Light Speed Uncertainty 0

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Background Questions

We are examining the proposition that, despite our measurements, we do not know the actual speed of light, and light does not in the physical universe ever travel at Einstein's Limit c because of

i) confusion in our measurements between comoving and proper distance,
ii) our poor knowledge of the Hubble rate,
iii) our ignoring the small (but ever-present) gravitation over long distances,
iv) our ignoring the small (but ever-present) refraction over long distances,
v) our ignoring the time (and hence speed) separation between long and short wavelengths.

Light-speed does get very close to c at places physically remote from large clusters of matter (in space which lies distant from, and between galactic clusters, for example).

We are also exploring some of the consequences of "slow" light, which may include the possibility of non-zero rest mass for the photon. The meaning of "non-zero photon rest mass" has to be examined very, very carefully to be sure that i) it does indeed have a meaning, and ii) that it is something that can be experimentally or theoretically tested.

Note that here we always take c (Einstein's Limit) to be the velocity used in the definition of some of the SI units of measure ($299792458 \ m \ s^{-1}$), which are in no way affected by these discussions.

Measurement Problems

There are problems in measuring light-speed. Some of these problems are:

Problem	Effects
Are we consistent in the types of distance used?	If we are inconsistent, our results are inaccurate
What rulers are we using?	If our rulers are inaccurate or inconsistent, then are results are inaccurate
What universal constants are used?	If the constants are unknown or inaccurate, then our results are inaccurate
Is Gravity being considered?	If gravity is ignored, then we are not measuring the true light-speed
Is Refraction being considered?	If refraction is ignored then (i) we are not measuring the true light-speed, and (ii) we are ignoring wavelength separation

Are we consistent in the types of distance used?

If we measure in, say, comoving distance, then we cannot use the results in proper distance without making the numerical conversion.

What rulers are we using?

What universal constants are used?

Is Refraction being considered?

If any of these is ignored then we are introducing inaccuracy into our measurement, unless we have some absolute estimate of the …...

Fundamental Values

There are several fundamental constants on the basis of which formulae in physics are based. Some examples of these are listed in the table below.

Symbol	Value	Description
c	299 792 458 $m\ s^{-1}$	Speed of light in free vacuum, Einstein's Limit
G	6.674 08 E-11 $m^3\ kg^{-1}\ s^{-2}$	Gravitational Constant, scaling masses and distances to gravitational acceleration
H_0	perhaps in range 67.6 to 77.6 $(km/s)/Mpc$	Hubble Constant, relating distance to recession velocity – value very uncertain
h	6.626 070 E-34 $J\ s$	Planck Constant
m_u	1.660 539 E-27 kg	Atomic Mass Constant
$N_A,\ L$	6.022 140 E+23 mol^{-1}	Avogadro Constant

Of these H_0 and G are the most uncertain in value: G has uncertainty of 4.7 E-5 and H_0 has an uncertainty of over 14%. This uncertainty affects the analysis and predictions that can be made using these constants. In particular, our very poor knowledge of H_0 affects our examination of universal expansion and the structure of space. Limited knowledge of G affects how we can make precise analysis of gravitational behaviour both locally (for Solar System bodies, for example) and at a distance, such as for galactic and intergalactic calculation.

Constants like h and m_u and N_A are known to great precision, based on both accurate measurement, and through theory, in each case to about $1.2\ E-8$, but G is known only to about $4.7\ E-5$. A sensible reliability for H_0 cannot at present be given.

Possible Relations

Some fundamental constants are related to others, sometimes by direct definition or by re-expression of other constants, or from analytic relationships. For example c has been measured accurately, and now is used as part of the very definition of the SI units, and hence is[1] completely precise; $\hbar$ is directly related to h by definition: $\hbar = \frac{h}{2\pi}$, and $\epsilon_0 = \frac{1}{\mu_0 c^2}$, both by definition; the von Klitzing constant is related by definition to a physical quantity e (the elementary charge) known by measurement to high precision, as $R_K = \frac{h}{e^2}$; and the Rydberg Constant R_∞ depends upon the accurately-known electron mass m_e and the fine-structure constant α which itself depends upon ϵ_0 :

$$\alpha = \frac{\mu_0 e^2 c}{2h} = \frac{e^2}{4\pi\epsilon_0 \hbar c} \qquad \text{and} \qquad R\infty = \frac{\alpha^2 m_e c}{2h}$$

In the SI *m/k/s* system, not all fundamental constants are related to others. Using the Planck Units, however, the units for mass length, time and temperature all depend upon the value for G . Plank length, Plank mass, Planck time and Planck temperature can be defined [WIKI17G] as:

$$l_P = \sqrt{\frac{\hbar G}{c^3}} \qquad m_P = \sqrt{\frac{\hbar c}{G}}$$

$$t_P = \frac{l_P}{c} = \frac{\hbar}{m_P c^2} = \sqrt{\frac{\hbar G}{c^5}} \qquad T_P = \sqrt{\frac{\hbar c^5}{G k_B^2}}$$

where k_B is the Boltzmann Constant (which in SI units is exact by definition).

(These definitions of the Planck Units may throw some philosophical doubt upon the (theoretical) stability of the SI units which, although those are not explicitly defined in terms of the value of G may just possibly depend upon it, invisibly, at base.)

Gravitational Constant

Constant G is known only by measurement. These measurements depend upon the gravitational behaviour of objects in the physical universe – for example the acceleration of falling bodies and the orbits of celestial bodies. To quote [WIKI17E]:

> “The accuracy of the measured value of *G* has increased only modestly since the original Cavendish experiment. *G* is quite difficult to measure, because gravity is much weaker than other fundamental forces, and an experimental apparatus cannot be separated from the gravitational influence of other bodies. Furthermore, gravity has no established relation to other fundamental forces, so it does not appear possible to calculate it indirectly from other constants that can be measured more accurately, as is done in some other areas of physics. Published values of *G* have varied rather broadly, and some recent measurements of high precision are, in fact, mutually exclusive. This led to the 2010 CODATA value by NIST having 20% increased uncertainty than in 2006. For the 2014 update, CODATA reduced the uncertainty to less than half the 2010 value.”

1 *by definition*

Most of the experiments for evaluating G use local perturbations caused by moving massive bodies, using updated versions of the Torsion Balance first used by Henry Cavendish in 1798. Some other possible search paths may be available [POPK16]:

> "Recent developments in cooling and trapping of atoms have enabled new approaches to the old problem, however. Guglielmo Tino of the University of Florence in Italy described a method known as "accurate measurement of G by atom interferometry," or by its Italian acronym MAGIA. Tino and his colleagues put rubidium atoms in two different quantum states with different momentums and tossed them up vertically in the presence of source masses. They then used the falling atoms' interference patterns to determine their accelerations, and ultimately derive a value for G.
>
> Atoms provide natural advantages, Tino said: Their masses are known to high accuracy, and their positions can be measured very precisely using lasers. But he admitted that, compared to the torsion balance (described by Cavendish as "very simple"), "the MAGIA apparatus is not very simple," requiring high vacuum and precisely tuned lasers. Tino's team published a result in 2014 with an uncertainty of 150 parts per million — relatively large but within striking distance of torsion balance results. He thinks he can improve his experiment and further reduce the uncertainty by one or possibly even two orders of magnitude."

There is some discussion as to whether G varies over time, $G(t)$. The bulk of the opinions seems to be that G would not vary by more than one part in E+10 over E+11 years [RAES83].

Quote from [RAES83]

> "**Abstract**
>
> Traditionally, theories of gravitation have received their most demanding tests in the solar-system laboratory. Today, electronic observing technology makes possible solar-system tests of substantially increased accuracy. We consider how these technologies are being used to study gravitation with an emphasis on two questions: (i) Dirac and others have investigated theories in which the constant of gravitation, G, appears to change with time. Recent analyses using the Viking data yield |Ġ/G| < 3 × 10-11 per year. With further analysis, the currently available ensemble of data should permit an estimate of Ġ/G with an uncertainty of 10-11 per year. At this level it will become possible to distinguish among competitive theories. (ii) Shapiro's time-delay effect has provided the most stringent solar-system test of general relativity. The effect has been measured to be consistent with the predictions of general relativity with a fractional uncertainty of 0.1%. An improved analysis of an enhanced data set should soon permit an even more stringent test. Technology now permits new kinds of tests to be performed. Among these are some that measure relativistic effects due to the square of the (solar) potential and others that detect the Earth's 'gravitomagnetic' field (the Lense--Thirring effect). These experiments, and the use of astrophysical systems are among the experimental challenges for the coming decades."

The mapping from Planck Units to the SI units depends upon our knowledge of G, and our incomplete knowledge of the value of G affects the mapping between Planck Units and SI units, making an error of at least on part in 43,000 in each of these correspondences.

Hubble Constant

The reciprocal of H_0 , the Hubble's Constant, is called the Hubble Time, t_H . This appears to have a value very close to the age of the universe since the BB. If we also consider the Hubble Constant to not be constant, but change with respect to time, such that $H(\tau)=f(\tau)$, with τ being the local time since the BB, then we can consider what is required of the function $f(\tau)$.

In terms of accurate measurement, the Hubble Constant is poorly known.

We suspect that H is decreasing over time, and that H_0 is the smallest value it has had. The simple reciprocal $f(\tau)=\frac{1}{\tau}$ is a possibility, but consideration must be taken for the pole at $\tau=0$. Another possibility would be $f(\tau)=k^{-\tau}$ for some constant k . Other possibilities for the mapping might include $f(\tau)=\frac{1}{\cosh(\tau)}$ or $\cot(H(\tau)+\pi)=\tau$ or $\tau=\frac{-1}{\cot(H(\tau))}+\frac{1}{H(\tau)}$ or numerous others (of doubtful probability).

For our analysis we shall (arbitrarily) adopt the simple

$$H(\tau)=\frac{1}{\tau}$$

as our mapping.

From [WIKI17F] we have:

> The Hubble constant H_0 has units of inverse time; the **Hubble time** t_H is simply defined as the inverse of the Hubble constant *i.e.* $t_H\equiv\frac{1}{H_0}=\frac{1}{67.8(km/s)/Mpc}=4.55\ E+17\ s\approx 14.4\ E+9\ years$. This is slightly different from the age of the universe $t_0\approx 13.8\ E+9\ years$. The Hubble time is the age it would have had if the expansion had been linear, and it is different from the real age of the universe because the expansion isn't linear; they are related by a dimensionless factor which depends on the mass-energy content of the universe, which is around 0.96 in the standard Lambda-CDM model.
>
> We currently appear to be approaching a period where the expansion is exponential due to the increasing dominance of vacuum energy. In this regime, the Hubble parameter is constant, and the universe grows by a factor e each Hubble time:
>
> $$H\equiv\frac{\dot{a}}{a}const.\Rightarrow a\propto e^{Ht}=e^{t/t_H}$$
>
> Over long periods of time, the dynamics are complicated by general relativity, dark energy, inflation, etc...."

Note that in the above a is the *scale factor*, which according to the FLRW metric $a(t)=\frac{1}{1+z}$, where z is the redshift as it was at time t when the light was emitted by the object being observed. The overdot represents differentiation with respect to time. By definition $H\equiv\frac{\dot{a}(t)}{a(t)}$.

Notes:

References

[RAES83] **Raesenberg, R.D.**; (1983) *The constancy of G and other gravitational experiments*; Phil.Trans. R. Soc. Lond.; A 310, 227-238; See https://www.jstor.org/stable/37406?seq=1#page_scan_tab_contents (Downloaded 2017.10.21)

[POPK16] **Popkin, Gabriel**; *Attracting New Ideas for Measuring to Big G*; American Physical Society (2016) See https://www.aps.org/publications/apsnews/201605/big-g.cfm (Downloaded 2017.10.21)

[WIKI17E] https://en.wikipedia.org/wiki/Gravitational_constant (Downloaded 2017.10.21)

[WIKI17F] https://en.wikipedia.org/wiki/Hubble%27s_law#/media/File:Hubble_constant.png (Downloaded 2017.10.22)

[WIKI17G] https://en.wikipedia.org/wiki/Planck_units (Downloaded 2017.10.23)

From
https://en.wikipedia.org/wiki/Photon#Wave.E2.80.93particle_duality_and_uncertainty_principles

> "In 1924, Satyendra Nath Bose derived Planck's law of black-body radiation without using any electromagnetism, but rather by using a modification of coarse-grained counting of phase space.[71] Einstein showed that this modification is equivalent to assuming that photons are rigorously identical and that it implied a "mysterious non-local interaction",[72][73] now understood as the requirement for a symmetric quantum mechanical state. This work led to the concept of coherent states and the development of the laser. In the same papers, Einstein extended Bose's formalism to material particles (bosons) and predicted that they would condense into their lowest quantum state at low enough temperatures; this Bose–Einstein condensation was observed experimentally in 1995.[74] It was later used by Lene Hau to slow, and then completely stop, light in 1999[75] and 2001.[76]"

If refraction occurs in steps, as a series of separate events ("things happening to the photon") then we have to consider what happens to the photon (*i.e.* what is the photon's state?) between these events (interactions). Thus does the photon actually travel at c between these events?

If we assume that the photon does actually travel at c , then two things follow:

i. the photon cannot have a rest mass, and
ii. the overall perceived speed $¢$ is c minus the cumulative step-changes at the interactions.

If, however, light *never* travels at c then we do have the possibility of the photon having rest mass – provided that $¢$ is adequately lower than c to prevent the moving mass from being too great *or* allowing the mass to depend upon the frequency *or* allowing the wavelength to depend upon the speed. If we set $¢=c(1-\epsilon)$ then (ignoring terms in ϵ^2 and smaller, we have $\frac{¢^2}{c^2}\approx(1-2\epsilon)$. Thus $\sqrt{1-\frac{¢^2}{c^2}}=\sqrt{2\epsilon}$ Then by special relativity we have $m_¢=m_0\sqrt{2\epsilon}$.

The usual formulation for the energy of a photon is $E=\hbar\omega=h\nu=\frac{hc}{\lambda}$ the momentum is (classically) $p=\frac{h}{\lambda}$ if we take $m_0\neq0$ then (under our suggestion) we also have $p=m_0¢\sqrt{2\epsilon}$ which gives us $h=\lambda m_0\sqrt{2\epsilon}$ which implies that at least two of m_0,ϵ,λ may change. If we take m_0 to be fixed, then we have $\lambda\propto(2\epsilon)^{-2}$. This would mean that as $¢\rightarrow c$ or $\epsilon\rightarrow0$ we have $\lambda\rightarrow\infty$, so as the speed of the photon approaches c the wavelength increases.

This last relationship of $h=\lambda m_0\sqrt{2\epsilon}$ may give us some factors to be be considered for refraction. We already know that “red travels faster than blue” in the refraction of visible light, and that relationship caries on through the rest of the electromagnetic spectrum. Thus CMB will travel faster than cosmic rays, for example, and we already know that the wavelengths associated with CMB are long >>>INSERT FIGURES HERE<<< which would give the CMB photons a greater apparent mass.

We have to be cautious about the possible values, though. We cannot allow λ to actually become infinite, hence we cannot allow ϵ to actually become zero (i.e. $¢=c$). ??? Or can we allow this pole to exist, since it never actually happens – except at the BB, when $¢=c$? ??? Is there any way to reformulate the expression $\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$ so that there is no pole at $¢=c$? If we choose a maximum wavelength of λ_{max} then we would have $h=\lambda_{max}m_0\sqrt{2\epsilon_{min}}$ to determine the minimum value of ϵ associated with any m_0 . ??? $p_{min}=\frac{h}{\lambda_{max}}=m_0\sqrt{2\epsilon_{min}}$.

The range of momenta currently spoken about in the literature ranges from ??? to ???. The value of Planck’s Constant $h\approx6.62607\ E-34\ m^2\ kg\ s^{-1}$ and given wavelengths in the range $\lambda<\text{1E-12}\ m$ up to $\lambda>\text{1E+9}\ m$ then we have photon momenta in the range $\text{6E-43}\ m\ kg\ s^{-1}$ up to $\text{6E-22}\ m\ kg\ s^{-1}$. If we are taking $\lambda_{max}\approx\text{1E+9}\ m$ then we have $\text{6E-43}\approx m_0\sqrt{2\epsilon_{min}}$. Squaring both sized we have (roughly) $\text{1E-21}\approx2m_0\epsilon_{min}$. Since ϵ_{min} is (by hypothesis) very small we can get a rather large value for the rest mass: $m_{max}\approx\frac{\text{5E-20}}{\epsilon_{min}}$.

Because of Dark Matter, and the possibility – the vague possibility – that Dark Matter is actually the mass of light, we would like to be able to make the total light-mass to be more than four times [or whatever the current figure might be] the visible mass. I do not know the amount of matter converted into light over time. I do not know the amount of light absorbed into matter over time. Let there be a function $C(t)$ whose value is the nett proportion of visible matter being converted into light at time t . Let M_0 be the total mass of the observable universe at some time “soon” after the BB when light becomes a separate entity. Take this moment, in the following discussion, as $\tau=0$. Let $M(t)$ be the total mass of the (then) observable universe at time t and let $D(t)$ be the dark-matter to light-matter ratio. Let $M_v(t)$ be the amount of visible (non-dark) matter in the (then) observable universe at time t . Thus $M(t)=M_v(t)D(t)$ (by definition). If we assume that the *total* mass-energy of the universe does not change, so that we have

$M(t) \equiv M_0$ then we have $M_0 = M_v(t) D(t)$. This has to be integrated over the age of the universe from $\tau = 0$ so that we have $M_0 = \int_{t=0}^{\tau} M_v(t) D(t) dt$ at any time τ .

??? could mass be a doublet (m_r, m_i) rather like a complex number? I am *not* suggesting $m = m_r + i m_i$ as that would imply $m^2 = m_r^2 + 2 m_r m_i - m_i^2$

In the formula

$$m_v = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

we can rewrite this as

$m_v^2 = \gamma^2 m_0^2$

where

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

If we are considering $m = (m_r, m_i)$ then we have to have a formula for m^2

We can try:

1: $m^2 = (m_r^2, m_i^2)$ or

2: $m^2 = (m_r^2 + m_r m_i, m_i^2 + m_r m_i)$ or

3: $m^2 = (m_r^2 + m_i^2, k m_r m_i)$ for some constant k (value to be determined) or

4: $m^2 = (m_r^2 + j m_r m_i, k m_i^2)$ for constants j, k (values to be determined)

Note that formula 1 is a special case of formula 4, with constants $j = 0, k = 1$.

This “doublet” for mass takes us off I know not where – so I shall not explore that path.

Light-speed may change over time. This would make the energy (for relatively stationary objects): $E(t) = m * c(t)^2$. If, for example, $c(t) = k/t$ for some constant k then we would have $E(t) = \frac{mk^2}{t^2}$ with the energy tied up in any fixed mass decreasing, with the decreasing speed of light, over time. It would also mean that at $t = 0$ (the moment of the BB) then all matter would have infinite energy.