Historical Perspectives

The concept of a constant velocity of light, Einstein's second postulate, is all important in the special theory of relativity. It is therefore necessary to place the developments of Maxwell, Lorentz, Einstein and others into a historical perspective, in order to gain an insight as to why the idea of a constant *c* became so ingrained in the development of their theories. The advantage of placing a historical perspective on the process of the development of relativity and some of its alternatives is twofold. The first reason was mentioned above. The second reason is that science is an obviously human enterprise, which cannot be cleanly lifted out of other social, political and historical issues of the time. The issue of social factors always resides in the background of science in some way, and its influence should not be underrated or ignored. For example, one cannot help but wonder about the relationship the theories of relativity had with the great waves of skepticism and doubt in our human abilities to make sense of the world which swept through the western hemisphere at the onset of the twentieth century. However, rather than launching into a long exposition regarding the interrelationship that science shares with social factors, this chapter instead pursues a more narrow approach by documenting the development of relativity and its precursors internal to science.

As usual, development in time does not necessarily follow conceptual and logical development. Oftentimes historical patterns influence the types of questions being raised, which are better understood in a sequence that is not necessarily time ordered. Even more significantly, this latter point is usually only understood after the fact--succeeding generations have the advantage of hindsight in order to better categorize their predecessor's foresight. In this respect, relativity is definitely no exception. This chapter and the next address some of the theoretical and experimental issues that preoccupied the physics community of the time, laying special emphasis on why and how certain issues were biased in terms of the interpretation of data and the types of reasoning imposed. We will see that it was this progression of reasoning along a certain initial line of thought that resulted in the overly restrictive definition of light speed, and subsequently the conclusion that only transformations of the type attributable to Lorentz held any validity in the "real" world.

After a long history of discovering the laws of nature through interpretation of experimental results, suddenly the theories of physics would be built on a series of thought experiments with ever increasing complexity. The world of Galileo and Newton, associated with the tower of Pisa and falling apples would be replaced by hypothetical light speed trains and elevators in free-fall toward the sun. It was partially this emphasis on mathematical speculation over the checks and balances of methodical experimental research that helped lead Einstein and his contemporaries astray in the early nineteen hundreds.

Maxwell's Equations

What many popular expositions of relativity ignore is the necessary relationship that exists between relativity and electromagnetic phenomenon, completely dynamically described by Maxwell's wave equations. This connection is really so extensive that it is better understood that special relativity is a derived consequence of Maxwell's equations, interpreted in a certain way. As already mentioned in chapter one, RCM theory is likewise another interpretation of Maxwell's equations. Interestingly, there exists literature that seeks to reverse this relation and derive Maxwell's equations out of a context of special relativity. Many modern physicists have been so indoctrinated that they marvel at the way in which Maxwell’s equations have Lorentz invariance built in—a priori to the discovery of this particular set of transforms by Lorentz. The fact that Lorentz actually developed his transforms to try and reconcile a bad theory with good experimental data is ignored or unknown.

Maxwell's equations consist of a set of four equations relating properties known as the electric and magnetic fields and the electric and magnetic flux. The four equations are sometimes referred to as Gauss's law, the law of no magnetic monopoles, Ampere's law and Faraday's law. The three laws named after individuals are related to the precursory discoveries of those individuals in their own areas of electric and magnetic studies. It is interesting to note that these four equations are written independent of any particular system of units, which further supports that the equations in and of themselves fail to predict a specific fixed speed for electromagnetic wave propagation.

Qualitatively, each of the four Maxwell's equations refers to a separate law of electromagnetic behavior previously known by Maxwell's contemporaries. For example, Gauss's law is basically an extension of the most basic equation of electrostatics, namely Coulomb's law. Coulomb's law itself describes the electrostatic force between two charged bodies to be proportional to the products of the charges and inversely proportional to the square of their distance, just as in the case of Newton's law of gravitation. Generally speaking, Gauss's law is a convenient extension of this principle, which basically says that the strength of a radiated electric field of a charged body depends on the amount of charge present. On the other hand, the principle of no magnetic monopoles says that the behavior of magnetic fields is fundamentally different from the behavior of electric fields. Whereas the electric field can be visualized as lines of force beginning and ending at various charged sources, magnetic fields are better visualized as closed loops of force, with no beginning or end, since modern physics has yet to discover a "unit magnetic charge" from which magnetic fields might originate.

Faraday's law is a relationship for moving charges, or currents. It essentially states that current loops respond in such a way as to counteract changes in the magnetic flux through the area they enclose. The basis of this property is known as inductance. Among other things, Faraday's law led to the development of the inductor, an electronic device indispensable in radios, televisions and almost all electronic products. Last, Ampere's law is an analog to Coulomb's force law in that Ampere sought to derive the force between two closed loops of wire. This force relationship was then condensed in a manner similar to the way in which Gauss's law condenses Coulomb's law--following the magnetic field around a closed loop of wire enables one to determine the net current density around the area enclosed.

Ampere's law as discussed above deals with steady-state current phenomena, in the absence of accelerating charges, based on his experimental work. This is not the full law described in Maxwell's equations. It took the genius of Maxwell to realize this limitation, and when he subsequently generalized Ampere's law to cover the phenomena of accelerating charges, he made an astounding discovery that electricity and magnetism are integrally related. In other words, he unified the electric and magnetic fields through his realization that rapidly oscillating charges *radiate* both electric and magnetic field components perpendicular to one another. He deemed this phenomenon electromagnetic radiation and went on to postulate the existence of an entire *spectrum* of electromagnetic radiative frequencies, of which visible light is but a tiny fraction. Even more fundamentally, Maxwell was able to link this notion with what was previously known concerning the phenomenon of electricity and magnetism, showing that all these seemingly diverse physical properties fit neatly under the canopy of electromagnetism, whose dynamic relations are so elegantly specified in his four equations.

The contribution on the part of Maxwell cannot be underrated. For one thing, his insights led into an entirely new avenue of research into radiative phenomena, resulting in the discovery of X-rays and other twentieth century advances. In another sense, he introduced a new model by which magnetism and electricity, previously conceived as separate, were unified to such a grand extent as to include the laws of optics. Perhaps even most significantly, the consequences of the Maxwellian model among other things introduced field and continuum notions into theoretical physics, and the push became to explain all phenomena in terms of continuum properties. Hence, the historical debate between Newton's corpuscle or particle model of light versus Huygens' wave model of light was revived and universalized to the extent that particle and wave models gradually became imposed universally throughout physics, leading, among other things, to the development of quantum mechanics. The wave-particle duality in quantum physics seems to imply that perhaps both Newton and Huygens were right in a very universal sense--matter and energy contain both wave-like and particle-like properties. To simultaneously accept these seemingly contradictory models, however, one must abandon the notion that the microphysical world can be visualized. This controversy on the visualizability of microscopic matter persists today regarding the issue of interpreting quantum physics. Perhaps the physicist Henry Margenau puts the whole controversy in perspective when he writes that: "Trying to visualize a subatomic particle is a bit like trying to 'smell' a beam of light."

The Maxwellian continuum model of radiation foreshadowed the development of relativity in an attempt to find in what kind of medium Maxwell's electromagnetic waves must propagate. This search is discussed more fully in the following sections. In summary though, the development of Maxwell's equations can be looked upon as an example of theoretical physics at its finest.

The Nature of The Velocity of Light

As mentioned already in the first chapter, in a strict sense (in other words based entirely on the implications of electromagnetic theory), the value of the speed of light can be viewed as a built-in parameter rendering the units consistent among the quantities in Maxwell's equations. One can exploit the characteristics of this parameter in such a manner as to verify its value experimentally. This, of course, does not mean that the experimentally observed results are the only values that the parameter can take on, any more than one would assume that because one observes a car traveling at twenty miles per hour the car always travels at such a speed. However, as we shall see, this is just the type of assumption made by the physicists studying the velocity of light.

Recall that Maxwell's equations were written in a manner that is unit-free. While this may seem desirable in the sense of mathematical simplicity, a system of units must be attributed to these equations for them to have any *physical* significance. Contrary to the case of mechanics, there is no absolute standard of measuring electromagnetic quantities. The main reason for this is historic. In the eighteenth century, Newton's mechanics arose simultaneously with the great concerns to develop a universal standard for measurements of length, time, mass and other physical properties. Electromagnetic theory, on the other hand, appeared nearly a century-and-a-half later, with plenty of experts using plenty of their own systems of units. We will employ this digression on units to reveal how the value of *c* is derived.

First of all, as a consequence of Coulomb's law, one can straight forwardly deduce that the equation describing the electric field is given by some constant times the ratio of a charge to the square of the distance from that charge, for any arbitrary unit of charge we define. Equally fundamentally, Faraday's law defines the force experienced by two infinitely long parallel wires as another constant times a ratio of the currents to the distance between them. Due to the choice of units arbitrarily assigned to the terms in these equations, a little bit of algebra reveals that the dimensions of the first constant divided by the second is a velocity squared. So at least in principle the units match those of c^2. At this point, assuming we do not yet specify a numerical value for *c*, we can state that the ratio of the two constants is defined as c^2. In this respect, c^2 is simply a *name* applied to the ratio of two arbitrary constants, and is not anything like "the speed of light squared."

In addition, Ampere defined a magnetic field, induction, as being numerically proportional to Faraday's force and a third arbitrary constant. Another treatment of Faraday's law produces yet a fourth constant of proportionality. Combining these equations and insisting that all equations have consistent dimensions, it can be determined that the fourth constant is actually just the inverse of Ampere's, thus we are left with only three undetermined constants. Substituting all the previously known values for the derived interrelationships among the constants, one concludes that *c* as arbitrarily defined above represents the velocity of propagation in Maxwell's electromagnetic wave equations. Notice, however, at this point there has yet to be a numerical *value* assigned to *c*, even though our demonstration indicates that *c* is a necessary parameter for consistency in the units expressed in Maxwell's equations. Still we have the three arbitrary constants at our disposal. It turns out that depending on how one selects the particular combinations of these values, one can construct a system of units of his or her choice. Yet, note that the interrelationships among the constants are always invariant in terms of their being in multiples or ratios of the parameter *c*, always with *c* being undefined as far as a specific value within any system of units is concerned. However, we can then make physical measurements of the desired quantities and ratios, and determine as a result of these experiments, that, at least in the realm of our experiments, the value of *c* is consistently the same, and that that value is roughly 300,000 kilometers per second. The important point to realize when specifying the value of *c* is that, of necessity, it is *dependent on the observer,* in this case whatever experimental apparatus we use for measuring the required quantities. We can say nothing about the value of *c* independent of the capabilities of our equipment. If our measurements were such as to produce different inputs into the determination of the three constants, then we would as a result obtain a different value for the quantity that we named *c*.

At the risk of becoming redundant, the purpose of these derivations was to explicitly reveal Maxwell's thesis concerning the fundamentally electromagnetic character of light, visible and otherwise. While *c* is shown to be a regulative parameter keeping straight all of the units in Maxwell's equations, in the final analysis, the value of *c* can be derived only from the basis of directly measured electromagnetic parameters. There are many experimental approaches to deriving *c* from purely electromagnetic considerations, though all are ultimately limited by necessity to the perceptions of the observer. Investigating the nature of *c* exhaustively reveals explicitly how special relativity and similarly RCM theory originate as consequences to particular interpretations of Maxwell's equations, special relativity by treating experimental observations as fundamental truths, RCM theory by considering only first principles.

For example, one means of determining the speed of light is to measure to quantities referred to as electric permittivity (ε_0) and magnetic permeability (μ_0) of free space. The speed of light to be detected by any particular observer is then simply one over the square root of the product of these two quantities. Any particular observer in free space (and idealized abstraction, but useful for illustrative purposes) will measure a certain, specific value for these two quantities. When that observer takes the inverse square root of their product, the result will be the value *c*, roughly 300,000 km/sec. We now allow another observer to travel past the first at some arbitrarily high speed. If that observer also makes measurements of ε_0 and μ_0 and takes the inverse square root of their product, the result will also be the value *c*. Thus, two observers in relative motion, making the same set of measurements at the same point in space, will each determine that the velocity of light at that point in space is *c* relative to the frame of reference of each. This will hold true no matter the number of experimenters or their relative velocities with respect to one another. Any number of observers will determine that the velocity of light from some distant source as measured at a particular point in space is *c* with respect to their individual frames of reference. This simple statement is all that such an experiment, or a conceptually similar experiment, can say about the velocity of light. All else is interpretation. The most obvious interpretation would be that in some manner or another light must travel in a continuum of velocities, such that any observer can find a component traveling at *c* in its own reference frame. Special relativity, however, concludes that light has only one unique velocity (even though, interestingly enough, that velocity is *not* measured with respect to the source), and that time and space distort and curl up around moving observers to make the mathematics work out. But when one considers the sequence of theories and discoveries at the end of the 1800's in perspective, some light can be shed on how this strange interpretaion came about, and, perhaps, why it has persisted for almost 100 years.

Obviously, the above derivation utilizing experimentally determined quantities revealed the observed velocity of *c* to be an invariant. In other words, the quantities that determine the constants are the same no matter the orientation or presumed velocity of the experimental set up. Since the quantities that determine *c* are always the same, then so it would seem that the value of *c* must be always the same. The question then became in what sense is the speed defined as *c* invariant? Since as Einstein discovered all matter to be essentially electromagnetic in nature, due of course to the existence of electrons, then investigating the shades of distinction regarding the invariance of *c* in electromagnetic theory has universal consequences. In fact, the discussion cannot really proceed unless we pick up where we left off in our story of the inception of Maxwell's equations. The fundamental pursuit during the end of the nineteenth century focused on the issue of trying to discern any "proper" frame in which Maxwell's equations reigned, if indeed such a "proper" frame could be said to exist at all. Hence we turn to the aether postulate and the subsequent experimental attempts to establish its existence.

The Aether Postulate

The advent and experimental confirmation of a continuous spectrum of electromagnetic radiation predicted by Maxwell's equations arrived with its own host of puzzling questions. For one thing, Maxwell's equations implicitly predict wave phenomena, leading of course to the endlessly verified postulate of the electromagnetic spectrum. However, resulting in a great historical irony, Maxwell had actually set out to construct a Maxwellian world-view, as influential as the Newtonian world-view, of which his famous four equations would be but a consequence thereof. Yet, physics students today remember Maxwell for his four equations, and not for any foundational contributions to physics of the type Newton is usually remembered for. As mentioned earlier, some consequences of the Maxwellian "continuum" world-view did seep their way into the mainstream just the same, namely in the form of wave-particle dualism and in the issue regarding the invariance of his four equations for all inertial frames of reference. It is this latter issue that led among other things to the development of relativity theories.

Fundamentally, it is a mistake to think that Einstein was the only physicist who endowed physics with a "relativity principle." Though it is true that Einstein made such issues very explicit, based on his insights and associations, relativity is really better understood as a systematic treatment of the relationship physical laws have with frames of reference. In other words, fundamentally, relativity can be thought of as the interface between physical principles and the geometry of the observer. In this respect, two important consequences ensue. First, one can never divorce mathematical physics from geometry. Second, relativity considerations are prior to, and implicit in, every equation expressing a physical law. For example, Newtonian physics is based on Galilean assumptions of the nature of space-time and the interrelations among observers; hence it makes sense to talk about "Newtonian relativity." Though Maxwell was unsuccessful in achieving his principle goal of a Maxwellian world-view, he nonetheless unwittingly opened the door to some of the deepest speculations that arose in the history of physics.

Maxwell put the aether hypothesis forth originally, as a consequence of his electromagnetic spectrum postulate. In his time, it was thought that in order to talk about waves; one must necessarily invoke the notion of a medium, so that waves as we generally understand them can exist at all. The reason for this proposal seems both obvious and subtle. In an obvious sense, waves are only one way in which energy chooses to transmit itself through a medium. Take, for example, the case of a fluid such as the ocean. The ocean is a medium, being bombarded by all sorts of energies such as thermal energy from the heat of the sun's rays, wind energy and tidal forces. By energy conservation, the ocean must *do* something with all the external energy it is absorbing from its environment. It disperses thermal and mechanical energy in two macroscopic modes: convection, in the form of ocean currents, and wave propagation. Certain conditions must be met for either mode to occur.

Energy transmission in the form of waves is a very efficient means of conveyance. The reason for this is illustrated as follows: the difference between convection and wave propagation is that waves don't carry the material along with them. Though the surface of the ocean appears to move, it is only the waveforms that are propagating--the water molecules simply oscillate in their stationary positions as the mechanical energy passes through them. A macroscopic illustration of this is the "wave" spectators sometimes make at large sporting gatherings--the spectators themselves certainly don't travel around the arena with the motion of the wave. An exception to the stationarity of the medium of the waves is the phenomenon of waves breaking along the shoreline. Here, there *is* fluid transport occurring along with wave propagation. This phenomenon is caused by the frictional forces of the increasingly shallow shoreline interacting with the waves propagating on the surface of the water. Seen from the wave's point of view, this frictional effect of the approaching ocean floor tugs at the fluid underneath it, literally causing the wave to trip over itself. This property is known as Kelvin-Helmholtz instability and arises whenever two media with different densities interface, causing frictional effects at the boundary.

Thus we see the obvious reason why one desires to refer to a medium for wave propagation, though, as we shall see later, quantum theory dispenses with this necessity. There is also a more subtle justification, involving the notion of action at a distance, which goes back to Newton and earlier. Newtonian mechanics at the time gave a complete mathematical description of the dynamic interactions among corpuscles or bodies, consistent with a Democratean world-view of corpuscles interacting in a void. In order to explain his dynamics, Newton postulated the existence of influences, or forces, that the bodies share among each other, a most notable one being universal gravitation. Such forces form the causal link in corpuscular dynamics, and behave according to the principles laid down in Newton's three laws. Newton's first law, the principle of inertia, states that a body at rest remains at rest unless acted upon by an external force. Similarly, a body traveling in a straight line will continue its motion at a constant speed unless acted upon by an external force. The second law states that the force acting on a body is equal to the mass of the body times the acceleration experienced by that body. The third law states that for every action or force applied, there is always an equal and opposite reaction, so that the mutual actions of two bodies on each other are equal and in opposite directions.

Students of physics today usually accept Newton's idea of force at face value, and do not understand that Newton originally distinguished between two kinds of force--innate and impressed or external. Innate force is proportional to the mass of the body and should be regarded as equivalent to the bodies inertia or "laziness," a direct property of matter. On the other hand, an impressed force is better thought of as external force acting on the body, not remaining in the body once the action is over. Gravitation is an example of an external force. One reason Newton distinguished two kinds of force centered on his strenuous attempts to rescue his concept of external force from the notion of action at a distance--that a body somehow feels the instantaneous influence of another body independent of their mutual distance. The idea of action at a distance implied somewhat of a troubling occult view of nature. In a certain sense, Newton was only partially successful in achieving this purpose, but the enormous empirical success of his formula for universal gravitation somewhat immunized him from the former criticisms regarding the all-too-disturbing similarity gravitation seems to share with action at a distance. Also in his favor, other philosophers argued at the same time that "action at a contact is not a whit more intelligible than action at a distance." The net result is that the debates regarding action at a distance in Newton's theory of gravitation have become academic. That is to say they are somewhat irrelevant from the standpoint of working physicists.

Upon some reflection, one will quickly realize that the notion of an aether for waves to propagate in likewise rescues electromagnetic theory from action at a distance. For just as in the case of Newton's laws of particle mechanics, whereby wave action is explained via the local interactions among the particles of the medium, likewise this idea was extended by Maxwell to cover electromagnetic wave phenomena. Without the aether, it becomes unclear how these waves can travel through otherwise empty space, any more than a wave set up in one bowl of water can travel through the air and suddenly appear in another bowl some distance away. Maxwell's peculiar coinage of the term aether came from Descartes' original definition of aether as imponderable matter. The reason why Maxwell considered this matter imponderable had to do with the disturbing issue that this matter was undetectable, and served no useful purpose save for acting as a necessary medium for his electromagnetic waves to propagate in. And of course, this medium was necessary in order to rescue his wave mechanics from action at a distance. Maxwell also felt, however, that this aether was subject to the same laws of dynamics as any other medium. As he wrote in *A Dynamical Theory of Electromagnetic Action* in 1865 concerning the aether:

> It appears therefore that certain phenomena in electricity and magnetism lead to the...conclusion...that there is an aethereal medium pervading all bodies, and modified only in degree by their presence... We are led to the conception of a complicated mechanism capable of vast variety of motion...these motions being communicated by forces arising from the relative displacement of the connected parts, in virtue of their elasticity. Such a mechanism must be subject to the general laws of Dynamics.

However, what Maxwell meant by dynamics had to do with mathematical methods attributable to Lagrange, themselves extensions of Newton's, save for the fact that in Lagrangian dynamics an explicit knowledge of the mechanism of the system is not needed. In other words, Lagrange's methods enable one to bypass listing all the impressed forces on the system of interest, in this case the aether-wave system. Thus Maxwell was also spared from having to describe explicitly the dynamical inter-workings of the aether while still claiming its ability to transport his electromagnetic waves in the customary manner.

Rest Frames and Inertial Frames: The work of Lorentz, Michelson and Morley

Towards the end of the nineteenth century, Maxwell's aether hypothesis was generally accepted. In fact, the famous physicist Oliver Heavyside went so far as to suggest that the existence of the aether should be accepted as primary, and matter itself should be shown to derive its own properties from those of the aether. This formed the beginning of the electromagnetic conception of matter, culminating eventually in the discovery of electrons. However, the temporary success of the aether hypothesis raised more basic questions; namely, ones concerning invariance in all frames of reference.

A reference frame is simply a coordinate system set up "with reference" to a particular physical situation. Reference frames can obviously be specified according to any configuration. As examples, the coordinate framework can be centered with respect to an observer, the Earth's surface, the sun's center, or the "realm of the fixed stars." In this sense, the roots of relativistic considerations originate in the work of Descartes and Galileo, the architects of the modern view of physics. The usage of the term "modern" is sometimes referred to in other contexts as twentieth-century physics. Yet, historians generally agree that the modern period began roughly during the early seventeenth century. In this respect, modern physics had its basis in this period, when a purely quantitative explanation of motion was initially developed. This new quantitative explanation implicitly assumed that nature could be mathematically specified to any arbitrary degree of precision. This viewpoint reached its culmination in eighteenth-century determinism, which held that if the position and momentum of all particles in the universe were known, then the future of the universe would become absolutely determined. This determinism was not seriously questioned until the advent of quantum physics during the first part of the twentieth century.

Regarding the fundamental similarity of different reference frames, Galileo first observed that whether one was at rest or in uniform motion with respect to one’s surroundings, the observer's local experience of nature's laws of motion should be invariant. In the *Diagolo* he writes:

> Shut yourself up with some friend in the main cabin below decks on some large ship, and have with yourself some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it, hang up a bottle that empties drop by drop... With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin... When you have observed all these things carefully have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still.

The purpose for citing Galileo directly is two-fold. For one thing, this idea of invariance was considered radical at the time, and indeed can only be effectively understood should one ignore considerations of air-resistance. Only when seeking to rewrite the laws of particle motion in a vacuum will it become "intuitively obvious" that whether a particular physical situation is in uniform motion or at rest should have absolutely no effect on the laws of dynamics experienced locally within such a situation. Secondly, upon hearing the above description, the entire concept seems within the realm of what one would call common sense. Oftentimes, it is mentioned that "genius is the art of seeing the obvious," a gift of which Galileo was certainly well endowed.

At roughly the same period, Renee Descartes developed analytic geometry, which in a more basic sense enabled one for the first time to develop and use a coordinate system specifying one-on-one the spatial relations of any conceivable object with respect to the origin of the coordinate frame. Hence, today we usually refer to such coordinate systems as “Cartesian,” after Descartes. Incorporating Descartes' mathematical innovation with Galileo's aforementioned principle of invariance enables one to speak of "reference frames" and "inertial reference frames." Informally, it is best to think of the latter as an ideally rigid frame obeying Newton's first law of motion or principle of inertia--a freely moving body will describe a straight line with constant velocity unless acted upon by an outside force. Hence, an inertial reference frame is a model that embodies the Galilean-Newtonian dynamical framework. Should one choose to specify the frame of reference as *inertial*, then it becomes possible to use Newton's ordinary laws of dynamics within it. Inertial reference frames can be either at rest or travel along in uniform motion with respect to a third coordinate frame, the absolute frame of reference or proper rest frame. For example, we can specify an absolute frame of reference as a coordinate system centered at a train station. We can then specify an inertial frame of reference moving relative to the absolute one as a train moving at a constant speed away from the station along a straight section of track. In addition, we can specify another inertial reference frame moving relative to the first as a passenger walking in a straight line at a uniform speed inside the train.

Though Galileo's and Descartes' writings preceded those of Newton, and Newton had to obviously draw on both contributions in order to develop his three laws of motion, we will combine Galileo's insights with Newton's laws in the *Galilean-Newtonian Theory* (GNT), a phrase coined by Carl Neumann. One must realize that Newton was considered radical for his time, for many of his contemporaries from the Cartesian tradition accused him of invoking quantities that in a strict sense were not spatio-temporal (able to be specified on a specific coordinate point with a specific associated time). For example, the notion of force can be expressed as a vector formula given by mass times acceleration. Although this relation contains geometrical properties that can be mapped onto a Cartesian coordinate frame, it actually describes the *effect* of the force, not the force itself. We shall see in chapter eight when considering the use of force to measure the mass of elementary particles how important this distinction actually becomes. Forces or influences are then seen as entities that affect the spatio-temporal trajectories of corpuscles, but are themselves not describable as localizable objects, and hence cannot be specified within a Cartesian coordinate system. These attacks, coupled with Newton's unsuccessful attempts to reconcile the issue of action at a distance, ironically gave Newtonian mechanics an aura of being excessively metaphysical, vitalistic and occultish among some of his detractors. Who though, when faced with the concepts of Einstein's relativity, would fail to embrace Newton's ideas as the last vestige of concrete, common sense physics?

The Galilean-Newtonian theory, or GNT, describes a dynamical universe, capable of being mapped onto some imaginable absolute coordinate frame, hence possessing an absolute center. This proper rest frame would span a potentially infinite class of inertial reference frames that are themselves mathematically connected to one another, and to the absolute frame, via Galilean coordinate transformations. As easy as it is to visualize, this notion of an identifiable absolute center or absolute rest frame to the universe is actually paradoxical in the scope of GNT, as it comes in conflict with Newton's first law--the principle of inertia. We see this by the following argument. GNT holds that dynamical laws are invariant with respect to Galilean transformations between inertial reference frames. Hence, there is no way to detect absolute motion from any inertial frame. The reason is that, assuming an absolute frame were to exist, from the observer's point of view it would be identical to any other inertial reference frame. Since there is fundamentally no difference in the way the physical laws would behave in such an absolute frame, and from first law considerations, there would be no observable qualities for detecting one's motion with respect to this frame. Any inertial frame could therefore declare itself to be the “proper” rest frame, and there would be no mechanism to distinguish the "true" rest frame from the impostor. Thus, even though the concepts of inertial reference frames related by Galilean transformations to each other is very useful and easily understood, as soon as we try to invoke an absolutely stationary reference frame against which all others can be measured, we run into problems. Such is the fate of the aether concept as well, as we shall see.

An important point regarding Galilean coordinate transformations addressed in the first chapter is the fact that *time* remains unchanged when moving from one inertial frame to another. This forms the concept of inertial time, the basis of simultaneity, which enables one to form an absolute and universal time scale in GNT. Hence, GNT implies that the state of the universe is described by the set of all simultaneous events at a given instant of time. It is this notion of absolute simultaneity across all space that enables a global synchronization of clocks to take place in GNT. Einstein, on the other hand, proposed that time is nothing more than the observable measure of changes in the universe. In this respect, a clock running slow, say in the presence of a strong gravitational field, would be marking the actual slower passage of time in that arena--because the observable clock has slowed, time itself has slowed. In this respect, it becomes impossible to speak meaningfully of simultaneous events, and thus, no absolute time scale exists.

The detailed exposition regarding inertial reference frames and their unique place in GNT is necessary in order to portray the context of the types of questions that inevitably arose regarding Maxwell's aether. As mentioned, Maxwell's aether rescued his electromagnetic theory by enabling it to be subject to the general laws of dynamics, yet, at the same time, the aether itself was spared from mechanical description. The main question then subsequently centered on what kind of preferred reference frame, if any, the aether resided in, and more generally, how did the notion of the aether pan out regarding Galilean-Newtonian concepts of absolute and inertial reference frames? For some reason, such questions most preoccupied the Continental physicists of the latter half of the nineteenth century, with the work of Hertz and Lorentz standing out in particular.

Hertz was most concerned with theoretical questions pertaining to the nature of the aether, who among other things demonstrated that ponderable matter and the aether must be completely de-coupled, to the point where the aether permeates unaffected through all matter. From the outset, this may seem contradictory in the sense that two forms of matter occupy the same locality in space. However, Hertz was able to show via a narrow interpretation of electromagnetic theory that such paradoxical considerations can be avoided, at least to the extent of performing the appropriate electromagnetic calculations. Seemingly contradicting himself, Hertz then went on to choose the view that the aether was somehow "dragged along" by ponderable matter. Even so, it was the work of Hertz that influenced Lorentz to try to reconcile Galilean-Newtonian notions of absolute and inertial reference frames with the aether, in ways going beyond purely ad-hoc considerations. This meant, among other things, that for Lorentz the microscopic structure of matter must be taken into consideration. In fact, it was Lorentz who first postulated the existence of charged particles swimming around matter interatomically, particles that he dubbed ions and electrons.

The principle question surrounding the issue of the relationship between GNT and the aether had to do with seeking to find an appropriate reference frame for the aether to reside in, which can be restated as the issue of finding a preferred or proper reference frame for Maxwell's equations. There were two principle reasons for asking such a question. First and foremost was the issue of the Galilean invariance of Maxwell's equations. Invariance means that Maxwell's equations transform between coordinate systems in such a manner that the *basic form* of the equations remains the same before and after the transformation. Accepting, as Maxwell did, the finite speed of electromagnetic action to be the *value c*, and at the same time writing out his equations for a given inertial reference frame, one quickly discovers that the equations do not invariantly transform between reference frames when utilizing Galilean transformations. In other words, unlike the Newtonian equations of motion, Maxwell's equations are not Galilean invariant when one assumes a constant value of *c* for the speed of electromagnetic propagation. As seen in the first chapter, however, revising the constraint of absolute constancy of the speed of electromagnetic action for all inertial reference frames to read that all such frames register *locally* an electromagnetic action traveling at *c*--the modified second postulate--one *can* demonstrate Galilean invariance in Maxwell's equations.

Maxwell was able to overcome this defect of non-Galilean invariance by postulating that in all experimentation, electromagnetic phenomena are dependent on two separate items. These are the experimental apparatus--the behavior of the ponderable bodies, and the *motion* of the experimental set up through the aether--the motion of the observer. The second issue naturally follows from the first, in that if the motion of the apparatus must be taken into consideration, the question concerning what reference frame in which to situate the aether naturally arises. For Maxwell, the issue was not altogether too crucial, for he pointed to the experimental success of his equations as indicating that although they were not Galilean invariant between terrestrial inertial reference frames, the *expected error* arising from applying the equations in a reference frame moving slowly relative to the aether had been thus far experimentally undetectable. So for Maxwell, the error in transforming between the aether's reference frame to an approximately inertial terrestrial frame was too minuscule to cause noticeable error in writing the equations with respect to the latter.

But the experiments to detect motion with respect to the aether got better. Numerously complex theories in optics had been already put forth by physicists in the early nineteenth century in order to explain observed stellar aberration first discovered by James Bradley in 1728. Stellar aberration is an effect whereby a star's position appears displaced at an angle due to the earth's motion. One theory of interest is that of Arago put forth in 1853 which held that light corpuscles were emitted at different speeds, yet the eye is only able to detect those propagating at *c*, a notion similar to the modified second postulate. However, towards the latter half of the nineteenth century it was generally accepted that Fresnel's notion of the aether being partially dragged was correct, at least as an operational principle, in explaining stellar aberration. In optics, the term aether was adopted as a device to explain the medium in which light propagated. Fresnel even developed equations showing the drag coefficient for a medium moving at some velocity relative to the aether to be directly proportional to that velocity. Then came the Michelson-Morley experiments.

In a series of experiments performed by Albert Michelson and Edward Morley in 1886-7, conflicting results emerged. Michelson and Morley used an interferometer, a device that causes two beams of light traveling perpendicular to each other to create interference patterns. By carefully tuning this device, one could supposedly measure very small velocities along one path of the device with respect to the aether by a change in the pattern obtained. The device was sensitive enough to detect the motion of the earth, which travels around the sun at roughly thirty kilometers per second and changes direction every six months. By performing the experiment with several equipment orientations and over several seasons, they hoped to determine the motion of the earth with respect to the proper rest frame of the aether. The first experiment supposedly provided a direct confirmation of Fresnel's formula for aether drag. In 1887, however, the experiment was repeated, using an improved interferometer incorporating additional modifications suggested by Lorentz, and the experiment rendered null results--there was no change in the interference patterns obtained. These results indicated that there was apparently no relative motion between the Earth and the aether. Since the Earth was clearly not stationary within the aether, the entire concept was suddenly in need of help.

Lorentz sought to reconcile Michelson and Morley's null results with the former issue pertaining to a preferred reference frame for the aether, from a *microphysical* basis. Two important points need prior clarification, concerning Lorentz's viewpoint. First of all, Lorentz did not try to identify the aether's rest frame with the paradoxical concept of absolute space in GNT. For Lorentz, an aether frame "at rest" meant simply a medium in which no part is in relative motion with itself, and a medium against which the motion of the celestial bodies can be measured. Note that Lorentz specifies "motion" of the heavenly bodies *relative* to the aether, which is different from saying *absolute motion* of the heavenly bodies relative to some absolute center. The statements only coincide when one makes the prior assumption that absolute space exists, and that the aether's frame coincides with absolute space. Secondly, Lorentz was able to write Maxwell's equations for individual electrons such that at each point their fields induce on matter in a *microscopic arena* a "Lorentz force" per unit volume. This force was then related to the charge densities and the relative velocities of the particles. However, since electrons don't interact instantaneously with one another (no action at a distance), and the aether itself was postulated as not subject to ponderable forces, the Lorentz theory apparently violated Newton's third law of equal and opposite reactions. Lorentz responded to this criticism by showing that the *macroscopic* Maxwell equations could be recovered using appropriate integrals, and additionally that his microscopic Lorentz force was derivable via variational principles. Hence he concluded that Newton's third law is a macroscopically derived phenomenon, arising statistically from microscopic interactions not subject to such a principle. This is much the same view as is held today in quantum mechanics, whereby individual particles have no definite position and momentum, yet macroscopic objects made up of millions of such particles do.

These macroscopic and microscopic considerations led Lorentz to consider possible variants of Galilean transformations, regarding each individual inertial reference frame of each electron. After some tinkering, Lorentz concluded that the earth's relative motion with respect to the aether would not be detectable to first-order approximations, providing that a certain set of transformations of time and length related to the square of the velocity were invoked. This set of manipulations carries the name *Lorentz transformations.* It is from these transformations which the term gamma, γ, arises, denoting the degree by which time slows and length contracts with velocity. This term is discussed in detail in the chapters dealing with the subjects of time dilation and length contraction.

These transformations were at first to Lorentz simply mathematical devices, intended to show to a first-order approximation how relative motion between the Earth and the aether frame could not be discerned. In his paper *Inquiry into Electrical and Optical Phenomena in Moving Bodies* in 1895, he generalized them in his so-called Theorem of Corresponding States. This theorem introduced the concept of local time, which varied with the velocity from proper time. The concept of local time described in the theorem was not given a physical interpretation by Lorentz, who saw it to be merely "an auxiliary mathematical quantity." Note also that in our prior descriptions of GNT, whereas absolute space is a contradictory notion, inertial time, implying an absolute time scale, is not. On the other hand, at a loss to explain Michelson and Morley's null results on their interferometer readings, and borrowing a notion suggested already by Fitzgerald in 1889, Lorentz chose to give a physical interpretation to the velocity dependence of length. The effect was subsequently described as "Lorentz-Fitzgerald length contraction." Lorentz-Fitzgerald contraction predicted that the length of a rod oriented perpendicular to the direction of the Earth's motion is contracted by the γ factor when suddenly rotated ninety degrees so as to become aligned parallel to this motion. From a microphysical standpoint, Lorentz showed this to be somewhat of a plausible, if in-testable, notion. In his *Inquiry* paper he was able to show that for a frame moving through the aether, the velocity-squared relation would skew the appropriate intermolecular forces. When comparing this frame to one moving perpendicular to the aether, integrating the effects of this force over space would produce the macroscopically predicted Lorentz-Fitzgerald contraction in length.

Lorentz admitted that such effects would probably not be exactly confirmed, since the theory assumes the molecules are at rest in their respective inertial frames of reference, whereas in actuality they oscillate about their positions of equilibrium. Thus at any point in time, some molecules would have a greater velocity, while others might be moving perpendicular to or even opposite the direction of the macroscopic body. The length contraction on each of these molecules would thus be different. Nevertheless, Lorentz was able to show that such "smearing" effects due to these random motions were of such negligible size as to be incorporated into the limits of normal experimental error. In 1899 Lorentz published a second paper, the *Simplified Theory of Electrical and Optical Phenomena in Moving Systems*, in which he extended his theory of corresponding states to effects of second order in terms of velocity with respect to the aether. Using a somewhat complicated approach, he introduced yet another series of transformations. At this time, however, he fully incorporated his previous notion of the intermolecular skewing of force (Lorentz-Fitzgerald contraction), arguing that "as soon as translation is given to the system, the transformation really does take place, of itself, i.e. by the action of the forces acting between the particles of the system, and of the aether." Despite this treatment of length contraction, no systematic treatment is given to the role of local time and its relationship to any physical time-keeping devices, or perhaps time itself. However, Lorentz states: "It is clear that the Theorem of Corresponding States cannot be experimentally significant unless the local time bears a definite relation to the physical time keeping processes observed in the laboratory." It is again necessary to stress that much of the development of this theory lies in the frame invariance of the observed velocity of propagation of electromagnetic radiation, and the assumption that this observed characteristic represents the true nature of that propagation itself. This correlation between observed phenomena and the actual nature of electromagnetic radiation was assumed true even before Einstein framed his second postulate concerning the same.

The theory of Lorentz may on the outset appear complicated and obscure. Even so, Einstein drew heavily on this work when he formulated his special theory of relativity. Despite the alienating notions of length contraction and observer dependent local times, Lorentz's insistence to explain the phenomenological facts of electromagnetism from a microphysical standpoint led to more basic experimental research into the structure of the atom. Lorentz's electrons were confirmed experimentally in the works of Rutheford, Millikan, J.J. Thompson and others, leading to the early development of atomic theory. In short, in certain ways, Lorentz's contributions may have been as significant as Maxwell's in terms of their eventual influence in the later development of physics, even aside from the considerations of relativity theory.

Albert Einstein

Lorentz introduced his transformations in order to allow overall Galilean transformations from the reference frame of the aether to any other inertial reference frame. In a paper published in September 1905 in *Annalen der Physik*, Albert Einstein suggested a new interpretation of the work of Lorentz regarding the significance of his transformations, which essentially bypassed the entire aether hypothesis altogether. Einstein's paper outlined and established the foundations of his theory of special relativity.

The impetus for his intuitive leaps and groundbreaking speculation actually lay in a previous paper, published in 1902. In this paper, Einstein expanded Planck's "quantal" interpretation of electromagnetic radiation and implied even more fundamentally that classical mechanics was, except in extreme cases, only an approximation to the actual dynamical behavior of bodies. This paper formed the conceptual foundations of the later "quantum" theory of microscopic matter, one from which ironically Einstein always kept himself at arm's length. The Einstein-Bohr debates are perhaps the most significantly philosophical debates regarding the interpretation of nature since the Newton-Liebnitz debates. Basically, Einstein differed with Bohr on the interpretation of quantum theory. Bohr believed that aspects such as Heisenberg's uncertainty principle reveal fundamental limits to our understanding of nature, whereas Einstein believed that a completed theoretical structure should possess the determinacy and precision of the prior physical theories of classical mechanics and electromagnetic theory. To suggest anything less was for Einstein nothing less than to undermine the very heart of the physicist's enterprise. In a similar sense, Einstein speculated that classical electromagnetic theory was not exactly valid either. Yet he could not deny the enormous predictive success of Maxwell's equations, both for macroscopic and for microscopic matter. Rather than taking Maxwell's electromagnetic theory at face value the way Lorentz did, and further speculate on aether-molecular interactions, Einstein instead sought some kind of a universal principle enabling Maxwell's equations to be operationally correct, without having to accept a priori and literally their implications regarding the nature of matter.

Einstein was able to formulate such a universal principle by postulating two claims, the relativity principle and the light principle, sometimes referred to as the first and second postulates of special relativity. Poincare described the relativity principle as stating that the laws of nature and the results of all experiments performed in a given inertial reference frame are independent of the translational motion of the system. In other words, there exists an infinite set of inertial reference frames moving relative to one another in which all physical phenomena occur in an identical way. Note how Poincare's relativity principle coincides with Galilean-Newtonian theory, if one neglects the additional postulate Newton made regarding the existence of absolute space. Actually, Einstein's relativity principle was more specifically worded and was subsequently more restrictive than was Poincare's. Einstein explicitly mentions that the inertial reference frames are connected by the Lorentz transformations. However, Einstein's relativity principle *anticipates* his second postulate--the constancy of the speed of light. Thus, relaxing the constancy of this quantity enables one to remove the constraint of Lorentz transformations and recover the acceptability of Galilean transformations. Perhaps more fundamentally, Poincare's statement is more correct in its generality, for there is no a priori reason to postulate that the inertial reference frames are connected by any special set of transformations such as Lorentz's unless one first says something about the nature of light. In this respect, neither Einstein's first nor his second principle are general enough to be given the status of fundamental postulates. The second depends on observational results, and the first is worded in such a way as to anticipate the second and limit the possible classes of transformations thus available.

The second postulate states that the speed of light is independent of the motion of its source. This is Poincare's paraphrase of Einstein's light principle that states that the speed of light is constant in vacuo and independent of the motion of its source. Note also that the modified light principle of RCM theory differs little from the second postulate, save for specifying that the *observed* speed of light is independent of the motion of its source, and the corresponding implication of a spread of velocities of light propagation. Einstein's proposal of the second postulate, implying the constancy of the speed of light in all frames, was originally suggested by him to indicate that these two postulates "are all that are needed" to develop a full theory of electrodynamics for bodies at rest, consistent with Maxwell's equations. Hence the concept of the aether could be dropped. His conviction of the light principle only solidified when he tried to develop the equations of motion of a ballistic model for the emission of light, but was unable to come up with any solution representing a wave with a velocity depending on the motion of the source. Einstein's light principle was in actuality an extraordinary gamble for him, since at the same time he was rejecting the enormously successful Maxwellian wave-aether theory of light.

On the notion of the significance of time, in Einstein's special theory there is no correlate of absolute time as there is in GNT, due to the results of the Lorentz transformations which are themselves derived out of the second postulate. Contrary to Lorentz, for Einstein the combination of the first and second postulates forced the issue of a physical interpretation for both length and time contraction. However, debate still lingers concerning the interpretation of time in the special theory of relativity. Basically, there are some writers who maintain that since every inertial reference frame is endowed with a local time scale, based purely on the relative motion it shares with other inertial frames, it becomes meaningless to partition events into simultaneity classes. Hence talk of an absolute time-scale is a matter of pure convention. Others interpret this notion of a local time scale as an indication that there actually are infinitely many partitions of simultaneity classes, one for each reference frame. Einstein, however, believed that the primary result of special relativity was that there is no simultaneity for distant events. This point will be discussed exhaustively in subsequent chapters.

Einstein's theory of special relativity revised space-time considerations that were formerly fundamental in physics and in mathematics. In mathematics, special relativity spurred the development of new techniques in space-time geometry in the work of Minkowski. Minkowski developed the algebra for a four-dimensional space, under the assumption that a quantity related to the sum of the squares of three spatial dimensions plus time is invariant for all inertial frames of reference. Similar relations were derived for velocity, momentum, energy and other quantities. The relations for kinetic energy and total energy of a system were derived explicitly working in Minkowski space-time and applying the usual principles of conservation of momentum and energy during collisions attributable to Newton. These two relations differed from the classically expected results by implying that there is a residual energy of all particles, preventing their energy from ever reaching zero. The oft-mentioned relativistic relationship for total energy links this residual term with the inherent energy of the particle system. This relation also contains the assumed relativistic mass increase due to velocity that supposedly increases to infinity when a particle is accelerated to a speed of c. This total energy expression, which serves as a basic assumption in all nuclear reactions, also led Einstein to speculate that the inertial mass of a particle represents somehow a form of "compressed energy" when he formulated his theory of gravitation in the general theory of relativity. This equivalence of mass and energy is also put forth by RCM theory, but for different reasons, as we will see in chapter eight. Einstein's theory of general relativity, is notoriously technical, requiring a mathematical grounding in tensor analysis and differential geometry, should one wish to follow its every implication. Hence, we will give only a qualitative summary into the basic conceptual inquiries that led him to develop the theory.

The foundations of Einstein's theory of gravitation lay in the work of Lorentz and Poincare. The essential concerns of the latter dealt with the unsettling notion of instantaneous action at a distance, implicit in Newton's theory of gravitation. Due to their prior work in electrodynamics, the common knowledge of the finite velocity for the seemingly instantaneous propagation of electromagnetic action led to speculation whether *c* also represented a limiting value in the case of gravitational propagation. Einstein, however, appreciating the success of Newton, sought to develop a general field theory of gravitation, whose ideal limit would result in Newtonian field theory. Based on the work of Poisson, one can rewrite Newton's law of gravitation in field form, in the same manner as Maxwell's field equations were developed from Coulomb's and Ampere's force laws. Inevitably, based on suggestions made by Planck, Einstein had to analyze Newton's separate ideas of inertial mass and gravitational mass. Based on what was known concerning mass loss in radioactive decay, and on the experimental fact that one must “weigh” something in order to find its mass, Einstein concluded that the inertial and gravitational mass of a system were exactly proportional at all times. This became the impetus for his principle of equivalence.

The central thought experiments performed by Einstein, leading him to develop the principle of equivalence, concerned uniformly accelerating reference frames, such as the kind experienced by a hypothetical free-falling elevator in a uniform gravitational field. Recall that our previous discussions on Newtonian and special relativity centered on the behavior of physical laws in inertial reference frames--reference frames differing from one another by a constant velocity only. Quite succinctly the principle of equivalence says that the relativity principle, or the first postulate, can be extended to uniformly accelerated frames as well. The previously derived proportionality of inertial mass with respect to gravitational mass was extended to the equivalence principle. This principle concludes that an experiment performed with ponderable masses should yield identical results for a frame accelerated uniformly and for a frame at rest in a uniform gravitational field with an identical constant of acceleration. Sometimes this notion is subdivided into a "weak" and "strong" relativity principle. The weak principle holds that the inertial mass and gravitational mass are proportional, and the strong principle asserts the aforementioned equivalence in experimental results for uniformly accelerating frames and for rest frames subject to an equivalent uniform gravitational field. However, it was the strong principle that provided the basis for Einstein's most daring speculations in his theory of general relativity. As mentioned by Roberto Torretti in *Relativity and Geometry*, "No analog of the Michelson-Morley experiment was at hand to support the extension of the equivalence principle to radiation, but...Einstein was content to point out that there was no evidence against it."

In a certain sense it is misleading to think of the equivalence principle as having “generalized” the relativity principle, for really the equivalence principle does not eliminate the physical difference between inertial frames and uniformly accelerated frames, or frames in a constant gravitational field. In fact, the equivalence principle entails that a freely falling frame by definition cannot be inertial. To this extent, the equivalence principle weakened the applicability of the laws of special relativity to local regions in the universe, where gravitational fields can be assumed as uniform. More precisely, in a space-time region around an event where the gravitational field is uniform, no effect of the gravity can be discerned within a given margin of precision. Hence the laws of nature in such a region will be invariant to those laws in an equivalent frame for a space-time region where gravity is absent. RCM theory exploits this notion in determining the gravitational potential experienced by a moving observer in chapter seven, and uses this analysis to predict the change over time in the perihelion of mercury's orbit and the deflection of starlight by the sun. In the above sense, general relativity drastically reduces the range of applicability of physical law, regarding equivalence only in terms of *measurable experimental results.* This does not, on the other hand, necessarily imply that there are regions in the universe where natural laws do not hold, but that under general relativity, the laws, rather than encompassing the entire universe, encompass only local fragments of it at a time. Thus we see that the second postulate, which forced the adoption of Lorentz transformations between reference frames, has now gone on to limit the applicability of those transformations to very small regions of consideration. Under general relativity we cannot uniformly apply the laws of physics with the same results across reference frames separated by vast reaches of space. In the local areas where we can, we are unable to agree on the simultaneity of events, the length of a ruler or the passage of time. Things appear to be getting more confusing with each new aspect.

To Einstein's credit, his general theory of relativity functioned as a grand theoretical framework in which to place, like a mosaic, all the local regions of uniform gravitation, where in a local and approximate sense, special relativity could apply. In other words, general relativity gives one the picture of space-time which can be thought of as a full collection of Minkowskian regions where special relativity applies to an approximate degree of precision, much the way a surface is approximated by a flat-faced polyhedron. In this sense, gravity warps such a Minkowskian mosaic the way the curvature of a surface would warp the polyhedron, when mapped upon it. Though this metaphor may sound strange and outlandish, it has its original inspiration in the work of the mathematician Riemann. Riemann had argued already in 1853 that the laws of geometry cannot be derived a priori from spatial considerations alone, hence geometry itself must be an applied science of spatial relations derived from the nature of the microscopic forces holding rigid rods together.

In summary, we will borrow a thought experiment from Einstein to illustrate how special and general relativity neatly fit together according to their respective postulates, the latter derived out of the former. The central illustration of the thought experiment is, not surprisingly, light. We will also use Einstein's illustration as a means to show how his postulates, namely the second postulate, may be interpreted in a different manner, as is done in RCM theory, leading of course to vastly different theoretical structures.

Einstein's thought experiment focuses on the behavior of light in a uniform gravitational field. Arguing from the equivalence principle, he shows that the radiation of a body must be affected in such a field, if the weight of the body emitting the radiation is truly proportional to its inertial mass. From special relativity it was shown that the inertial mass of a body decreases or increases according to the total factor $E = mc^2$, based on an equivalent amount of energy radiated or absorbed. Imagine two points in space, with one point at a position higher than the other in a uniform gravitational field. Let the mass emitting the radiation be stationed at the lower point, with the radiation moving from the lower to the higher point. As mentioned above, this radiation must be affected by the uniform gravitational field in a manner equivalent to the inertial mass lost by the emitter. If this were not so, energy conservation would become violated. The reason for this is that the radiation would be lifted "at no cost" between the two points, and, by returning this energy from the higher to the lower point, an additional amount of energy would be returned, stored in the form of a falling body. Thus, the total energy of this cycle would be greater than the emitted radiation by a factor proportional to the distance between the two points. Hence, to satisfy energy conservation, the absorbed energy at the high point must be less than the energy emitted below. As shown in chapter seven, due to the contributions of Max Planck, the lost energy shows up in the form of a lower frequency being absorbed at the high point than was emitted from the mass.

Einstein concluded from this analysis that gravitational fields affect the local time of observers placed in that field, since an observer at the higher point records a periodic process, in this case the frequency of the radiation, differently than an observer at the low point. In other words, the number of "ticks" registered by one observer per unit interval of "proper" time being less than those "ticks" recorded by the other observer imply that the lower observer's time unit itself is longer than the other's. Hence, clocks must slow down as the gravitational potential increases, and gravitation is thus linked with the local time of an observer. At the same time, the second postulate in special relativity says that the speed of light is constant in an ideally gravity-free environment. But the speed of light is measured by the local time of an observer in the vicinity of the light itself. If the observer's local time is effected, then so is the speed of light, and the second postulate does not strictly hold in the presence of a gravitational field. In other words, special relativity applies only to the "Utopian" case in which no gravitational fields are present. It was this type of thought experiment that provided the motivation for Einstein's theories of gravitation, which later became known as the general theory of relativity. This line of reasoning allowed Einstein to account for the deflection of light in a gravitational field, as well as its slowing, or a change in the value of c, in the same field.

It is perhaps also fitting here to highlight the different approaches regarding this same thought experiment as handled by general relativity and RCM theory. After some reflection, one realizes that the conclusions made by Einstein in his thought experiment concerning the photon in a uniform gravitational field are derived from the assumptions made by special relativity. This is despite the fact that Einstein shows in this thought experiment that special relativity is correct only in an ideal sense. The first and second postulates give rise to the theory of special relativity, which, among other things concludes that time is "local" in each inertial reference frame, and that this time in general differs from what one might call universal "proper" time. These conclusions concerning the nature of time and the *ideally* constant speed of light forced Einstein to conclude in his thought experiment that the gravitational field induces different local times for clocks at different locations within the field. As subsequent sections show, RCM also agrees with Einstein that the inertial mass of a body is equivalent to its radiated energy, and that a photon is affected by a uniform gravitational field. However, the RCM model of light gives implicitly a modified interpretation of the second postulate, one that is much less restrictive, as already shown in chapter one. Light radiated under this modified postulate will also lose energy as it climbs through a gravitational field. Additionally, though time-dilation is dealt with explicitly in RCM theory, this measured effect is due to issues not resembling those predicted by either special relativity nor general relativity.

In short, it is important to realize that although three postulates are used to develop the theories of relativity--the relativity, light and equivalence principles--it is by far the second postulate, the light principle, that is most significant, and that renders coherent the special and general theories. As has already been shown, the Lorentz transformations of special relativity arise purely out of the second postulate. By the same token, relaxing the second postulate unravels the certainty of the conclusions posed by general and special relativity. When focusing on a theory, it is best to start by focusing on its axioms. It is clear that the special and general theories are *an* interpretation of the results of physical and thought experiments of the late nineteenth and early twentieth centuries. However, they are not the *only* interpretation. It is Einstein's ad-hoc restriction limiting electromagnetic propagation to the observed speed of light in his second postulate, and the subsequent limiting of reference frame transformations to those of the type of Lorentz's that requires the complex restructuring of space and time in the special and general theories. RCM theory returns to the basic axioms of the relativity principle, the modified or relaxed light principle and the equivalence principle, and is built from the ground up in the same manner as Einstein's theories. However, RCM theory maintains what feels right and intuitive about Galilean-Newtonian physics rather than overturning all common sense notions of space, time and simultaneity.