fifty Samuel turned away from politics and devoted his time to philosophy. His principal objective was to find some common ground between philosophy, science, and religion. This led to his conception of a *Threefold Cord,* a book which contains no mathematics and is easily understood by all who are interested in the laws of nature.

Samuel was a firm believer in some form of ether and Dingle could not shake Samuel's faith in this abstract concept. Nevertheless, when Dingle discussed time dilation and the twin paradox, which states that a space traveler ages slower than his twin brother on earth, Samuel was ready to admit:

> "…. but I feel that any theory which is in such flagrant contradiction with common sense would need much more powerful arguments before it would be likely to command any measure of general support."

To this Dingle replied:

> "Your reaction to my account of this controversy is that to be expected of any intelligent person whose reasoning power has not been destroyed or paralyzed by over-indulgence in symbol manipulation: it is that of incredulity."

This shows that Dingle was very much aware how, in the twentieth century, physics had become dominated by mathematics (symbol manipulation) to the detriment of physical models which were based on observational evidence (common sense). In the end, physics must be expressible in words if it is ever to become comprehensible. Unfortunately, students are now regularly taught that physics is written solely in the language of mathematics and often defies "common sense" and they had simply better get used to it. Dingle along with the authors of this present book believe that intelligible physics must be at least the goal if not the outcome of any theory. Dingle demonstrated the dangers of over reliance on mathematical theory with his proof of a massive internal contradiction in Einstein's theory of SR.

The word "relativity" has traditionally meant that if two bodies move relative to each other, it is not possible, by experiment or otherwise, to claim that one of them is moving more than the other. Relativity was obvious to scientists of the eighteenth and nineteenth centuries. They saw little need to discuss the subject. This natural relativity is often called Galilean relativity as the Italian astronomer had apparently demonstrated that from below decks on a calm sea, it was impossible to measure the steady speed of a ship without looking out of a port hole.

Einstein defined the principle of relativity in a more complicated way. In his first paper on SR [11.7], and later translated into English, [11.8] he said:

> "The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred to the one or the other of two systems of coordinates in uniform translatory motion."

For example, if a train moves through a station with a constant velocity, any event inside the train or on the platform can be analyzed by any observer either on board or on the ground using the same laws of physics. It becomes purely a matter of tradition who is considered to be moving and who is stationary.

However, as Dingle explained with great clarity, the symmetry of relative motion breaks down if the predictions of SR are correct. He referred to the clock paradox, which is also known as the twin paradox, and has been discussed extensively in both the specialist and popular physics literature throughout the twentieth century. Einstein claimed that SR predicts that if one of the twins goes space traveling and later returns home to earth, he finds himself to be younger than his brother. Somehow in Einstein's world model, space travel involves more motion with respect to the earth than the motion of the earth with respect to the space ship. This is purported to result in asymmetrical aging.

In 1972, ten years after the publication of the *Threefold Cord*, and after several more public dialogues with eminent physicists and philosophers in well respected journals, Dingle had still not achieved his goal of encouraging a general rethinking of Einstein's theory. As a consequence, he published another book, *Science at the Crossroads* [11.9]. It is a book which he conceded he had not wanted to write. However he felt obliged to point out that expensive and dangerous physics experiments were now being undertaken in labs all over the world and he was convinced that they were being designed based on an implausible theory. By 1972, after thirteen years of honing his argument down to the simplest possible exposition he wrote:

> "It would naturally be supposed that the point at issue, even if less esoteric than it is generally supposed to be, must still be too subtle and profound for the ordinary reader to be expected to understand it. On the contrary, it is of the most extreme simplicity. According to the theory [special relativity], if you have two exactly similar clocks, A and B, and one is moving with respect to the other, they must work at different rates, i.e. one works more slowly than the other. But the theory also requires that you cannot distinguish which clock is the 'moving' one; it is equally true to say that A rests while B moves and that B rests while A moves. The question therefore arises: how does one determine consistently with the theory, which clock works the more slowly? Unless this question is answerable, the theory unavoidably requires that A works more slowly than B and B more slowly than A – which it requires no super-intelligence to see is impossible. Now, clearly, a theory that requires an impossibility cannot be true, and scientific integrity requires, therefore, either that the question just posed shall be answered, or else that the theory shall be acknowledged to be false. But, as I have said, more than 13 years of continuous effort have failed to produce either response."

In 2005, the 100th anniversary of the birth of the theory of SR and 33 years after Dingle's last plea for logic to prevail, nobody has answered his question and Einstein's theory is still held to be the bedrock of modern physics. This overwhelming level of support for SR is based on several famous experiments which seem to numerically support some of its predictions. If Dingle was correct in his reasoning, this situation can only have arisen if generations of physicists have not been applying the theory to experiments correctly. We show later in this chapter that this is precisely what has occurred.

The Foundations of 20th Century Physics

What is the reason for asymmetrical aging in special relativity ? Or more importantly, why is it absent in Newtonian physics? The answer can be found directly in Einstein's motivation for creating the theory. By the end of the 19th century, the accepted foundations of physical theory rested on two pillars, the Machian reinterpretation of Newtonian physics and the Maxwell-Lorentz theory of electromagnetism. Mach's mechanics is often quoted as Einstein's primary inspiration for his emphasis on the importance of Galilean relativity.

The difficulties that Einstein confronted, arose when it became clear that Maxwell's field equations were not invariant under Galilean transformations. In less technical jargon, this means that according to Maxwell's theory, the strength and nature of the electromagnetic fields surrounding a body depended on its absolute velocity with respect to an ether. This comes about because Maxwell's equation's are built around a constant called *c*, which he defined to be the absolute velocity of propagation of electromagnetic fields through an ether. It seemed to everyone a natural analogy to the highly successful theory of acoustic waves which travel at a speed which depends entirely on the physical properties of the medium through which they flow. *c* is of course now universally described as the speed of light. However, to Einstein, the undetectable ether felt very similar to the abhorrent notion of Newtonian absolute space. Mach's rejection of the concept of absolute motion clearly inspired him to seek a way of philosophically rescuing Maxwell's equations. In his theory, he eliminated the ether, and ensured that the physics that one observed did not depend on the absolute velocity of one's steady motion.

Einstein's argument rested on the assumption that the speed of light, *c*, was a universal constant for all inertial (moving with a steady velocity) observers. As Louis Essen has pointed out, Einstein somehow managed to persuade his peers that his assertion regarding the constancy of the speed of light for all observers was more fundamental than keeping a well understood and consistent unit of time. Remarkably it seems that Einstein's proposal to overthrow all previous concepts of time was greeted with great enthusiasm, whereas it may have been prudent to consider other possibilities before jumping headlong into the destruction of conventional timekeeping. The bold assumptions of SR also directly conflicted with the long established and highly successful theory of Newtonian mechanics.

Einstein's drastic measures were clearly considered an acceptable sacrifice in order to save the Maxwell-Lorentz electrodynamics. It seems that very little attention was paid at the time to any alternative theories of electrodynamics which would not have required a radical distortion of space and time in order to satisfy Galilean relativity. History has somehow forgotten that there was indeed another available theory of electrodynamics based on the action at a distance laws of Andre Marie Ampère, Franz Neumann, Augustin Coulomb, Wilhelm Weber and Gustav Kirchoff. This philosophically distinct approach to the subject was highly praised by Maxwell who actively encouraged his readers to keep an open mind and let future discoveries determine which approach was more accurate. This now forgotten body of understanding has been reviewed in our earlier book, *Newtonian Electrodynamics* [11.10] in which it is demonstrated that the relativistic Maxwell-Lorentz field theory cannot be applied to all situations and a return to an action at a distance Newtonian electrodynamics is urgently required. The acceptance of such a field free theory would have removed the need for the invention of SR and the consequent distortion of the units of space and time. However history tells another story, the glorification of Einstein's imagination.

The Michelson-Morley Myth

The theory of special relativity achieved its goal of making Maxwell's equations invariant for all inertial observers. However, the weakness of Einstein's theory lies in the fact that it was not built empirically upon a body of solid experimental knowledge. Instead Einstein based his model on the unsubstantiated assumption that the speed of light is constant for all unaccelerated observers. In his seminal paper in which he presented the theory of relativity in 1905 [11.7], Einstein provided no references at all and certainly gave no clue regarding what information he had used to justify his assumption. Even though Einstein later claimed that he was unaware of it at the time, his colleagues and followers soon started quoting a now famous experiment by the American physicists, Albert Michelson and Edward Morley, as the evidence that confirms Einstein's assumption.

The elaborate and expensive test that is now universally referred to as the Michelson-Morley experiment was performed at the Case School of Applied Science in Cleveland, Ohio and published in 1887 in the American Journal of Physics under the title, *On the Relative Motion of the Earth and the Luminiferous Ether* [11.11]. The scientists were clearly under the influence of Maxwell's electromagnetic ether model and were attempting to prove its existence by measuring the speed of light in two orthogonal directions at the same time using a device now called a Michelson interferometer. This experiment is analogous to trying to measure the strength of the current in a river by taking two identical swimmers and timing their return trips over 50 meter courses in two directions at right angles to each other. If their times are different, then one can calculate the speed and direction of the water flow. One can also make the clear deduction that identical swimmers can move at different speeds relative to the river bank depending on external conditions such as the current. Instead of swimmers, Michelson and Morley attempted to measure the speed of light in differing directions to determine whether external conditions affected it. The details of the Michelson-Morley experiment are not as important as the calumnious manner in which the results of this experiment have been represented over the intervening years.

Without exception, all modern undergraduate physics textbooks report that the Michelson-Morley experiment is the most famous and important null result in the history of science. In other words, they use this famous paper to confirm that no differences in the speed of light were found in any direction. This is however not what Michelson and Morley reported. In fact they wrote

> "... the relative velocity of the earth and the ether is probably less than one-sixth the earth's orbital velocity, and certainly less than one-fourth. ...The

experiment will therefore be repeated at intervals of three months, and thus all uncertainty will be avoided."

Unfortunately, they never did repeat the experiment at different times of the year, but most importantly they certainly did not report a null result. The measured speeds were simply less than they expected and getting near the limits of the resolution of their equipment. There is certainly no finding in the paper strong enough on which to justify Einstein's construction of a completely new physical model. However, the null result interpretation clearly became attractive to Einstein and his followers primarily if it meant that Maxwell's theory could be saved.

Similar experiments were built by Morley and one of his students, Dayton Miller, in the first few years of the 20th century. However, like the original, they suffered from not enough readings to make a solid case. Nevertheless, they consistently published evidence of differences in the speed of light. However in 1921, two years after the publication of Eddington's eclipse data and the wide acceptance of General relativity, Dayton Miller was visited by Einstein and they both felt that it was imperative to determine once and for all whether the Michelson interferometer produces a null result as required by SR. Miller was awarded a lavish research budget and set up the most elaborate interferometer to date. He made measurements with it in Cleveland and at the Mount Wilson observatory in Southern California.

The most thorough set of experiments was performed at Mount Wilson between 1925 and 1926. In this period, he took over 100,000 readings taken from 6,402 turns of the interferometer. The readings were taken in four batches separated by three months to investigate the effect of four epochs of the earth's orbit around the sun. In comparison, the original Michelson-Morley data was taken during a single four day period involving only 36 turns of the device. In addition, Miller had taken the previous two years to perform control experiments which involved subjecting his apparatus to known mechanical and thermal distortions so that these effects could be eliminated from the final experiment. The history and final results of his investigations were finally published in 1933 [11.12].

In order to appreciate the magnitude of Miller's discoveries, it is necessary to understand one astronomical concept, that of the sidereal day. A conventional 24 hour "civil" day is the time required for the sun to reappear the next day at the same east-west longitude. This is the time we measure on our watches. In this time, however, the earth has moved a small part of its orbit around the sun and as a consequence, every 24 hours, the sphere of background stars has shifted by a few degrees. The amount of civil time between the reappearance of the fixed stars in the same location for a given observatory is actually 23 hours 56 minutes and 4 seconds.

This is the definition of a sidereal day which is split evenly into sidereal hours, minutes and seconds.

Miller reported in 1925 that after analysing the data from the first three epoch periods :

> "the curves for the three epochs were simply averaged and it was found that when plotted in relation to *local civil time*, the curves are in such phase relations that they nearly neutralize each other; the average effect for the three epochs thus plotted is very small and unsystematic. The curves of observation were then plotted with respect to *sidereal time* and a very striking consistency of their principles was shown to exist, not only among the three curves for azimuth and those for magnitude, but, what was more impressive, there was a consistency between the two sets of curves, as though they were related to a common cause. The average of the curves, on sidereal time, showed conclusively that the observed effect is dependent upon sidereal time and is independent of diurnal and seasonal changes of temperature and other terrestrial causes and that it is a cosmical phenomenon."

It is quite surprising that after 40 years of this type of experiment, nobody else had plotted the data against sidereal time. However, only Miller had taken such a large amount of data spread throughout an entire year. Over the course of a few days, there is not much shift between civil and sidereal time, but over the course of three months, the two time bases get out of synchrony by 6 hours. The difference between the averaging with respect to the two time scales is shown in figure 1. The "azimuth" simply represents the compass direction at which the experiment produced the most effect at any given time. Clearly the average with respect to sidereal time reveals a true phenomenon which displays a direct interaction with the fixed stars.

When a scientific experiment is being designed, there is always one or more hypotheses under investigation. By the time Miller came to design his equipment and experimental timetable, he was attempting to investigate at least half a dozen differing ether hypotheses that had been proposed by various scientists over the previous forty years to explain the Michelson-Morley results. The most famous of these included a static ether as Michelson had first proposed, or an alternative was an ether that was static in the universe but was locally pushed by the earth as it moved through it. There was of course Einstein's hypothesis that there was no ether at all which went with his prediction that the equipment became shorter in the direction of motion. Miller actually wanted to divorce himself from all preconceived theories and directly discern whether he could measure what he called the “absolute motion of the earth” with respect to the distant stars.

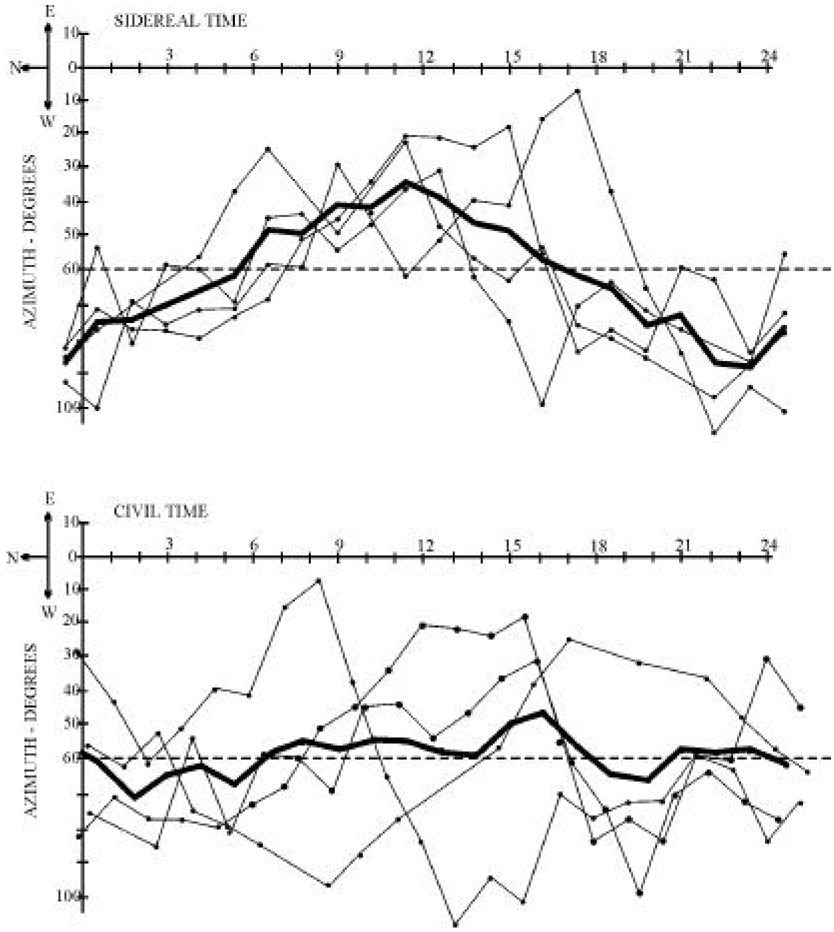

Figure 11.1 : Miller’s demonstration of the dependence between his positive effect and sidereal time (from [11.13]). Thick line is the average.

Miller’s predecessors had only been concerned with the possible effects on a terrestrial experiment due to a local ether wind. As a result, they failed to appreciate two important aspects of their results. They knew that the orbital speed of the earth around the sun was approximately 30 km/sec, and therefore assumed that the ether wind would be at least this speed or more. When their experiments produced results that were non-zero, but nevertheless lower than their expectations, they assumed that the positive results were erroneous. Miller felt strongly enough that these results were inconclusive and fortunately had the foresight, determination and most importantly funding to make more accurate measurements at four different times of the year. From his vast volume of recorded data, Miller eventually concluded that the only interpretation of his results was that the earth and solar system were moving against the backdrop of distant stars with a velocity in excess of 200 km/sec in a direction toward a star in the constellation Dorado in the Southern Sky. Unfortunately his interpretation of the cause of his data were inevitably based on his own assumed version of the ether and thus his final predictions regarding the motion of the solar system are also inconclusive. However Miller's data definitely confirmed that the speed of light is not the same in all directions with respect to the background stars

Even by 1921, Einstein was very concerned by the preliminary positive results of Miller's experiments. He wrote to his colleague Robert Millikan [11.14]:

> "I believe that I have really found the relationship between gravitation and electricity, assuming that the Miller experiments are based on a fundamental error. Otherwise, the whole relativity theory collapses like a house of cards"

In the meantime, nobody has discovered a "fundamental error" in Miller's results. However in the early 1950's, Miller's successor in the physics department at Case Western Reserve University, Robert Shankland formed a close relationship with Einstein and undertook to revaluate Miller's data. In a paper [11.15] published in 1955, fourteen years after Miller's death, Shankland's team analysed several of the 24 hour data series and revealed that the data was indeed quite noisy, induced primarily by temperature variations which naturally occur during any given day. Miller had naturally foreseen this problem and this is why he took such an overwhelming amount of data to try and average out these experimental distortions. At no point in Shankland's lengthy analysis did he take into account that Miller had found a strong dependence on sidereal time as opposed to civil time. The temperature variations to which Shankland paid attention were due to changes between night and day which clearly depend on civil time but over the course of a year have no relation to sidereal time To Miller and his supporters, the correlation with sidereal time proved that the speed of light depends on direction with respect to the fixed stars. This aspect was completely ignored in Shankland's incomplete analysis.

Not surprisingly given the overwhelming support for Einstein's relativistic theories by the mid 1950's, Shankland's dismissive paper has become the celebrated final accepted word on the issue. Unfortunately, since Shankland's investigation, the vast number of data sheets to which he had access in the Case Western Archives have gone missing.

So successful was Shanklands discrediting of Miller's conclusions, that a Michelson-Morley type experiment performed in 1964 [11.16] never even considered to take data over the course of a year so that an effect with respect to sidereal time could be investigated. Following the logic of Michelson, this group only tested the hypothesis that the earth was possibly moving through a static ether. As a result they based their findings on results taken only over the course of a single day. Not surprisingly, they came to the conclusion that there is no discernible effect on the speed of light due to the earth's motion around the sun.

Fortunately, the Miller results have been reinvestigated at least once more, notably by the very eminent French physicist and economist, Professor Maurice Allais. He won the Nobel Prize in economics in 1988 for his work on maximising the efficiency of national economies. However, his professed true love was fundamental science and in 1978 he was awarded the Gold Medal of the National Centre for Scientific Research, the highest honour in French Science, for his contributions. He had a particular interest in gravity and during the 1950's was widely lauded for his discovery of still unexplained gravitational anomalies during eclipses. In the 1990's Allais unearthed the work performed by Miller 70 years earlier and went as far as declaring the current teaching of this subject to be a "cover up". In one of his recent papers on the subject [11.17], he wrote

> "The highly significant regularities displayed by Miller's observations do correspond to a very real phenomenon which cannot by any means be attributed to temperature effects. Consequently the light velocity is not invariant to its direction over time. As a result Einstein's special theory of relativity is based on a principle, the invariance of light velocity, which is contradicted by observation data"

It is tragic that during the last 80 years, nobody has successfully performed an experiment like Miller's. As a result, scientists are using Einstein's theory of relativity with complete confidence even when the foundation of its assumptions have been experimentally disproved. Unfortunately the Miller experiments are now either completely ignored or discredited and seen purely as an unsuccessful negative attack on the conventional understanding of modern physics.

In contrast, a positive interpretation of the results of not only Miller, but also his fellow interferometer experimenters, is that terrestrial physics is directly affected by the distant universe or what Mach referred to as the fixed stars. In the 19th century, it was initially quite shocking that Foucault's pendulum appeared to display a connection with the fixed stars. However, eventually this was seen to be an exciting advance on our knowledge of our position in the universe. While perhaps similarly disturbing to field theorists who believe that all of physics is restricted to local phenomena, eventually Miller's results will force us to come to terms with the fact that the speed of light is not constant and also has a connection with the distant cosmos.

The Experimental Tests of Special Relativity

Length Contraction ?

In 1905, Einstein's assumptions were considered to be reasonable and the perceived theoretical benefit was the survival of Maxwell's electrodynamic equations. However, controversies soon arose when the theory was applied to the motions of real material objects. SR makes predictions about physical changes to objects. It states that if we take two identical objects, A and B, both at relative rest with each other and then accelerate one or both of them to a high velocity, then if we can observe object B from the rest frame of A, it will appear shorter than when the two were at relative rest. This is the famous notion of Lorentz length contraction which has never been tested experimentally because of the technical difficulties with the necessary measurement.

The Lorentz length contraction however leads to a famous theoretical paradox, first described by Paul Ehrenfest within four years of the publication of Einstein's theory. He considered a solid spinning disk in which the periphery can be considered as a chain of very short, virtually straight rods. Since each of these short segments is moving with a higher velocity than the short length of material which is next to it but closer to the centre, then they should undergo a Lorentz length contraction which should decrease the circumference of the disk. However, if we look at the disk as made up of small length segments in radial directions, then at any given distance from the centre, each segment is moving at the same velocity as its neighbours and should not suffer a Lorentz contraction. The Ehrenfest paradox therefore asks how a spinning disk can reduce its circumference while retaining the same radius. This would mean that ð, the ratio of the circumference to the diameter of a circle would not be a constant as is commonly believed.

Thomas Phipps, a contemporary American critic of relativity theory has beautifully compiled the many reactions to Eherenfest's dilemma in his book, *Heretical Verities* [11.18]. He describes the first public responses to the Ehrenfest challenge by two mathematicians who published individually, but whose work was later compiled as the Herglotz-Noether theorem. In essence, they predicted that as a result of SR, a rigid disc cannot spin. Physicists at the time were not completely satisfied with this solution since they, like all of us, had observed many rotating discs, and as a result came to the conclusion that there was no such thing as a perfectly rigid body and therefore spin was actually possible. Unfortunately this solution completely ignored the fact that Einstein's theory of SR only applies to perfectly rigid bodies. According to Phipps, this allowed a new concept to enter the world of physics, the "impermissible idealization". With such a notion, it becomes possible to have a theory that can never be tested experimentally. For the majority of physicists and mathematicians who accept Einstein's theory, this apparently causes no concern, but for others typified by Dingle and Essen, it means that SR is a useless theory.

Mass Variation ?

Another prediction of the special theory of relativity is that as an object gains velocity, it also increases in mass. As the matter approaches the speed of light, its mass is supposed to tend to infinity, thus dramatically increasing the force of inertia acting on it. This process is a mechanism which prevents matter from travelling at or beyond the speed of light. Einstein saw this as a very important feature of his paradigm. Unfortunately, the supposed tests of this relativistic effect have been inconclusive in their logic. Instead of attempting to measure the mass of rapidly moving particles, these experiments have only confirmed what is known as the *e/m* ratio. This is the famous charge to mass ratio that was originally measured in 1897 by J.J. Thompson when investigating the nature of the then recently discovered mysterious cathode rays that now lie at the heart of conventional television tubes. His discovery that *e/m* was a constant for cathode rays, which was almost 2000 times larger than for atomic hydrogen ions, led to his proposal of the first subatomic particle, the electron.

This ratio became of interest, because for historical and technical reasons it was possible to measure it before either quantity on its own. It took 20 years before the first measurement of the fundamental charge on an electron in 1917 by R.A. Millikan. In 1908, Alfred Bucherer measured *e/m* for electrons moving over a large range of speeds up to 70% of the speed of light. He claimed that *e/m* decreases with velocity in a manner which is in accordance with the theory of SR and this was hailed as a confirmation of the theory.

However, there are at least two other explanations of Bucherer's results. One is that the charge on the particle could decrease with velocity. This possibility was only seriously considered and rejected in 1960, when it was theorized that such a relationship between charge and velocity would make it impossible to guarantee the charge neutrality of atoms made up of slow heavy positive protons and less massive and faster electrons. [11.19]. Another possible explanation has never been publicly considered which is that the electromagnetic forces acting on a charged particle may be affected by the velocity, v, of the particle relative to the charged plates or magnets used in the accelerator apparatus. If we entertain the notion that these forces might depend on v/c then it becomes impossible to deduce whether it is the force or the mass that is varying with the speed of the particle.

However, the entire motivation for the theory of SR was to attempt to secure the validity of the Maxwell-Lorentz field theory which included the Lorentz law of electromagnetic force on a charged particle which always increases with velocity. Consequently to test SR one must assume the validity of the Lorentz force law and the only explanation of the Bucherer results is that mass varies with speed. This however is pure assumption and it is just as valid to assume that mass remains constant at all velocities and the electromagnetic force on a charged particle decreases as its speed approaches c, the speed of light. This does however require a different electromagnetic force law which is not currently described in any conventional textbook.

The electromagnetic force law proposed by Wilhelm Weber in 1850 would however have supported this unvarying mass interpretation of the Bucherer experiment. It is remarkable that several years before Maxwell began publishing his electromagnetic field ideas, Weber had already introduced the fundamental constant c. As described in chapter 10, he needed this constant in order to unify the physical units in Coulomb's law of electrostatic force and Ampere's law of electrodynamic force. Weber defined c as "the relative velocity for which two electrical masses do not at all interact" [11.20]. Weber and his colleague Rudolph Kohlrausch took five years to measure this constant which they achieved with remarkable accuracy given the experimental equipment of the day. Much to their dismay, they arrived at a figure which was very close to the best measure of the speed of light in 1856. However, they could see no connection between their electromagnetic constant and the speed of light. It was Maxwell, ten years later, who finally connected the action at a distance constant, c, with the concept of electromagnetic radiation which included light. Utilising Weber's definition of c, Newtonian Electrodynamics seems to have anticipated the results of the Bucherer type experiments in which it became evident that it was impossible to accelerate matter faster than c by means of electromagnetic forces.

Since 1908, many similar experiments have been performed that all purport to confirm the varying mass predictions of SR. However all of these claims suffer in the same respect in that they exclude the possibility that electromagnetic forces may well decrease with increasing relative velocity between a charged particle and an external magnet or charged electrode. These type of experiments are therefore simply inconclusive and certainly provide no evidence for or against SR.

Time Dilation ?

Most of the assurance that conventional physicists feel with the theory of special relativity therefore comes from another family of experiments. These are the supposed tests of SR's prediction of time dilation. It is now proved beyond doubt that the speeding up and slowing of clocks and other time measuring devices often occurs as a result of their motion. This effect has a critical role in at least one area of technology which is widely used every day.

With a small hand held receiver, it is now possible to discover one's precise location on earth thanks to GPS (Global Positioning System) satellites developed primarily by the US defence industries. The accuracy of the measurement is crucially connected to the precise atomic clocks which are in each of the 24 satellites orbiting the earth at an altitude of approximately 20,000 km. In order for the system to work, each satellite broadcasts a unique signature code as well as the precise time of signal transmission. A GPS receiver needs to receive signals from four or more satellites in order to calculate its location in three spatial dimensions as well as time. For a position to be calculated, it is crucially important that all of the satellite clocks are ticking at the same rate as each other. This is achieved by continuously monitoring the positions and clocks of the satellites from six strategically located ground stations. If any of the clocks is found to be keeping incorrect time relative to the ground station, the satellite is advised and readjusts itself. The type of atomic clocks used in this system are generally found to randomly gain or lose a few nanoseconds (billionths of a second) in a day.

There is however a very important difference between the atomic clocks in the satellites and those in the ground station on earth. The clocks that go into space are specifically constructed to lose 38.4 microseconds (millionths of a second) per day compared to the clocks which will remain on earth. Only, then when the clocks are placed into their very specific orbit will they tick at the same rate as the earth based clocks. This is equivalent to taking a normal watch which might perhaps gain or lose one second per week and then engineering it to lose an hour every day. In other words, the clocks that are placed on the satellites run very differently from the earth based ones when sitting next to each other on the lab bench before and after take off. However when the clocks are in orbit, all of the clocks including those on the ground tick at the same rate. This is indisputable evidence that motion affects the performance of clocks in a predictable manner.

This behaviour has been interpreted as a confirmation of Einstein's theory of relativity. However, it cannot simply be a prediction of SR which predicts that the satellite clock, which is moving faster than the ground clock around the centre of the earth, should tick slower. In fact, as we have just seen the clock in orbit actually speeds up. The relativistic explanation of the speeding up of the clock comes from Einstein's theory of General Relativity. This aspect is often described as the gravitational redshift and predicts that clocks slow down in increasing gravitational fields. Since the satellite clock is further away from the centre of the earth than the terrestrially based clock, it has less gravitational force acting on it and therefore is predicted to tick faster. We see that Einstein's two relativity theories predict two entirely distinct mechanisms that both affect the timekeeping of a clock, one depends on inertial velocity and the other on gravitational force.

Examining the GPS satellite clock more closely, we can say that it is not moving inertially, which would require that it be unaccelerated and under the influence of no external forces. A clock in earth orbit, which is moving in an almost circular trajectory, is always accelerating toward the centre of the earth. In fact, its centripetal acceleration is its only dynamical property. For a GPS satellite in a stable orbit at 20,000 km above the surface of the earth, the acceleration toward the centre of the earth is about 1 m/s^2. The atoms in this clock therefore feel an equal and opposite force of inertia equal to their mass multiplied by 1 m/s^2 pushing away from the centre of the earth. Since every part of the satellite feels equal and opposing gravitational and inertial forces, there is no externally produced relative acceleration between any parts of the clock. This physical situation is often called "zero *g*" or "free-fall". It allows astronauts to float freely in their spacecraft and clocks to beat at their natural frequency.

In the general discussion on clocks presented at the end of this chapter, it will be shown that in a clock, not in a zero *g* environment such as on the surface of the earth, part of the internal mechanism that moves relative to the case has an extra acceleration component relative to the case. This occurs because the outside of the clock is being acted on by an external contact force such as the upward reaction applied by the earth's crust. This extra internal acceleration can cause the clock to tick at a frequency that is slightly different from its natural frequency. It is therefore an empirically based hypothesis that the timekeeping of clocks is affected by external forces which affect the relative accelerations of their internal parts. Unlike Einstein's theories, our new hypothesis makes no claims as to the nature of "time", but instead simply describes how the relative ticking frequency between two identical clocks depends on the physical forces to which each is subjected.

Such a theorem explains the discrepancies in timekeeping of identical clocks with a single physical mechanism, namely external force. However, unlike SR, it ascribes no effect on clocks as a consequence of inertial (force free) motion. This is important for as we will see in the next paragraph, none of the supposed "time dilation” experiments have been performed on clocks undergoing anything like inertial motion.

As Dingle had observed, if two clocks are both moving inertially without the influence of any external forces, at most, they can only meet each other once and at this moment, they can compare their readings. They will never meet again and thus one could never by direct measurement actually determine whether one was ticking faster than the other. Einstein’s solution to this dilemma was to propose the twin paradox in which one of the twins travels inertially at high velocity and then turns around and returns again moving inertially and finds himself younger than his brother who stayed at home. Needless to say, this experiment has never been performed, but a century long debate has slowly raged about whether the turning around (acceleration) of one of the brothers, presumably by the firing of rockets, made him the one who would be younger upon their reunion. The famous pioneer of quantum mechanics, Wolfgang Pauli [11.21], pointed out that it was not until 1918, that Einstein made brief mention that the acceleration of the traveller during the turn around must be involved, however there remained no use of acceleration or force in his equations of time dilation. The case of the travelling twins reveals the clue that not only are applied force and acceleration critical in determining which clock ticks faster than another, but that acceleration is always required simply to perform any such experiment at all.

Textbooks attempt to resolve this dilemma by arguing that if one had a fantastic telescope and could observe a clock moving at a speed near *c*, then it would appear to be running slow. As a result modern physics is now completely ambiguous whether the moving clock is actually running slow or whether this is just an outcome of the method of observation. Needless to say, no such telescope yet exists and thus this aspect of SR is also unproved experimentally.

Most of the experiments that purport to demonstrate time dilation involve time keeping instruments moving in circular paths. As with the atomic clocks in the GPS satellites, caesium clocks have also been placed in jet airplanes and flown around the world on commercial flights. A famous experiment was performed in 1971 by Hafele and Keating under the auspices of the United States Naval Observatory (USNO). They published their results in the journal, Science, [11.22] in 1972. They reported that:

> “These results provide an unambiguous empirical resolution of the famous clock “paradox” with macroscopic clocks”

This apparent success for Einstein’s theories was so widely disseminated that in the same year a leader article in Nature [11.23] claimed that “the agreement between theory and experiment was most satisfactory”. This experiment is still extremely famous and described in every modern relativity textbook. However, in 1995, a very enterprising Irish engineer, Alphonsus Kelly, under the US Freedom of Information Act, was able to secure a copy of the originally classified USNO internal report filed by Hafele and Keating in 1971 which included all of their raw data and analysis. [11.24] In this document, Kelly found that as in the Eddington eclipse debacle, much of the data had been left out of the published paper including mention of how they justified huge manual clock corrections, some ten times larger than the measured result, which completely changed the outcome of the experiment. Kelly [11.25] has analyzed these original results closely, but the conclusion made by the original scientists is by far the most damning. Hafele wrote in the internal report:

> "Most people (myself included) would be reluctant to agree that the time gained by any one of these clocks is indicative of anything … …the difference between theory and measurement is disturbing"

Clearly, the Hafele and Keating results should not be used as evidence for or against the theory of SR. What is however much more worrying is that the authors and their supervisors allowed such dishonest science to be published, and said nothing when it became clear that it was being held up by the scientific community as some of the strongest evidence supporting Einstein's relativity theories at that time.

The most striking clock distortion results come from particle accelerators in which very fast sub-atomic particles travel around a storage ring. The most famous of this type of experiment was performed at CERN in Switzerland in 1977. Muons are relatively unstable particles which undergo spontaneous decay into electrons and neutrinos. They must have some kind of timekeeping mechanism contained inside them since a group of such muons can be defined as having a repeatable "half-life" which is the statistical time during which we can expect half of them decay. Such a period can be measured when the muons are at rest relative to the accelerator. However if a collection of these particles is accelerated by large electromagnets in multiple revolutions of a storage ring, the half life is found to increase. This has been interpreted by Einsteinian relativists as the internal time keeping of the particles being slowed down. The scientists whose results were published in the journal, Nature [11.26], made the claim to have slowed down the internal timekeeping of the particles by a factor of 29.3. They achieved this by subjecting very fast muons to a huge centripetal acceleration of $10^{18}g$ in order to keep them in the storage ring. While this result has been cited on many occasions as one of the strongest pieces of evidence supporting the theory of SR, it can easily be seen that the muons are being massively accelerated and therefore cannot remotely represent a clock moving inertially as required by SR. This result would also have been much more convincing, if the authors had firstly been able to directly measure the muon velocity. Instead they were forced to calculate the speed using SR theory. Secondly, they were unable to publish an experimental numerical relationship between velocity and lifetime dilation over a range of velocities because their accelerator could only contain muons at a single so called “magic” energy. Therefore it could be a complete coincidence that their time dilation factor matched the SR prediction using the calculated muon velocity. The analysis presented with these results clearly represents an unjustifiable circular logic in which the validity of SR has to be assumed in order to perform a test on its own predictions. Whether this experiment supports SR or not, it certainly provides yet another strong connection between applied force and the slowing of a clock.

Almost all of the time dilation experiments that have been used to supposedly provide support for SR have involved clocks moving in circular trajectories, whether they be particles in an accelerator or atomic clocks in planes or satellites travelling around the earth. Since, by definition, circular motion involves acceleration and external forces, none of these tests have actually examined the claims of SR which only applies to clocks moving inertially.

There is however one well known supposed test of SR that does not involve circular motion. Like the experiment at CERN, it also involves the use of muons as clocks with a predictable decay half life when at rest relative to the laboratory. This experiment was first performed in the early 1940’s by Rossi and Hall [11.27] and then later with more accuracy by two MIT scientists Frisch and Smith [11.28]. In both of these experiments, the goal was to measure the number of particles which have decayed while traversing a known flight path at a constant velocity.

In these experiments, they did not detect the actual decay events, but rather measured the number of radioactive particles at two different locations. In the case of the MIT experiment, these sites were the top of Mount Washington in New Hampshire at an altitude of 1930 meters and a lab at sea level in Cambridge Massachusetts. For the purpose of this experiment, these two locations are near enough to each other to be considered at the same place but at different altitudes. The muons are created in the upper atmosphere by the collision of cosmic ray particles from the sun with atomic gas nuclei. These muons fly in all directions including toward the earth surface with speeds greater than 0.99*c*. As they descend, some of them decay so that we would expect to find less of them at sea level than at the top of the mountain. On top of Mount Washington, they aimed to measure the number of muons with velocities between 0.9950*c* and 0.9954*c*. They claimed to achieve this by using a thick piece of steel in front of a thin plastic particle detector. Muons which were too slow would not penetrate the steel and those that were too fast would pass through both the steel and the detector and not be counted. The muons that were detected had therefore been reduced to a negligible velocity by the steel and thus their "low velocity" lifetime in the detector could be measured. In this way, they counted 568 particles per hour with a mean lifetime of 2.2ìs at the top of the mountain. They argued that particles travelling near the speed of light would pass from 1930 meters to sea level in 6.4ìs, and based on their measured distribution of lifetimes, they expected only 27 particles per hour to survive all the way to sea level based on a non-relativistic calculation. However, they report a sea-level measurement of 412 particles per hour. They then claim this as evidence that the particles live longer when travelling at high velocities in accordance with the predictions of SR.

However, this famous experiment which is presented to every physics undergraduate to confirm their belief in SR is tainted with a piece of experimental fudging which is rarely if ever discussed and has been overlooked by a generation of physics teachers. Scandalously, the measurement apparatus at both locations was not in fact identical, for as Frisch and Smith point out that "by the time they (the muons) reached sea level they had been slowed down somewhat by the air". Later in the paper, they estimate that this deceleration amounts to approximately $2\times10^{13}g$. They required this change in velocity as justification for using 40% less steel in front of their detector at sea level in order to make a measurement.

Probably, the strongest promotion of this experiment to students of physics is the textbook entitled *Special Relativity* [11.29] by the author and MIT professor A.P. French. He fills four pages of his book with a detailed description of the Frisch and Smith experiment including still frames from a film made during its operation. In French's presentation of the experiment, he completely ignores the fact that the two detectors, one on the mountain top and the other at sea level are not identical. The fact that such a thorough physicist would omit to describe such a major feature of the experimental set-up is certainly highly suspicious. As a result of the fact that different detectors were used for the two measurements, this test can certainly not be considered to be a controlled laboratory experiment. The argument used by Frisch and Smith to justify their removal of 40% of their steel absorber is entirely based on relativistic kinematics. Unfortunately, it is illogical to conduct a fundamental test of a theory if one is required to assume the validity of the theory in the analysis. Rather, at best such an experiment can only demonstrate that Einstein's theory is mathematically self consistent which it undoubtedly is. However in no way should these results continue to be promulgated to future generations of students as a valid proof of relativistic time dilation.

There are several other types of experiments that are traditionally accepted as evidence in support of relativistic time dilation. Tests to investigate Einstein's prediction of a relativistic redshift involve the observation of an oscillator such as a light emitting source by a detector in relative motion. If one applies the assumptions of relativity theory in order to interpret the observations, then one can infer that the internal timekeeping of the source appears to have slowed down. However, this analysis requires the use of Einstein’s purely hypothetical conjectures regarding the speed of light in order to confirm the effects ascribed to the theory. This is again circular reasoning and cannot be used to prove or disprove SR.

As Dingle would have predicted, in all of the years of trying, nobody has performed an experiment in which an unaccelerated clock has been shown to increase or decrease its elapsed time with respect to another unaccelerated clock. Therefore, empirically, we are drawn to the conclusion that it is applied force and acceleration which affect the internal mechanisms inside clocks whether they be oscillating wheels in mechanical clocks, quartz crystals, electron vibrations in atomic clocks or even faster microscopic beating inside sub-atomic particles. This is the fundamental connection between inertia and the act of timekeeping.

Mach and others quite reasonably objected to Newton’s concept of absolute time, which historically led to the eager acceptance of Einstein’s revolutionary conception of relative time as something that varies for every observer. Both Newton’s and Einstein’s concepts of time are very difficult to handle philosophically and instead it is proposed here that the concept of time has no meaning at all, since all that we can actually measure and describe are the relative ticking rates of different clocks.

Timekeeping

It can be said that during a series of seasonal events that we traditionally call a year, the moon goes around the earth 12.4 times while the earth spins on its axis 365.24 times. The ratio of these two is a dimensionless number which is the relative ticking frequency of two clocks. It is an experimental fact and has nothing to do with units of time such as the second or the year or even the choice of observer. There are many other astronomical events which we have discovered always occur at frequencies which stay roughly constant with respect to each other. As long as these measurements are taken using the apparently fixed distant stars as a background reference, these ratios remain consistent for all reasonably local observers whether they be on the earth or any other planet in the solar system or even in a passing spaceship. Through the centuries, astronomers have used these ratios of periodic events involving objects which are all subject to nominally unchanging forces in order to develop a system of units which are useful to us. Once we had an arbitrary unit such as the year, horologists devised machines which tick a repeatable number of times during one of these years and then called the period of one of these ticks another name. In our age of reliable clocks, the most common unit of time is now the second. Until, the 1950’s, clocks were specifically constructed to count seconds in such a way to ensure that there always 31,557,600 of them in a year. Now the second is defined by a certain number of vibrations of a cesium atom which is even more accurate than the motions of celestial bodies.

During a day the earth revolves once upon its axis with respect to the sun while the second hand on a trusted watch moves 86,400 times. Can we expect these ratios to always remain constant? The answer is of course that clockmakers have been aware for centuries that mechanical clocks are very sensitive to external conditions. Temperature and humidity variation were major problems for early clock makers. Abrupt shocks which involve significant accelerations can also change the ticking rate with respect to the spinning of the earth. The need to reduce this acceleration sensitivity has been one of the primary drivers of technological innovation in clock design for the last 300 years. By the late 17th century, there was a desperate need for more reliable clocks which were required for navigation at sea and which could work in the harsh environment of constant wave motion, and a wide range of atmospheric conditions. By the middle of the 18th century, John Harrison was awarded a princely £10,000 prize for creating a watch that lost only 5 seconds after 81 days at sea.

A further social change that demanded technological improvement was the introduction of the wristwatch, which was initially a fashion accessory for well to do Victorian ladies who had no waistcoat pockets in which to hold a conventional watch. The quick accelerations of the human wrist compared to the relatively steady torso required further refinements to the delicate springs and balance wheels that make up a mechanical watch. These advances were achieved primarily by decreasing the physical size of the oscillating mechanism and developing more stable and powerful springs which allowed the clock to tick at a faster rate. Harrison's best chronometer oscillated once per second, while a modern mechanical watch may tick up to 10 times per second. There appears to be little use in beating faster because friction and lubrication problems start to become significant. These developments would have been unnecessary unless there was a direct connection between externally applied forces and the ticking frequencies of a clock.

Such problems with wristwatches have now been virtually eliminated by the advent of the quartz crystal watch which almost everyone now uses. They are very cheap to produce and the crystal vibrates fairly reliably 32,768 times per second. This makes them immune to the types of acceleration that humans regularly experience.

In this light, a clock can be viewed not as an instrument for measuring the vague notion of time, but rather a machine designed by nature or man in which one part performs a regular oscillation with respect to the rest of the clock. For the sake of this discussion, we call one part the case and the other the oscillator. By definition, the two must have a non-rigid connection and the only fundamental difference between them is that the case is considered to be the part that directly experiences local contact forces.

For a mechanical wrist watch, the case is clearly the outside of the clock which includes the dial face and is in direct contact with an arm. The oscillator is a finely balanced wheel rotating back and forth inside the case. The frequency of the oscillation is determined by the mass of the wheel and the very accurate reversing force it receives at either end of its oscillation. These parameters in conjunction with the force of inertia caused by the distant universe prescribe the acceleration of the wheel relative to the case at its end stops. This is how the force of inertia acquires a crucial role in the running of a clock.

One way to externally accelerate a mechanical watch is to physically rotate the case around the same axis as the internal balance wheel. It is easy to see that if the case is revolving with the same angular velocity as the balance wheel, it will never reach the next end stop and the watch will have stopped functioning. This is an extreme example of how adding relative acceleration between the case and oscillator can affect the timekeeping of a clock. Fortunately, the rotational motions of the human wrist are not very large, but all mechanical watches with balance wheels are slightly affected by case rotation.

The quartz watch, which has a crystal which vibrates linearly tens of thousands times per second, is much less susceptible to vibration than a mechanical watch. It is also vastly cheaper to make a reliable quartz watch than a mechanical one and as a result it has become the most common time measuring device in the world. These crystals now find themselves in modern communications, navigation and radar systems in which they are subjected to vibrations and accelerations far larger than those produced by a human wrist. For instance a guided missile has navigation equipment aboard that employs quartz clocks, and it is now well known that such a crystal subject to a steady acceleration has a slightly different natural frequency than the same resonator experiencing zero acceleration. [11.30] There is therefore commercial and strategic importance in the precise mathematical relationship between acceleration and frequency for this very important crystal. The amount of frequency shift has been found to be proportional to the magnitude of the acceleration and also dependent upon the direction of the acceleration relative to the axis of vibration of the crystal.

It is therefore reasonable to assume that all clocks are sensitive to acceleration, however, the higher the frequency of the clock, the less the susceptibility. We will not be able to find a relationship between acceleration and frequency shift that is the same for every type of clock since each have differing mechanisms of internal oscillation. For instance, the rotation that can stop a mechanical watch will have no effect on a quartz crystal undergoing linear vibration.

We do not know the frequency of the interior oscillation inside a muon, but it is quite reasonable that accelerations of $10^{18}g$, such as found in the CERN experiments, are capable of affecting their ticking frequency and therefore their average lifetime. At first, one might think that like a satellite clock in earth orbit, a muon in an accelerator ring is in a zero *g* environment. However, in a satellite clock, every piece of matter experiences the same centripetal acceleration due to the equal and opposite forces of gravity and inertia. Contrastingly, the very small constituent particles that make up a muon have different electric charges (positive, negative or neutral) and thus react to the external accelerator magnets differently. This must lead to differing internal accelerations inside the muon than those that occur when the particle is not subject to external electromagnetic forces. Therefore we can understand qualitatively how the ticking rate of a muon can be affected by circular motion in a storage ring.

Similarly, in an atomic clock on the earth, all of the matter inside the clock feels the downward force of gravity, but only part of the clock that is in direct contact with the earth feels the upward reaction force caused by the surface of the earth. Therefore, there is a small but real extra acceleration between case and oscillator that does not exist in an identical clock in orbit in a zero *g* environment. This is probably the real reason that a GPS satellite clock runs faster in orbit than an identical clock on earth.

Unlike their velocity, self contained systems can directly detect their own acceleration without reference to another nearby body. This can be achieved with accelerometers which take advantage of the forces of inertia which are caused by direct interaction with the distant universe as proscribed by Mach’s principle. For instance a person can act as an accelerometer. If he is in a closed box without windows, the acceleration of the box can be determined by measuring the change in the force between him and the floor with a set of bathroom weighing scales. We now see that clocks can be viewed as another type of accelerometer. This book has demonstrated that the forces of inertia can produce very real effects such as pulling rubber off a tyre on a car in a high speed turn, or compressing the springs of a weighing scale. Now we know that the force of inertia can also cause a shift in the ticking frequency of a clock.

Contrary to the conventional presentation in textbooks on SR, it is now apparent that the frequency distortion of clock mechanisms can be attributed to acceleration caused by the application of external forces. This experimentally based explanation of some of the very real and observer independent clock effects, that until now have been described as “time dilation”, frees us from the unverifiable philosophical confusion imposed by SR in which physical effects are assumed to depend only on inertial velocity which has a different value for every possible observer. It now seems that both the timekeeping of clocks as well as the strength of the force of inertia depend on acceleration which as we have seen throughout this book can only be accurately described in relation to the background of fixed stars, implied by Mach’s principle.

Therefore in Machian philosophy, timekeeping is analogous to acceleration itself and only has meaning if the entire universe is involved. Mach’s principle describes a background of stars and galaxies that are so far away from us that on the timescales of any measurement we are ever likely to make the stars remain fixed in space. We need this apparently unmoving distribution in order to meaningfully compare our measurements of acceleration. Similarly, we can also imagine a background of distant clocks, ranging from vibrating sub-atomic particles to galaxies orbiting around each other. This ensemble can be considered from the point of view of our human sized experiments to be working with constant relative ticking frequencies. We need such a group in order to compare the changes in ticking frequency in clocks near us when subjected to external forces. Thus a virtually steady Machian background composed of real objects is essential for the understanding of clocks.

Einstein went to great trouble in order to save the Maxwellian theory of electrodynamics and left us with a philosophy based purely on relative motion between nearby objects. He hoped that the behaviour of clocks would eventually prove his theory to be physically real. We have now seen that no controlled experiment has yet confirmed Einstein’s relativistic theories. Instead, all we have is clear evidence that acceleration can cause clocks to change their frequency.

By maintaining and comparing large numbers of clocks, mankind has been able to create the comfortable feeling of measuring the passage of time, a process usually called timekeeping. When most clocks remain in synchrony, but one is found to change its relative ticking frequency to the rest, then this can usually be related to an acceleration of the particular clock caused by an external force. (Sometimes however it is simply an unpredictable failure of an internal part.) This does not require any metaphysics or requirement of time to be a fundamental property of the universe. Instead, the act of timekeeping is a human activity which requires counting as well as an understanding of force and acceleration. Mach’s principle makes clear that in order to preserve the principle of momentum conservation, the relationship between applied force and acceleration is controlled by forces of inertia caused by the self-interaction of the entire universe. Therefore timekeeping and the study of clocks are fundamental aspects of our understanding of the force of inertia.

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