



FREQUENCY VARIATIONS, THE SPEED OF SOUND AND THE GRAVITATIONAL RED SHIFT

Robert J. Buenker*

Fachbereich C-Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, Gausstr. 20, D-42097
Wuppertal, Germany

*For correspondence. (rjbuenker@gmail.com)

Abstract: The relationships between frequency, wavelength and speed of waves is considered for both sound and light waves. Einstein's prediction of the gravitational red shift was based on an important observation about the dependence of measured frequencies of light waves on gravitational potential. He pointed out that the only reason observers located on the earth's surface and the lower potential of the sun could differ on their value of a given light frequency is because their respective timing devices do not run at the same rate, even though they are otherwise completely equivalent ("gleich beschaffen"). This amounts to assuming that the unit of time varies with gravitational potential. The analogous conclusion holds for all other physical properties. In effect, this means that there is a *conversion factor* between the units of each quantity for any pair of rest frames that the respective stationary observers located there can use to quantitatively relate the measurements of one another. How this factor, referred to as *S*, can be determined in general is discussed. Furthermore, it is argued on the basis of experiments with atomic clocks that an analogous conversion factor (*Q*) can also be determined for each pair of rest frames. On basis of the Law of Causality it can be assumed that the rate of an inertial clock cannot change spontaneously. This conclusion (Newtonian Simultaneity) rules out any occurrence of remote non-simultaneity, contrary to what is predicted on the basis of the Lorentz transformation.

Keywords: gravitational red shift; Doppler effect; universal time-dilation law; Newtonian simultaneity; Newton-Voigt space-time transformation; Galileo's relativity principle

1. Introduction:

The study of wavelike phenomena has been a subject of great interest in physics dating back at least to the work of Huygens in the late 17th century. A wave is characterized by a definite frequency and wavelength. The latter is defined as the distance separating successive wave crests whereas the frequency is the number of wave crests passing a certain point in space in a given amount of time. One of the basic questions about frequencies and wavelengths is how they are affected by motion of the source relative to the observer. In 1842 Doppler gave a detailed description of a phenomenon that was well known in everyday life, namely the fact that the pitch of sound waves becomes higher when the source approaches the observer and then decreases after the source has passed and begins moving away from him. He showed that it is a first-order effect depending on the ratio of the speed of the observer relative to the location of the source of the sound waves to that of the sound itself relative to this source. The analogous effect is also observed for light waves, but Einstein predicted on the basis of his theory of relativity in 1905 [1] that there is also a second-order effect. The latter is caused by the slowing down of clocks upon acceleration (time dilation). Several years later [2] he predicted what has come to be known as the gravitational red shift for the frequency of light waves observed on the earth's surface which have been emitted from the sun.

The speed of light and sound waves in free space is obtained as the product of the associated frequency and wavelength of the associated radiation. The question that will be discussed below is how the relative motion of the observer to the source affects the value of the speed of the waves measured by him.

2. Variation of the speed of sound:

Consider the following application of the Doppler effect. A fire truck in the station starts his siren. The sound waves it emits have a frequency of ν_0 and a wavelength of λ_0 . The corresponding speed relative to a stationary observer is therefore $v_0 = \nu_0 \lambda_0 = \lambda_0 / \tau_0$, where $\tau_0 = 1/\nu_0$ is the corresponding period of the waves. The truck then exits the station and starts moving toward the observer until it reaches a constant speed v . The period $\tau = 1/\nu$ of



the sound waves (i.e. the time it takes for successive wave crests to pass a given point) that now reach the observer has therefore decreased to a value of $[(v_0-v)/v_0](1/v_0) = (1-v/v_0)\tau_0$, in accord with the formula for the Doppler effect. At the same time, the corresponding wavelength of the waves reaching the observer has been reduced to $\lambda=(1-v/v_0)\lambda_0$. As a consequence, the speed of the waves reaching the observer is unchanged from its initial value since $\lambda v = \lambda/\tau = \lambda_0/\tau_0 = \lambda_0 v_0 = v_0$.

The above example raises a critical question, however. What is the situation when it is the observer who is moving relative to a fire truck with the same speed v ? Conventional wisdom has it that it does not matter: the frequency, wavelength and speed of sound will all be exactly the same in both cases. This position misses a basic point about frequencies, however, *namely the number of wave crests emitted per unit time by the source is independent of the motion of the observer*. Einstein made this point in his elucidation of the gravitational red shift [2, 3]. It would be a violation of the Law of Causality to claim that the motion of the observer can have an effect on the frequency of the waves emitted by the source.

Consequently, it does make a significant difference whether it is the source or the observer who is in motion relative to the original rest frame. In the case first discussed, the frequency ν of the waves measured by the observer is changed as per the Doppler effect, whereas in the opposite case where the source does not move, the frequency of the emitted waves remains unaffected by the motion of the observer.

The situation with wavelength variations is qualitatively different, however. All that matters in either case is the relative speed of the source to the observer. The waves are cramped into the intervening space of the medium through which they move. As a result, the same formula for wavelengths holds in the second case as well, namely $\lambda=(1-v/v_0)\lambda_0$. As a consequence, since the observed frequency is now equal to the source frequency ν_0 , the speed of the waves is simply proportional to the wavelength, i.e. $\lambda\nu_0 = (1-v/v_0)\lambda_0\nu_0 = \nu_0 - v$, unlike the first case in which the speed of the waves measured by the observer is the same as the speed of the waves relative to their source (ν_0).

The case in which the source remains stationary while the observer moves toward it raises an interesting physiological point. Since the brain registers a change in pitch as the observer increases his relative speed to the source, *the effect cannot be caused by the frequency of the waves* since it remains constant throughout. As long as musicians in an orchestra are stationary, it is clear that the frequency of a tuning fork determines the desired pitch for the various instruments, but the corresponding wavelength changes in exact proportion to this frequency. Therefore, it is also clear that one might just as well say that it is the wavelength which is involved in the tuning process. If the musicians/observers were to move away from the tuning fork at constant speed, however, this would not affect the frequency of the sound emitted. It would nevertheless change the pitch of the sound used in the tuning process because the motion affects its wavelength.

The variation of wavelengths with motion is also related to the phenomenon of "sonic booms." If the relative speed v of the observer to the source becomes equal to v_0 , the value of the wavelength $\lambda=(1-v/v_0)\lambda_0=0$. This can occur when an airplane catches up with waves it produced at an earlier location, for example. The de Broglie relationship between momentum p of the particles such as electrons which are associated with a wave pattern states that p is inversely proportional to the wavelength λ of the waves. This formula is key to understanding the nature of the Compton effect and electron diffraction, for example. Specifically, $p=h/\lambda$, where h is Planck's constant (6.625×10^{-34} Js). When applied to the above situation with sound waves, the result is that the momentum p of the molecules responsible for the sound waves becomes infinite at this point. The general formula for the increase in momentum relative to the starting value p_0 prior to increasing the speed of the airplane is: $\Delta p/p_0 = (\lambda_0/\lambda)-1$. In practice this means that the momentum of the molecules in the air approaches a very high value up to the point where v is just slightly less than v_0 , and then rapidly decreases as the speed of the airplane becomes even greater. The sonic boom occurs at the precise moment when $v=v_0$. The energy E of the waves is proportional to the momentum p at all stages of the process because of the general relation: $E=pc$. Hence, the energy also increases according to the analogous formula: $\Delta E/E_0 = \Delta p/p_0 = (\lambda_0/\lambda)-1$. Because of the conservation of energy principle, this means that the increased energy $\Delta E=E-E_0$ when λ approaches 0 must be completely ejected from the region of the airplane, therefore leading to the sonic boom.

The two examples discussed above emphasize that the measurements of wavelengths and frequencies do not allow for an unambiguous decision as to the value of the speed of the sound waves relative to the observer. Even though the speed at which observer and source are separating from one another is exactly the same, the speed of sound deduced on the basis of measured wavelengths and frequencies is different depending on



whether it is the observer or the source that is moving relative to original rest frame of both. If the source moves toward the observer, then the conclusion is that the speed of sound is v_0 (Doppler effect), whereas if it is the observer who is moving toward the source, whose waves are moving toward the observer, the answer is $v_0 - v$. In the former case one can say that it is the speed of sound relative to the source that is being measured on the basis of the measured frequency and wavelength of the waves, whereas in the latter case, it is the speed of the sound waves relative to the observer.

The way to settle this discrepancy is to go back to the definition of speed as the distance traveled by an object in unit time. Take the case where the source moves away from the observer and the waves are moving in the same direction. The waves travel a distance of v_0T while the source itself moves a distance of vT in a given time T . The total distance is then $v_0T + vT$, so the speed relative to the observer, whether he moves from the original position or not, is by definition equal to $v_0 + v$. If the waves move toward the observer on the other hand, while the source is again moving away from the observer, the distance traveled relative to him is $v_0T - vT$, i.e. the corresponding speed relative to his original position is clearly $v_0 - v$.

In this calculation it is immaterial whether it is the source or the observer that is moving relative to the original position of the latter, only that the relative speed to each other for both is v . The magnitudes of the speed are obtained using ordinary vector addition. One can easily generalize the method of calculation for the case when the waves do not travel in the same direction as that in which source and observer separate from one another. Vector addition is the modern name for what is traditionally called *the Galilean or classical space-time transformation*. In other words, it is that transformation which can be used in all cases to compute the speed/velocity of the sound waves relative to the observer's current position.

There is one other point that is easily missed and is perhaps the most perplexing aspect of the whole discussion. Using vector addition in the case where the observer moves toward the source of the sound waves which are moving toward him, the computed speed of the waves relative to him is $v_0 + v$. In the calculation based on wavelength and frequency for the same case, however, the speed of the sound waves is $v_0 - v$ (because the wavelength decreases while the frequency stays the same). This just shows that the latter method does not always give the correct answer for the *actual speed* of the waves relative to the observer, which is $v_0 + v$ in this case.

3. The speed of light in free space:

As discussed in the previous section, Einstein made a crucial observation in his 1907 paper [2, 3] regarding the behavior of light frequencies. He did this in the context of his prediction of the gravitational red shift. On the basis of the Lorentz transformation which he derived in 1905 [1], he concluded that the frequency of light should have a lower value when received on the earth's surface than its value emitted on the surface of the sun. Einstein argued that the frequency of the light waves did not change on the way to the earth, however. Instead, he assumed that the local clocks at the two locations did not run at the same rate. Another way of putting this is to say that *the unit of time for local clocks decreases as the clocks are moved upward* between the two gravitational potentials.

This prediction has been definitively verified in experiments involving atomic clocks which were moved to a higher location for an extended period of time. It is found that the clocks on the mountain had gained time relative to their like counterparts which remained behind at the lower gravitational potential. The fractional gain in frequency is $\Delta\nu/\nu = S = 1 + gh/c^2$, where g is the local acceleration due to gravity (9.8 ms^{-2}).

The same fraction can be deduced in a decidedly simpler way for energies, however, again based on a result of Einstein's 1905 version of relativity theory [1]. The argument goes as follows. At the lower potential, $E_l = mc^2$, where m is the inertial mass of the object. At the higher potential the energy E_h of the same object is higher by mgh . In concert with Einstein's assumption for frequencies, one can therefore conclude that $E_h - E_l = \Delta E = (1 + gh/c^2) E_l$ simply because the unit of energy is $S = gh/c^2$ times greater at the higher gravitational potential, not because the *local* energy value measured at the higher potential is other than mc^2 . In other words, to obtain the correct value of the energy of the object from the point of view of the observer at the lower potential, it is necessary to multiply E_h , i.e. the value actually measured at the higher potential, with S .

The first credible experiment that delved into the question of how the wavelength and frequency of light waves is affected by motion of the source was carried out in 1938 by Ives and Stilwell [4]. The authors set out to study



the effects of accelerating a light source in the laboratory. They took for granted that the Doppler effect would apply and therefore assumed that the speed of light would not change from its standard value of c but that the wavelength and period of the light waves would increase by equal amounts when the source moved away from the laboratory and decrease by the same fraction when the direction was opposite. The fraction of the change was expected to be equal to v/c , where v is the speed of the source relative to the laboratory.

Their main interest was not in the Doppler effect itself, but rather in testing Einstein's prediction of time dilation that is implied by the Lorentz transformation [1]. By recording the wavelengths of light emitted from the accelerated source moving in opposite directions on the same photographic plate, they expected to eliminate the v/c change in the wavelength to uncover the second-order effect (known as the transverse Doppler effect) in v/c predicted by time dilation. They were successful to within experimental error in this attempt. The same experiment was later carried out with higher accuracy [5] and it also verified Einstein's prediction.

There was nonetheless something about the Ives-Stilwell experiment which did not fit in with Einstein's theory. According to the latter, the lengths of objects in general should *decrease* upon acceleration (Lorentz-FitzGerald length contraction), whereas the actual findings showed that the wavelength increased instead. This fact has largely been ignored, but this inconsistency in the predictions of the Lorentz transformation is far from unique.

The simplest way to see this is to examine its prediction of *remote non-simultaneity*. According to the Lorentz transformation [1], events which are simultaneous for one observer might not be so for another who is in relative motion to the first. This possibility stands in direct contradiction to a conclusion regarding the nature of *inertial clocks*, however. In the absence of an external unbalanced force, there is no reason to expect that the rate of such a clock would ever change; it would be a violation of the Law of Causality.

This means that the ratio of the rates of two such clocks would be forever constant. One must therefore conclude on this basis that elapsed times Δt and $\Delta t'$ measured for the same event by two such inertial clocks must always occur in the same ratio: $\Delta t = Q \Delta t'$, where Q is simply the proportionality constant for the two rates [6-8]. As a consequence, it is impossible to have an event which is simultaneous for an observer in one such inertial frame ($\Delta t=0$) to not be so in the other ($\Delta t' \neq 0$). In recognition of his views on this general subject, this state of affairs has been referred to as "Newtonian Simultaneity."

One therefore has the clear choice of either believing in the Lorentz transformation on the one hand, or the Law of Causality, on the other. In the present case, the latter implies that the assumption of Newton Simultaneity is correct. It is impossible to believe in both the Law of Causality and the Lorentz transformation and still remain in the realm of logical discourse.

Perhaps the main reason that the Lorentz transformation has not been rejected by physicists over the years is its compatibility with the relativistic velocity transformation (RVT). It is obtained in a straightforward manner by simply dividing the spatial variables in the Lorentz transformation by the corresponding time quantity. It is possible to derive the RVT in another way, however, which allows the theory to also be consistent with Newtonian Simultaneity [6-8]. The resulting set of equations has been referred to as the Newton-Voigt transformation (NVT) [9, 10] in earlier work.

A key difference is that the NVT employs a different form of the light speed postulate. Accordingly, it is assumed that the speed of light in free space *relative to its source* is always equal to c . Einstein assumed instead that the speed of light is *independent of the state of motion of the observer* [1], and therefore that light could be traveling at a different speed than c relative to its source.

There is a clear analogy between the NVT version of the light speed postulate and what has been found in Sect. II in the discussion of the dependence of the speed of sound waves. If one analyzes the distance traveled by light in time T in the Ives-Stilwell experiment [4-5], it is assumed that the light waves themselves travel a distance of cT relative to the source while the source itself moves a corresponding distance of vT . The sum of these two distances is $(c+v)T$ if the source moves toward the laboratory as the light also moves toward it, but it is $(c-v)T$ if the source moves away from the laboratory when the light moves toward it.

As is the case with sound waves, it is found that the speed of the light waves is described perfectly by the Galilean transformation and is therefore different from c in both cases. The NVT version of the light speed postulate therefore indicates that the original formula Bradley gave in 1727 for the aberration of starlight from



the zenith is perfectly correct, and that the extra factor of $\gamma=(1-v^2/c^2)^{-0.5}$ Einstein added to compute the angle of aberration is not.

4. Application of scale factors to predict the values of physical properties:

There were several key advances in Einstein's 1907 paper [2] in which he discussed measurements of the properties of light waves. He used his Equivalence Principle therein to predict the gravitational red shift. Accordingly, light rays emitted near the sun with a given frequency were expected to have a lower value from the vantage point of an observer located on the earth's surface. He argued [2, 3] that the reason for this distinction *was not that the frequency itself had changed* as the light passed between the sun and the earth. This is because, by definition, frequency is the number of wave crests emitted in unit time from the source, and there is no reason that this quantity should somehow depend on the observer's position in a gravitational field.

Of more general significance, however, he concluded that the true reason why the observers disagree on the value of the frequency is *because the clocks they employ to make this measurement do not run at the same rate* even though they are completely identical ("*gleich beschaffen*"). An effective way to understand the above distinction is to say that *the unit of time* differs in the two locations. Specifically, he concluded that rates of clocks, which determine the value of this unit in a given case, decrease as they are lowered in a gravitational field; the slower the rate, the larger the unit of time. Such a change has since been verified using atomic clocks located at different altitudes for an extended period of time. Einstein predicted correctly that the ratio of the two rates is equal to $S = 1 + \Delta\Phi/c^2$, where $\Delta\Phi$ is the difference in gravitational potential of the clocks. It also has been shown in Sect. II that an exactly equivalent situation exists for the energies of objects located at different potentials. For example, in a small region of space, $\Delta\Phi=gh$, where g is the local acceleration due to gravity and h is the difference in altitude. Using Einstein's mass-energy equivalence relation [1], one can conclude that the energy measured at the higher potential is equal to mc^2 , while that measured at the lower potential is $Smc^2 = mc^2 + mgh$. Note that the Conservation of Energy Principle is satisfied during free fall. The absolute value of the object's energy is the same at both altitudes. *The gain in kinetic energy as a result of free fall is thus interpreted as a consequence of the smaller value of the unit of energy at the lower potential.* The same procedure applies for the gravitational red shift, in which case $S < 1$ from the vantage point of the observer on the earth's surface. He measures a lower value for the light frequency purely because his unit of frequency is greater than that extant near the sun.

It is possible to extend this approach to all other physical properties [11-13], but before discussing this it is important to consider another related question. Why not have a similar approach for the effects of kinetic acceleration? It is easy to see why Einstein did not pursue this possibility. It was because of his belief in the Lorentz transformation [1]. Specifically, it leads unequivocally to the prediction that the rate of a moving clock is lower than its standard value, and by a specific fraction of $\gamma=(1-v^2/c^2)^{-0.5} > 1$. Accordingly, if two observers exchange light signals of the same frequency ν , they will each find that the signal they receive will have a smaller value of ν/γ . This is known as *symmetric time dilation*. Under the circumstances it is impossible to have a similar situation in this case as for the effects of gravity. It makes no sense to talk about units of frequency and time in different rest frames *since the respective observers can't even agree on whose clock runs slower*.

As discussed above, however, the Lorentz transformation is not viable because of its false conclusion of remote non-simultaneity. Consequently, one is freed of any and all of its predictions in attempting to formulate a workable theory of relativity. Newtonian Simultaneity, so-named in the previous section, suggests that the proportionality constant Q provides a ready candidate for the analog of S in Einstein's treatment of gravitational effects. Consider the situation presented by the Ives-Stilwell experiment [4, 5]. The slowing down of the standard clock in this example indicates that the value of Q should be equal to γ , i.e. the unit of time in the accelerated rest frame is γ s. This means not only that the laboratory observer measures a value of the emitted frequency using his timing device of ν/γ , but also that the corresponding measurement for the same source located in the laboratory would be found to have a value of $\gamma\nu$ in the units of the accelerated rest frame. This is *asymmetric time dilation*, not the symmetric variety implied by the Lorentz transformation. Indeed, this prediction has received verification in the subsequent experiments with high-speed rotors carried out in 1960 by Hay et. al and others [14-16].

The study of atomic clocks carried onboard circumnavigating airplanes carried out by Hafele and Keating in 1970 [17-18] provide a clear means of determining the value of Q in the general case. Their results indicated



that the elapsed time recorded on a given clock is inversely proportional to $\gamma(v)$, where v is the speed of the clock relative to the earth's center of mass (ECM) during this portion of the flight. Perhaps the most striking result of the HK experiment was its finding that clocks on the east-bound flight recorded less time for the entire journey than their identical counterparts left behind at the airport of origin, which in turn was less than that recorded by the corresponding clocks carried onboard the westward traveling plane. The exact amounts of the various elapsed times fit in quite well with the above theoretical prediction.

On this basis one can formulate a *Universal Time-dilation Law*. To apply the UTDL [19-20], it is first necessary to establish a rest frame (Objective Rest System ORS [21]) from which the rates of the clocks need to be determined. It is the ECM in the HK study, the axis of the rotor in the Hay et al. experiment, and more generally the rest frame from which a force has been applied to a given object that is responsible for its acceleration. The latter definition is completely consistent with Einstein's original statement of his Clock Paradox [1]. He predicted, for example, that a clock located at the Equator would run slower by factor of $\gamma(v_E)$ than one located at either of the earth's Poles (v_E is the speed of the earth around its axis). The UTDL then allows for the unique evaluation of the constant Q for an arbitrary pair of rest frames. If the speed of the clock employed by the observer relative to the ORS is v and that employed in the other rest frame is v' , then $Q = \gamma(v')/\gamma(v)$.

If there are different ORSs for the two inertial frames, one can still use the UTDL to compute the value of Q . For this purpose, it is necessary to know the relationship between the two ORS frames. For example, if one is the rest frame of a satellite orbiting the earth and the other is the rest frame of a satellite orbiting the moon, one knows that the former is the ORS for the latter. Therefore, one can use the UTDL to compute a partial value of Q which looks upon the ECM as the "observer" rest frame and the "object" rest frame as the moon's center of mass. In this way, one can combine various bits of information to determine the overall value of Q connecting the two satellite rest frames, and therefore directly convert the values of measurements carried out on the satellite orbiting the moon to the corresponding units employed on the satellite orbiting the earth.

To complete this survey, it is also necessary to be more specific about the calculation of the gravitational constant S . Integration of the value for the case of an infinitesimal altitude difference discussed above leads to a key definition [22, 23], namely: $A_p = 1 + GM_s/c^2 r_p$. In this formula, G is the universal gravitation constant ($6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$), M_s is the gravitational mass of the active source of the field, and r_p is the distance separating the object (denoted by p) from the active mass. The value of S is then obtained as the ratio A_o/A_p , where A_o is the corresponding value for the observer.

Once these two values (Q and S) are obtained for a given pair of object-observer rest frames, it is theoretically possible to convert the measured value of any physical quantity in the object rest frame to the corresponding value in the units employed in the observer's rest frame. The conversion factors for the object's measurements to the units of the observer are products of S and Q [22, 23] in all cases, as shown in the following summary. If the object's energy value is E , the corresponding result in the observer's units is $QS E$. For time T , the observer's result is $QS^{-1} T$. The same ratio holds for inertial mass m ($QS^{-1} m$). The ratio for length/wavelength λ is $Q \gamma$. Each of these ratios is based on experimental data of various kinds [22, 23].

The last three of the above ratios are for the fundamental physical units that are used in the mks system, for example. One can determine the corresponding ratio for any other physical property on the basis of its constitution in terms of time, inertial mass and length. For example, speed is the ratio of distance traveled to corresponding elapsed time. Hence, the conversion factor is $Q/QS^{-1} = S$. This agrees with Einstein's analysis in 1907 [2,3] in which he concluded that the speed of light increases with gravitational potential and therefore has a value less than c near the sun's surface. The value for energy of QS can be obtained in the analogous way. Its composition is $\text{kgm}^2\text{s}^{-2}$. Hence, the conversion factor is determined to be $(QS^{-1})Q^2(QS^{-1})^{-2} = QS$, as required. This value also is consistent with $E=mc^2$: $QS=QS^{-1}S^2$, where the above conversion factor for speed has again been used in this determination. Another way to obtain the same result is through the use of Planck's radiation formula $E=h\nu$. The frequency ν has a unit of s^{-1} and thus its conversion factor is SQ^{-1} , the reciprocal of that for time. Planck's constant h has units of Js and therefore has a conversion factor of $QS(QS^{-1})=Q^2$. Therefore, Planck's formula leads to a conversion factor for energy E which is again equal to QS .

One of the most pleasing features of the present scheme is its complete internal consistency. For example, momentum p is equal to the product of internal mass and velocity/speed. Its conversion factor is thus equal to $(QS^{-1})S=Q$. The de Broglie relation $p=h/\lambda$ is therefore consistent with this result ($Q=Q^2/Q$). Another relation



involving energy, namely $E=pc$, also fits in perfectly with this scheme ($QS=QxS$). Finally, there is straightforward means of determining conversion factors solely in terms of S and Q as well [24-25].

5. Effect of free fall on the values of physical properties:

The experiment carried out by Pound and coworkers [26] to simulate the gravitational red shift in an earth-bound setting provides an excellent example for illustrating how the above conversion methods can be used in practice. These authors placed a Mössbauer x-ray source on the top of a building and measured the deviation in frequency of the emitted radiation when it was received at ground level. The value of Q is obviously equal to 1 from the latter perspective while that for S is $1+ gh/c^2$ (h is the vertical distance between the two rest frames). As a consequence, one expects the observed frequency at ground level to be Sv as compared to the standard value of v in the rest frame of the source. The interpretation based on the analysis of the previous section is that the absolute value of the frequency did not change since it is defined as the number of wave crests emitted per unit time.

This conclusion is consistent with that used in Einstein's original prediction of the gravitational red shift [2, 3]. Since the Mössbauer receiver on the ground has maximum efficiency for the original frequency v , it was advisable to move the latter away from the rest frame in which the radiation arrived directly below the position of the source. In this way, the Doppler effect comes into play and reduces the frequency arriving at the receiver by a factor of $1 -v/c$. Comparing this value with S shows that maximum efficiency should occur for $v = gh/c$, in which case the two effects on the frequency of the radiation would exactly cancel. The experiment found that this expectation was fulfilled to a high degree of approximation. It also can be noted that the Planck radiation formula indicates that the energy of the photons in the experiment changed in a similar way since the value of h is the same at both altitudes (since $Q=1$). This has been interpreted [27] as showing that electromagnetic energy has "gravitational charge," since the difference in the two energy values is equal to $(S-1)E= (E/c^2)gh$. The above analysis indicates on the contrary, however, that all that is involved is a change in the unit of energy employed at the two altitudes, i.e. E at the roof translates into SE in the unit employed at ground level. Energy is actually perfectly conserved in the process, as must be expected.

The example dealing with the free fall of light waves brings up an interesting point. Consider the case of an object with non-zero inertial mass falling between two points P and O in a gravitational field. Seen from the vantage point of an observer located at infinity moving with speed v relative to the ORS, the energy of the object when it is located at altitude r_p is equal to $QSE = [\gamma(v_p)/\gamma(v)](1/A_p)$, where v_p is the corresponding speed of the object relative to the same ORS (in accordance with the UTDL and the definition of the A factors given in the previous section). The corresponding value of the energy of the object after it has arrived at altitude r_o (with $r_p > r_o$) is equal to $[\gamma(v_o)/\gamma(v)](1/A_o)$ from the same vantage point (infinity). The Conservation of Energy Principle therefore requires that the above two energy values are equal, whereupon one concludes that $\gamma(v_p)/\gamma(v_o) = A_p / A_o$.

Note that this is the generalization of the well-known result of classical gravitational theory: $v^2=2gh$ [28]. From the vantage point of the observer located at altitude r_o , the energy E_o of the object both before and after fall has the value of $QS E_p = [\gamma(v_p)/\gamma(v_o)] (A_o/A_p) E_p = E_p$, i.e. $QS=1$. In other words, in free fall the two conversion factors are not independent of one another. In the Pound et al. example [26, 27], it is completely impractical to use the UTDL to determine the value of Q for photons because the respective γ factors at the two altitudes are both infinite, but the analysis can be carried out exclusively on the basis of S anyway. The reciprocal relationship found above can be used to advantage in calculations of planetary orbits [29, 30]. In that case the value of Q can be inferred directly from the change between A_p and A_o in a given portion of the trajectory without requiring any consideration of the change in the corresponding speeds of the planet relative to the active gravitational source.

6. Conclusion:

When a fire truck approaches someone standing on the sidewalk, the wavelength emitted by its siren depends on its relative speed v . The effect is the same if the fire truck is stationary and it is the observer who is moving toward it. The situation is qualitatively different for the frequency of the waves, however. This is because the observed frequency is simply the number of wave crests that arrive per unit of time. Einstein used this fact in his derivation of the gravitational red shift in 1907. He concluded that the reason the frequency of light waves emanating from the sun *decreases* as it passes through the gravitational field toward the higher potential of the



earth is because the unit of time on which the measurement is based differs in the two locations, but not because the number of wave crests passing a given point in space is not the same for observers in the two locations.

When this principle is applied consistently to sound waves, it is found that their frequency depends on whether it is the fire truck or the observer who is moving relative to the sidewalk. If the fire truck moves, consistent with the Doppler effect, it is found that the frequency ν increases in direct proportion to the difference between the local speed of sound v_s and the truck's speed v relative to the observer. This is because the period between successive wave crests emanating from the fire truck is decreased accordingly. In the opposite case, however, it does not matter what the value of $v_s - v$ is. The number of wave crests arriving at the observer's stationary position is completely independent of the speed v of the truck, consistent with Einstein's general conclusion regarding light waves emitted from the sun.

By contrast, the wavelength of the sound varies in inverse proportion to $v_s - v$, in either case. It does not matter whether the observer is standing still or not. The distance between successive wave crests is the same in both cases. The speed w of the sound waves, which is defined as the product of the frequency and wavelength measured by the observer, is therefore also dependent on whether the fire truck or the observer (or both) is moving relative to the sidewalk. This means that the observer can change the speed of sound waves reaching him simply by moving toward or away from a stationary siren.

Application of the above principles to light waves leads to completely analogous conclusions. For example, in the Ives-Stilwell experiment, the laboratory observer finds that the speed of the light waves reaching the laboratory observer from the accelerated source based on his measurements of wavelength and frequency is equal to c regardless of whether the source is moving toward or away from him. Ultimately, he is simply measuring the speed of light waves relative to the source in both cases. The situation would be qualitatively different if the tables were turned, however, and it was the laboratory observer who is moving toward or away from a stationary light source. In that case, he would find the speed of the light waves, i.e. the product of his measured wavelength and frequency, to be $c+v$ if he moves away from the stationary source with speed v , or $c-v$ if he moves toward it. This is because his motion has no effect on the frequency of the waves he measures although it does change their corresponding wavelength.

In actuality, the speed of sound and light waves relative to the observer does not depend on whether it is the source or the observer or both that is moving. Only their relative speed v to one another is relevant, as the Relativity Principle demands. To obtain the correct and therefore unique value of the speed of the waves relative to the observer, it is necessary to revert back to the fundamental definition of the speed of the object as the distance it travels in unit time. For example, if the light source moves *away* from the observer with speed v , the distance it travels in time T is vT . If the light pulse emitted by the source moves with speed c relative to it, the corresponding distance traveled is cT . Therefore, the total distance the light moves relative to the observer is $(c-v)T$, so that the corresponding speed is $c-v$. It will be recognized that this result agrees perfectly with that expected on the basis of the classical (Galilean) transformation, that is, vector addition. It is $c+v$ when the source moves toward the observer.

Einstein's version of relativity theory is inconsistent with this conclusion, but that is only one of many reasons to reject the Lorentz transformation. It is important to note that the Law of Causality demands that an inertial clock will not change its rate so long as no unbalanced external force is applied to it. This fact leads directly to Newtonian Simultaneity, since it rules out any possibility that any two such clocks can be expected to disagree as to whether a pair of events occurred at the same time or not. Since the Lorentz transformation requires that there be "remote non-simultaneity," it can be rejected on this basis alone. As a consequence, one can also ignore its controversial prediction that two such clocks can each be running slower than one another at the same time.

Once one is free of the error of remote non-simultaneity, it is possible to take full advantage of one of Einstein's greatest innovations, namely that the reason two observers at different locations in a gravitational field disagree on the value of a given physical property is because they employ different units to express their respective numerical results. There is a conversion factor between these units which has been denoted above as S . It can be easily determined on the basis of a minimum of information about the two rest frames. Newtonian Simultaneity allows for a completely analogous situation for the conversion of measured results obtained by observers in different states of motion. The constant Q required for this purpose can be determined uniquely in terms of the Universal Time-dilation Law (UTDL). It is necessary to identify an Objective Rest Frame (ORS)



for each rest frame in order to evaluate Q .

There is an internally consistent set of conversion factors for any two rest frames in the universe which is based solely on the fundamental constants S and Q in any given case. This arrangement is perfectly consistent with Galileo's Relativity Principle, but with an important amendment: The laws of physics are the same in every inertial system, *but the units in which they are expressed vary in a well-defined manner*. Finally, an alternative to the Lorentz transformation known as the Newton-Voigt transformation (NVT) is formed by combining Newtonian Simultaneity with Einstein's relativistic velocity transformation (RVT). This is necessary to explain the Fizeau/Fresnel light-damping experiment for motion of light through media with non-zero refractive indices, in which case the Galilean transformation does not apply.

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