Light Propagation in a Gravitational Field

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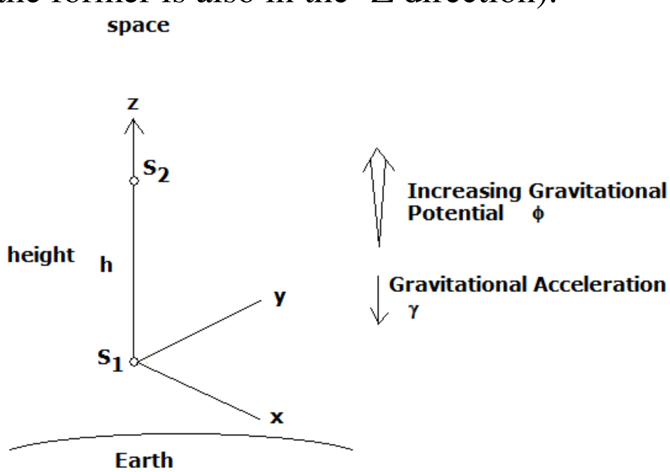
In 1911 Einstein published the paper "On the Influence of Gravitation on the Propagation of Light." This paper laid down some of the essential tenants of the General Relativity Theory, as it dealt with the effects of gravity on the propagation of light.

Einstein began by establishing some definitions:

- An object in a higher gravitational potential ϕ is one that is further from the surface of the massive body.

- A frame accelerating in the Z direction is equivalent to being in a gravitational potential with a gravitational acceleration in the -Z direction (since the G force in the former is also in the -Z direction).



Einstein first argues that:

1) If we have two objects, S1 and S2, the gravitational potential of S2 is greater than S1 by $\boldsymbol{\gamma h}$.

2) If energy E2 is emitted at c from S2 to S1, the time to reach S1 will be h/c. However, S1 can be conceived of having a velocity at the time the energy reaches it, since the gravitational acceleration is similar to an actual acceleration of the whole system. The velocity of S1 when the energy reaches it is equivalent to: $\boldsymbol{\gamma h/c = v}$.

3) Since S1 has an equivalent speed, the energy received is not E2 but a greater value E1.

$E1 = E2\ (1 + v/c) = E2\ [1 + (\gamma h/c)/c] = E2\ (1 + \gamma h/c^2)$. (Based on Special Relativity)

4) The gravitational potential $\phi = \gamma h$. (as a matter of convention)if the gravitational potential at S1 is taken to be zero.

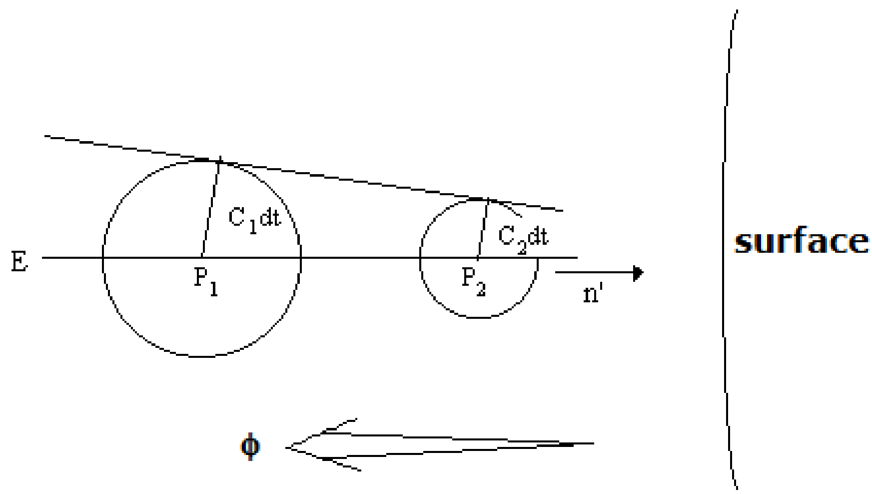
Then: $E1 = E2\ (1 + \gamma h/c^2) = E2 + (E2\ \gamma h\ /c^2) = E2 + (E2\ \phi\ /c^2)$

This is because mass is equivalent to energy. Since $E = mc^2$, then the potential energy held in the mass is $m = E/c^2$. If the mass has less potential energy by being lowered say in a gravitational potential, the potential energy is equivalent to $E\phi/c^2$.

This holds true:
1) If energy is emitted from S2 to S1 - energy absorbed is $E2(1 + \gamma h\ /c^2)$.
2) If a mass M is lowered from S2 to S1, the work done is $M\gamma h$.
3) Gravitational mass and inertial mass are equivalent, any change in a gravitational potential = $E\ \phi\ /c^2$.

Time and Velocity of Light in a Gravitational Field: (Same Paper of Einstein)
1) Light is **blue-shifted** (has a higher frequency) as it approaches a massive body (when measured using identical clocks). It blue-shifts as ϕ decreases.
Freq: $f1 = f2(1 + \gamma h/c^2) = f2(1 + \phi\ /c^2)$.
Similarly, light **red-shifts** and goes to a lower frequency as it escapes a massive body (when measured using identical clocks). In this case ϕ is negative.
To counter the absurdity that more or less periods per second can be received than were emitted, Einstein argues that this is because the time is dilated near a massive body:
2) Time at S1 runs slower than time at S2. For S1 and S2 to read the same time, the clock at S2 must be calibrated to run slower by $(1+ \phi\ /c^2)$.
3) Frequency counted at S1 is higher than at S2. By slowing the clock at S2, the frequencies and wavelengths at S1 and S2 become the same.
This leads to a fundamental issue for general relativity:
4) When the velocity of light c is measured at S1 and S2 with identical clocks in local time, the speed of light is always the same. When clocks corrected for gravitational time dilation are used instead, (count in common or absolute time) the light at S2 is travelling faster than the light at S1. The speed of light c is no longer constant, but increases with increasing ϕ. $c = c_o(1+ \phi/c^2)$. where c_o is the speed of light when $\phi = 0$.

From this proposition then, as light passes by a massive object, the wave-front closest to the object will slow down, with respect to absolute time . This will bend the wave-front towards the surface slightly.



The light is bent through an angle, which must be calculated by integrating along the entire path of the beam. This results in a final amount:

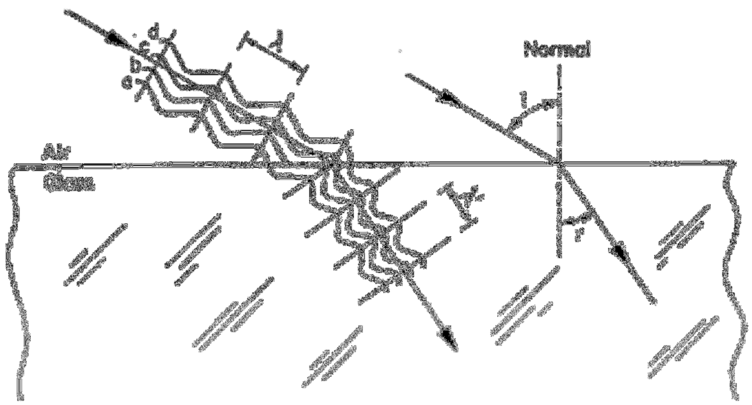
$$\theta = \frac{4GM}{rc^2}$$

where G is the gravitational constant, and r is the distance from the center of the body.

The mechanism of Actual Refraction and How this is similar or Different for a Gravitational Potential:

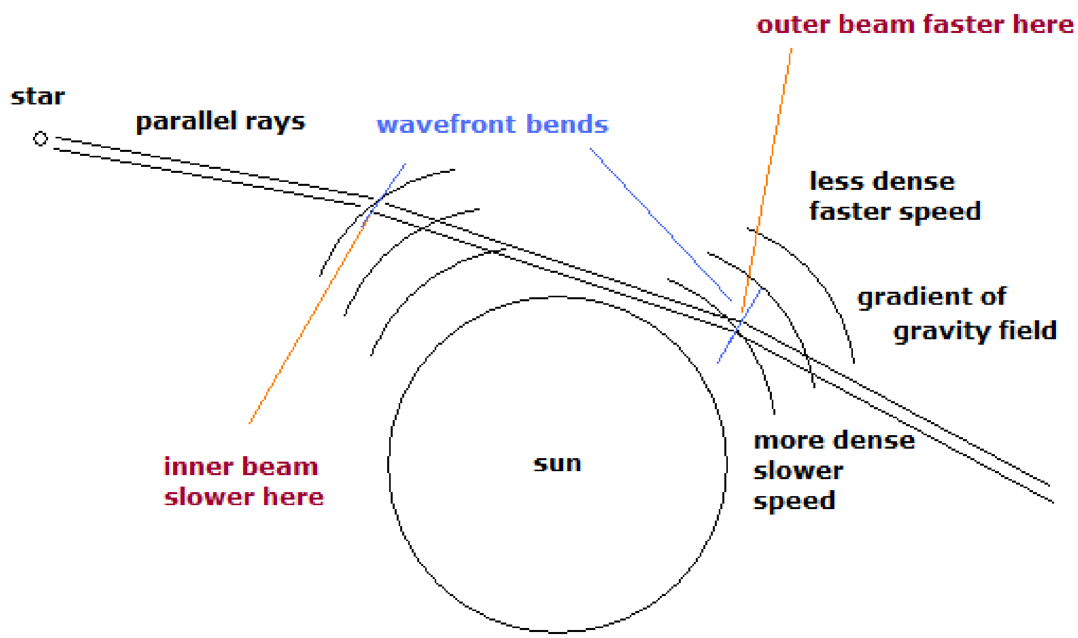
Can the bending of light be explained by "**gravitational refraction**"? In actual refraction, as a wave-front shown in the diagram below enters a medium of higher density, the various rays a, b, c, and d are affected in sequence.:

1) Ray "a" slows down in speed, becomes **blue-shifted**, before b, c, and d. The rays go through this process in sequence, bending the wave-front down. It is the shortening of the wavelengths and the slowing of the speeds in sequence that bends the wave-front.



The energy of the wave is unaltered. Its frequency remains the same (the wavelengths are smaller, but they are travelling slower). If we contemplate that a similar process occurs with light in a gravitational field, then how should light pass through such a "gravitational lens."? In such a model. the refractive index would have to increase as one goes deeper into the gravitational field.

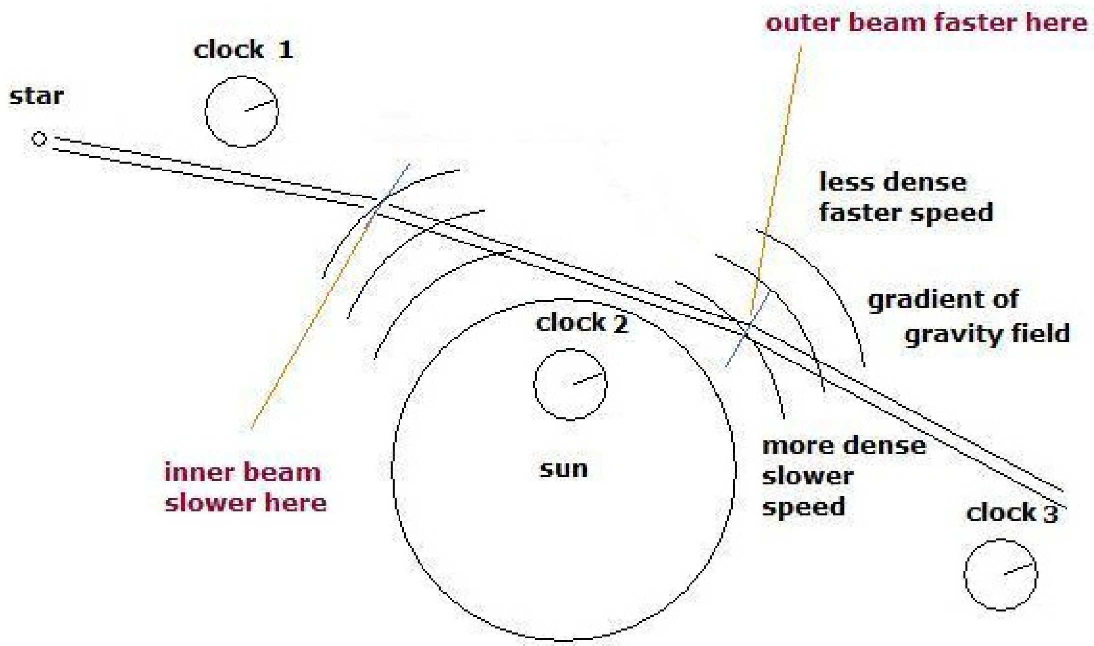
If gravity was like a normal refracting medium, how should starlight be affected?:



Starlight always bends around the sun because the outer beam is always faster than the inner beam!

Like in normal refraction, the energy of the beam should remain unaffected. The light should blue-shift and go slower (freq. remains the same) as one approaches the center of the field, and then red-shift and go faster as one exits the field. The net effect on speed and color should cancel. Only the light angle is bent since the outer parts of the wave-front are always in less of a gravitational field than the inner parts of the wave-front. This is **Gravitational Refraction**.

Effect on Clocks: Gravitational Refraction Theory:



If clock 1,2 and 3 are identical in construction and not compensated for "time dilation", then:

1) clock 1 runs mechanically faster in space

2) clock 2 runs mechanically slower on the sun

3) clock 3 runs mechanically faster in space.

In absolute time, the speed of light slows down near clock 2, the frequency remains the same, and the wavelength gets shorter. When viewed from the local time of clock2, the frequency is higher since the clock counts slower. This is consistent with gravitational refraction, and consistent with Einstein.

How is Einstein's explanation different from Gravitational Refraction: Similarities:

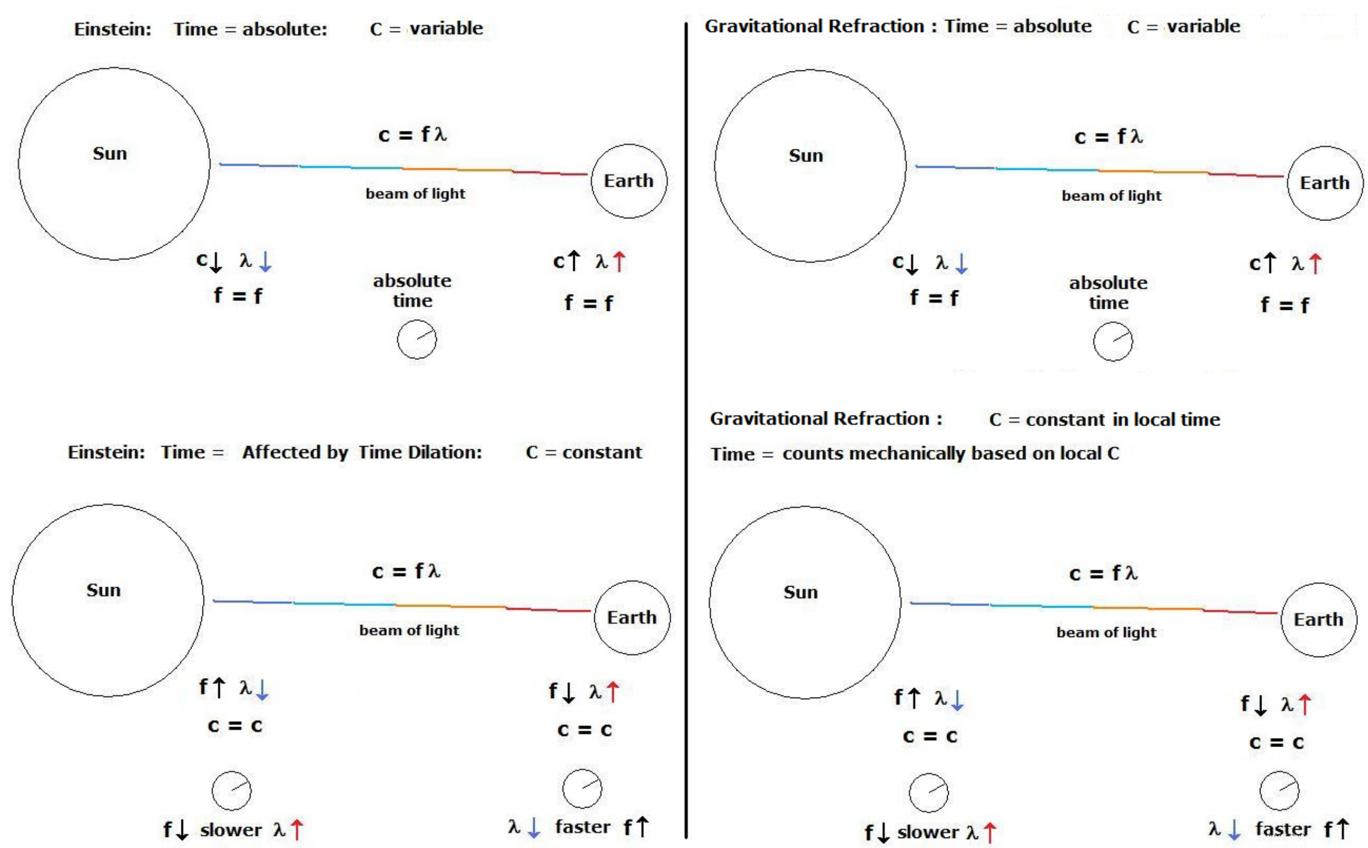
Einstein points out the absurdity of fewer periods arriving at Earth from the sun than were emitted. From both the Einstein and Gravitational Refraction view, the light is bluer and slower at the sun, and redder and faster at the Earth (where gravity from the Sun is less). The frequency is the same, and this is why the same number of periods arrive in absolute time at the Earth. The light appears to be redder since the local Earth clock is counting faster than the local sun clock (the sun clock is in the higher gravity field).

Differences:

1) With Gravitational refraction, the frequency shift is *virtual* and caused only by the mechanical effects of gravity on clocks. For Einstein however, because he believes that time dilation is *real*, the frequency shift for him is also *real* and must be explained as a change in energy as a light beam crosses a gravity field.

2) For Einstein, the speed of light across the beam is at different speeds in absolute time because local time is running slower on the side of the beam closest to the massive body. This means that the beam is curving in time (each point across the wave-front is in a different local time). With gravitation refraction, the beam bends due to simple refraction - the gravitational field slows the light because associated with that field is some change in the density, pressure or acceleration of the medium of space, to be discussed in detail in the next section. Time is the same across the wave-front.

In the diagram below, is a comparison of the two theories as it applies to the transit of light from the Sun to the Earth.



Both Gravitational refraction and Einstein would view the speed of light as being variable in absolute time - i.e. after the clocks on the Sun and Earth are synchronized to run in a common time (P.33 of Einstein's 1911 paper).

In absolute time:

1) Light travels slower near the Sun and faster near the Earth. Both theories agree.

2) Light is blue-shifted near the sun and red-shifted near the Earth. However this is not visible because the frequency does not change. Both theories agree.

In Local Time:

1) The speed of light is constant for Einstein because of time dilation in local clocks. For Gravitational refraction, the speed of light appears constant because local clocks slow mechanically in the gravitational field.

2) Light is blue-shifted near the sun and red-shifted near the Earth. This is visible because the frequency changes (Einstein) due to time dilation, or the frequency changes due to the mechanical slowing of clocks in a gravitational field. The theories disagree, but the experimental observation will be the same, thus the theories cannot be distinguished.

The constancy of the speed of light is only conserved when we measure the light speed using clocks affected by the gravitational potential of their place - i.e. in "local time".

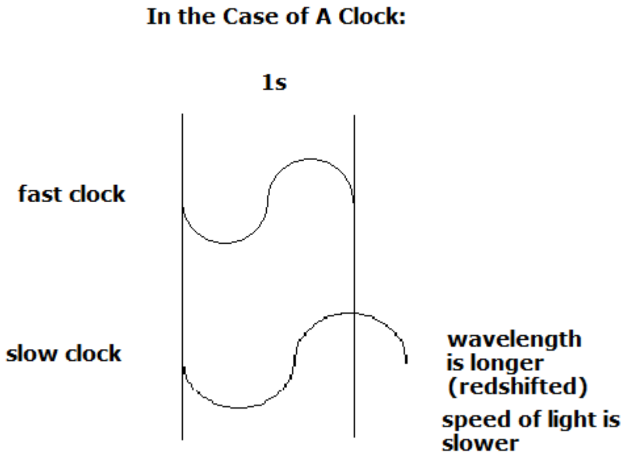
Since E = hf is the energy of a photon, if f decreases during transit to the Earth, then the energy of the photon decreases, and vice versa. Energy is not conserved in Einstein's view. This is why Einstein argues that if Energy E2 is emitted from S2 to S1 (towards the massive body), the energy arrives at S1 with extra energy $E1 = E2(1 + \phi /c^2)$.

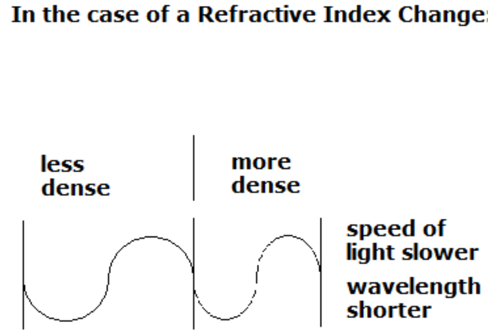
On the other hand, in our view, the speed of light is variable before the effect of gravity is taken into account on the mechanical speed of local clocks. This variable speed of light becomes invisible by a conspiracy of light (the clocks are mechanically effected to the exact extent to cancel observing the effect). Since the two theories arrive at similar conclusions, separated only by whether time dilation is real or mechanical, tests of Einstein's theory should also verify a Gravitational Refraction theory.

Experimental Test:

The Pound and Rebka experiment used two atomic resonators (one an emitter and the other a receiver) of the same frequency, one higher in the gravitational field than the other. When light was emitted from the higher one to the lower, the blue-shifted light could not be absorbed, unless it was mechanically Doppler shifted to the red by putting the emitter on an elevator that receded from the receiver at a fixed speed, to cancel the blue shift.

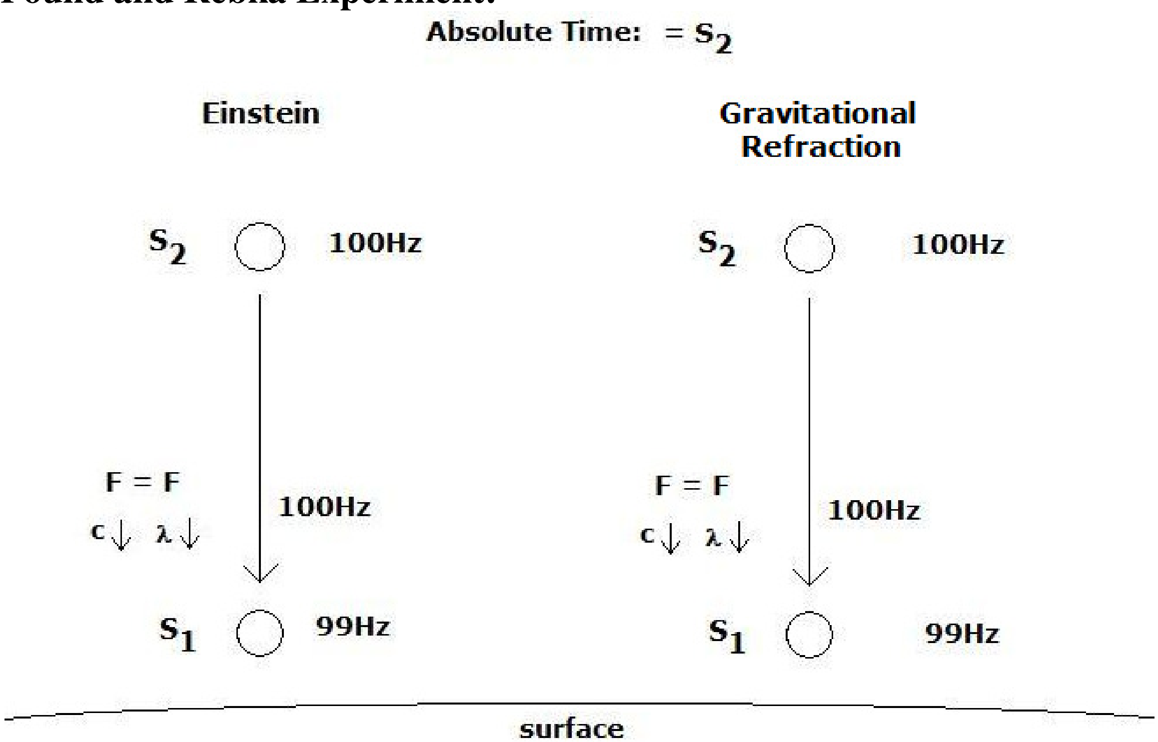
Examine what happens to clocks in this experiment, and whether a clock that is running slower is blue-shifted or red-shifted with respect to a clock that is running faster. Imagine two clocks running at different speeds:





Therefore, a receiving clock that is running slower is running at a frequency less than that of the emitting clock. If the frequency of the emitted light is the same, it needs to be red-shifted to match the period of the receiving clock.

Pound and Rebka Experiment:



Einstein: From the timeframe of S2, the light emitted reaches S1 at less than C, is blue-shifted, and the frequency is 100Hz. With respect to the clock at S1, the frequency appears to be greater than S1 (more energy), since S1 is counting slower (at 99Hz). The light must then be red-shifted by the emitter to be absorbed at S1. The light gains 1% energy in the transit from S2 to S1.

Gravitational Refraction: From the timeframe of S2, the light emitted reaches S1 at less than C, is blue-shifted, and the frequency is 100Hz. The resonant frequency of the S1 clock is mechanically slower (99Hz). The light must be red-shifted by the emitter to be absorbed at S1. The light energy is conserved from S2 to S1.

Thus both scenarios can fit the results. The only way to tell the difference is to see if more energy is absorbed or not at S1. From my review of the literature, I can't find any experimental reference testing this idea that a beam of light gains energy in a gravitational field, or looses energy escaping it. This is hard to accept, since the emission and reception of light by electrons in atoms does not affect its mass. Also, why should the amount of energy be + or - depending on whether the emission is directed out of the field or into the field? Also, where does this energy come from? It would have to be taken out of the gravitational field - thus light transiting the gravitational field towards Earth would continually weaken it.

Conclusions: Summary of the Two Theories:

Gravitational Refraction: In refraction, if the clocks at S1 and S2 read absolute time, then the refracted light has the same frequency at S2, and S1. In refraction, the speed of light slows down in the denser medium and the wavelength becomes shorter, thus it is redder at S2 and bluer at S1. This is not visible since in refraction the frequency remains the same so there is no blue-shift or red-shift. However, when the mechanical clocks are affected by their place, the S1 clock will count mechanically slower due to the gravity, thus making the frequency appear higher and the wavelength bluer.

Time Dilation: In Einstein's explanation, when his clocks S1 and S2 are synchronized (both measure time in the frame of U1, we will call this absolute time), then the frequency of the light is the same at S2 and S1. When the speed of light is also measured with such corrected clocks, the speed of light is faster at S2 than it is at S1. Thus the wavelength must be larger (redder) at S2 than at S1, but this is not visible, since the frequency is the same. However, when both clocks measure in their own timeframe, the frequency will appear to be higher (bluer) at S1, since U1 is counting slower. ***This is consistent with refraction + mechanical slowing of clocks in gravity.***

This is why the two explanations give the same answer in the Pound and Rebka experiment. Einstein has attempted to explain the bending of light in a gravitational field using a model of refraction, except that the light is refracted in time rather than in space. In so doing, he creates the paradox that a beam of light gains energy from a gravitational field as it falls into it. This notion is inconsistent with the theory of the conservation of energy. A more plausible explanation, as put forward herein, is that the light only appears to be of a higher frequency to a clock deeper in the gravitational field because this clock is counting slower, and thus must absorb energy at a slower rate. This is an effect of the receiver and not one of the light. This is a potential error introduced by Einstein, which was necessary for him to conserve his idea that the speed of light is constant for local observers. From this error has sprung most famously the idea of the black hole, where light loses so much energy trying to escape that it falls back into the massive body. Such notions should be seen to be unnecessary in light of a theory of Gravitational Refraction, which has as its foundation the notion of an absolute time.