Statistical Analysis of the Velocity of Light and Related Data

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ABSTRACT

Norman and Setterfield (1987) prepared a report in which they examined the possibility that the experimental values of the speed of light, c, have undergone secular change in the last 300 years. The purpose of this paper will be to examine the data by statistical techniques not used by Norman, critique the results of Norman and respond to some of Setterfield's theoretical considerations.

INTRODUCTION

Hypothesis testing is a technique of choosing between two mutually exclusive statements, the null hypothesis and the alternative hypothesis, by means of a statistic. The nature of the statistic depends on the nature of these hypotheses. Hypothesis testing also requires an evaluation of the acceptable risk of error. If the statistic exceeds the 95% confidence level, the decision maker risks less than a 5% chance of error when rejecting the null hypothesis.[1]

The Norman and Setterfield[2] report contains nine tables of c measurements obtained by various methods, plus a tenth table of most 'reliable' values. I do not have the resources to check the completeness nor the accuracy of the data quoted. The following analysis must, therefore, be read with the caveat that it is valid for the data as stated but that major additions to or deletions from the data might invalidate the results. Also, I consider the Roemer datum is highly controversial and has been omitted from my analysis.

Norman's statistical technique involved the Student-t test and a linear regression method which produced a best fit straight line through the data in each table. The slope of the line was then tested against a null hypothesis that the slope was zero. In all cases but one the null hypothesis was rejected at the 95% confidence level.

Only post-1967 data, where atomic clocks were used, failed to reject the null hypothesis. In evaluating this work, the reader must keep in mind that since the trend of the data is not linear the results are indicative not rigorous. Nevertheless, the consistent rejection of constancy, as opposed to linear decline, as well as the rejection of the constancy of c at 299,792.5 by the t-tests, are sufficient to warrant further investigation.

The two hypotheses to be tested are constancy (the null hypothesis), versus a monotonic decreasing trend (the alternate hypothesis). The two statistics which I have used are the mean square successive difference (MSSD) and the run test. The former uses the ratio of the sum of the squares of the differences between successive data to the variance of the data. The latter compares the number of strings or runs of positive and negative residuals to the number expected from a random binomial distribution.[3,4] The advantage of using these two statistics is that they test the hypothesis directly and are therefore not tied to any single model or theory.

Professor Hasofer, of the University of New South Wales has also done a linear regression test in which the data are weighted by the inverse square of their error bars.[5]

His analysis rejected a linear fit to the data but did confirm a significant rejection of constancy in both quadratic and cubic polynomial models. Again, if the trend is neither quadratic nor cubic, the result might be spurious. What is impressive, however, is that the earlier data have the biggest error bars and thus carry very little weighting in the fit. The test is, therefore, a very harsh test indeed of the Setterfield hypothesis. I have yet to find such a technique in a statistical textbook and must conclude that it is either rarely needed or is highly unpopular. In my opinion, a simple inverse of the error bar weighting would be less likely to overwhelm the information contained in early data. Professor Hasofer's results do provide stimulus for more direct testing of the data.

OUTLIERS

Outliers are data which appear inconsistent with the remaining data. I have removed outliers from various tables of data since the MSSD is very sensitive to even single extreme values. They have been determined primarily by graphing the data with the control that they must lie outside the interval bounded by the mean plus/minus three standard deviations of the non-outlier data. This resulted in the removal of values 1 and 2 of the Roemer table; values 1 and 2 of the Toothed Wheel table; value 1 of the Rotating mirror table and value 1 from the ESU/EMU Ratio table. Four of the six values were higher than the accepted value of c, 299,792.5 km/s, so that their removal would harm rather than help the Setterfield hypothesis.

PRELIMINARY REMARKS

I have also included the Student-t test for these tables. This statistic tests the mean of the data against the expected (read conventionally accepted) value. The larger the number of data used to obtain the mean, the closer it should come to the expected value. The null hypothesis is, c is constant at 299,792.5 km/s. Rejection implies either a different constant value or a non-constancy. This is a very frequently used and robust test and its results are an important quality control on the interpretation of the other tests.

The MSSD and Run test require time-ordered data. In cases where several values occur in a single year, I have averaged the data because the results could be different (and therefore biased) by choosing one order over another. In addition, values in the same year are likely to be more closely grouped and thus bias the MSSD and Run statistics towards rejection of constancy.

Lastly, the reader should be aware that the MSSD is a parametric test, that is, involves the use of the actual values used. The Run test is a non-parametric test as it involves the use of the position of the data rather than the value itself. The Run test is therefore not affected by error bar considerations. There is a price to be paid for such a quality and that is it requires much bigger data sets to be an effective statistic. I have limited the Run test to those tables which have a minimum of 15 values.

DISCUSSION OF RESULTS

A summary of the statistical analysis of c data is shown in Table 1 (see also Figures 1, 2 and 3). There are 3 of 7 t-tests which exceed the 95% confidence level on a single-tailed test. One of these tests is on post-1960 data which Setterfield claims is measured by atomic clocks and therefore expected to show constancy. Thus 4 of the 7 tests are supportive of his position. However, this increases to 6 of 7 at the 94% confidence level. Only the Toothed Wheel experiments are unsupportive. The reader will note that I have omitted the Kerr Cell results, as they support neither constancy at today's values nor Setterfield, and are known to contain systematic errors. I have not analysed the Standing Wire results since they have large error bars and there are only six data points. Any results in either direction could easily be dismissed on these grounds.

The MSSD and Run tests provide support for Setterfield in 7 of 8 cases at the 98% confidence level, 8 of 9 if the 1960–83 results are included. Overall, at the 95% confidence level, 12 of 16 tests are supportive of Setterfield, 10 of 14 if 1960–83 results are excluded. This increases to 12 of 14 at the 95% confidence level. The one exception is the Toothed Wheel results.

Method	Confidence Level of Test			Agreement to Theory		
	T-Test	MSSD	Runs	T-Test	MSSD	Runs
Roemer	97	99.9		Y	Y	–
Bradley	94	99	98	N	Y	Y
Toothed Wheel	80	40		N	N	–
Rotating Mirror	94	98		N	Y	–
1945–60	99	98		Y	Y	–
1960–83	85	25		Y	Y	
ESU/EMU Ratio	99	99.9	95	Y	Y	Y
POSITIVE RESULTS:	T-Test 4 of 7 MSSD 6 of 7			Runs 2 of 2 Total 12 of 16		

Table 1. *Table of statistical test results for c-data.*

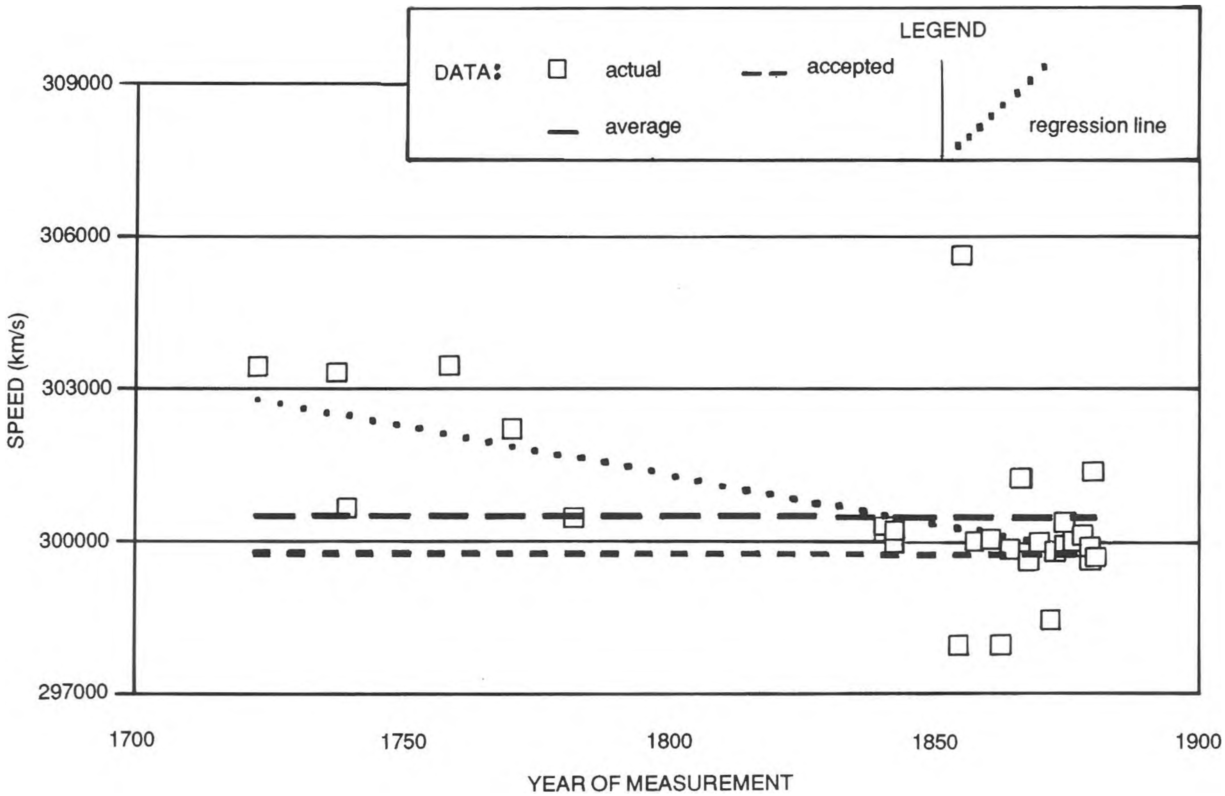

Figure 1. *Velocity of light measurement 1723–1880), excluding those values obtained by the emu/esu and standing wire methods (because their error bars are very large and they contain a substantial number of outliers).*

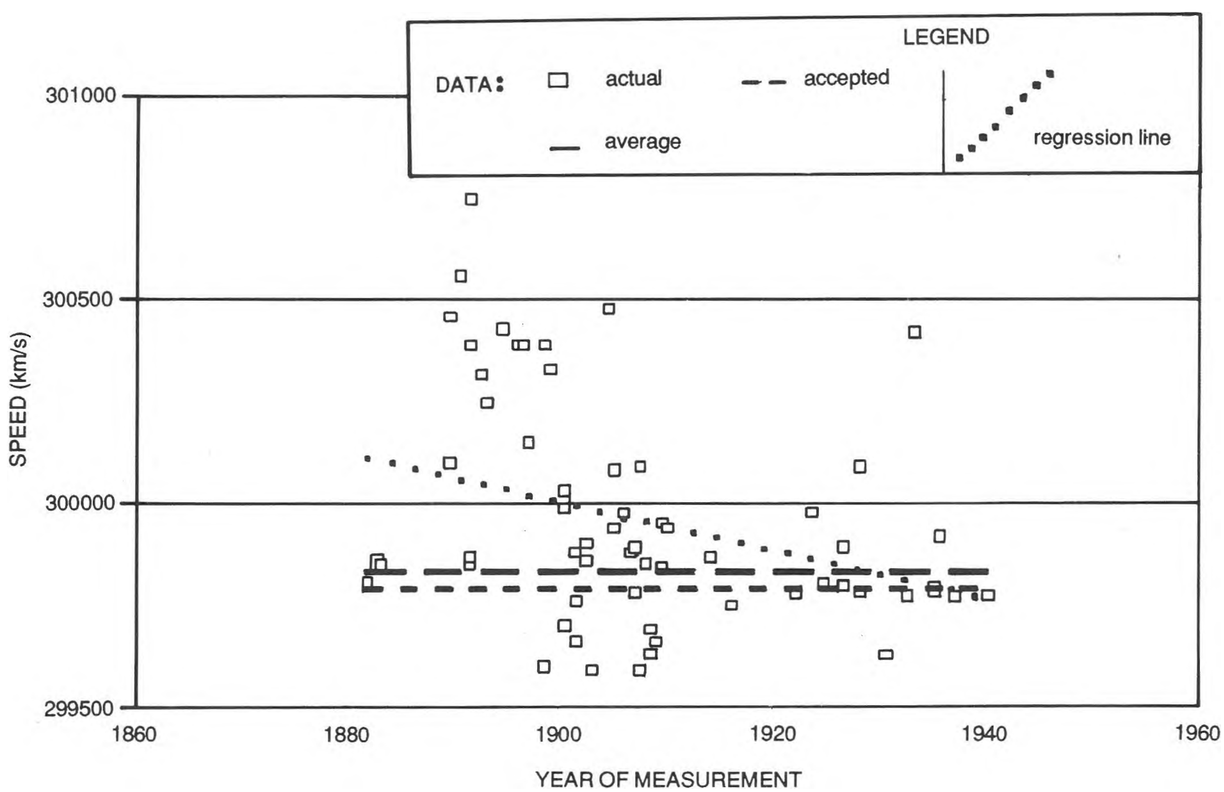

Figure 2. *Velocity of light measurements (1881–1940), excluding those values obtained by the emu/esu and standing wire methods (because their error bars are very large and they contain a substantial number of outliers).*

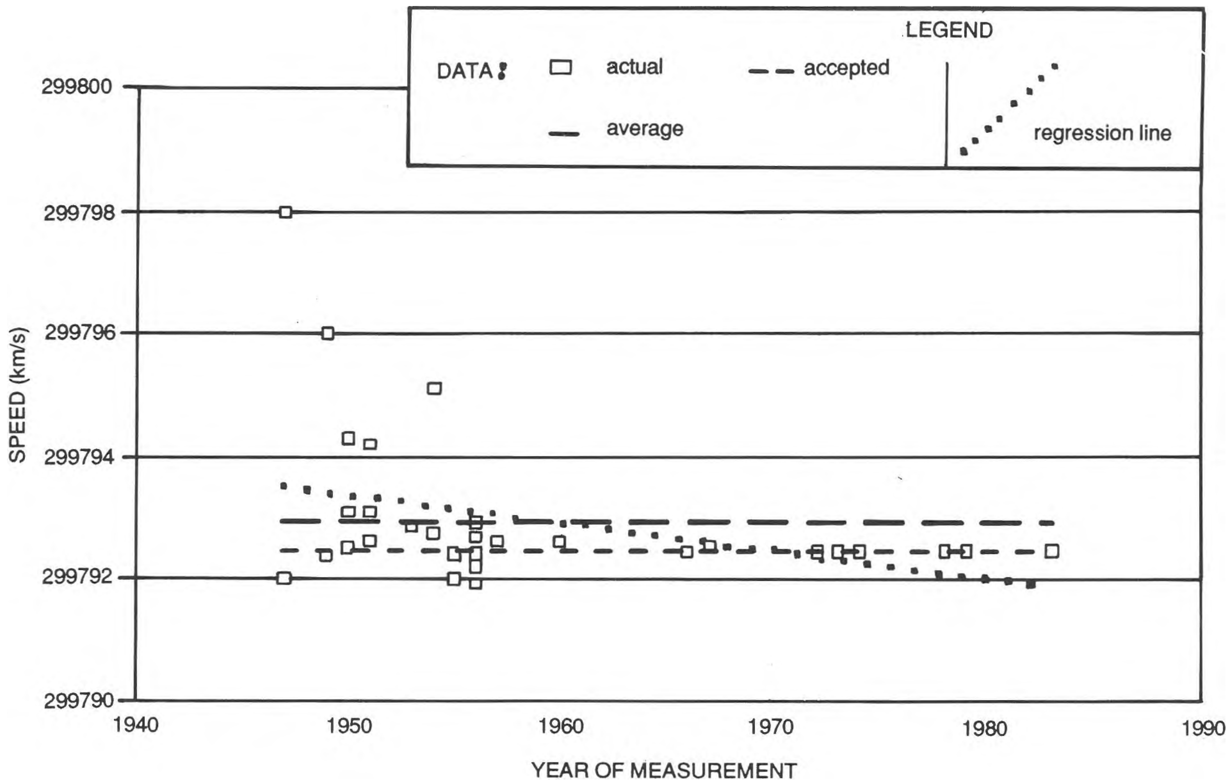

Figure 3. *Velocity of light measurements (1947–1983), excluding those values obtained by the emu/esu and standing wire methods (because their error bars are very large and they contain a substantial number of outliers).*

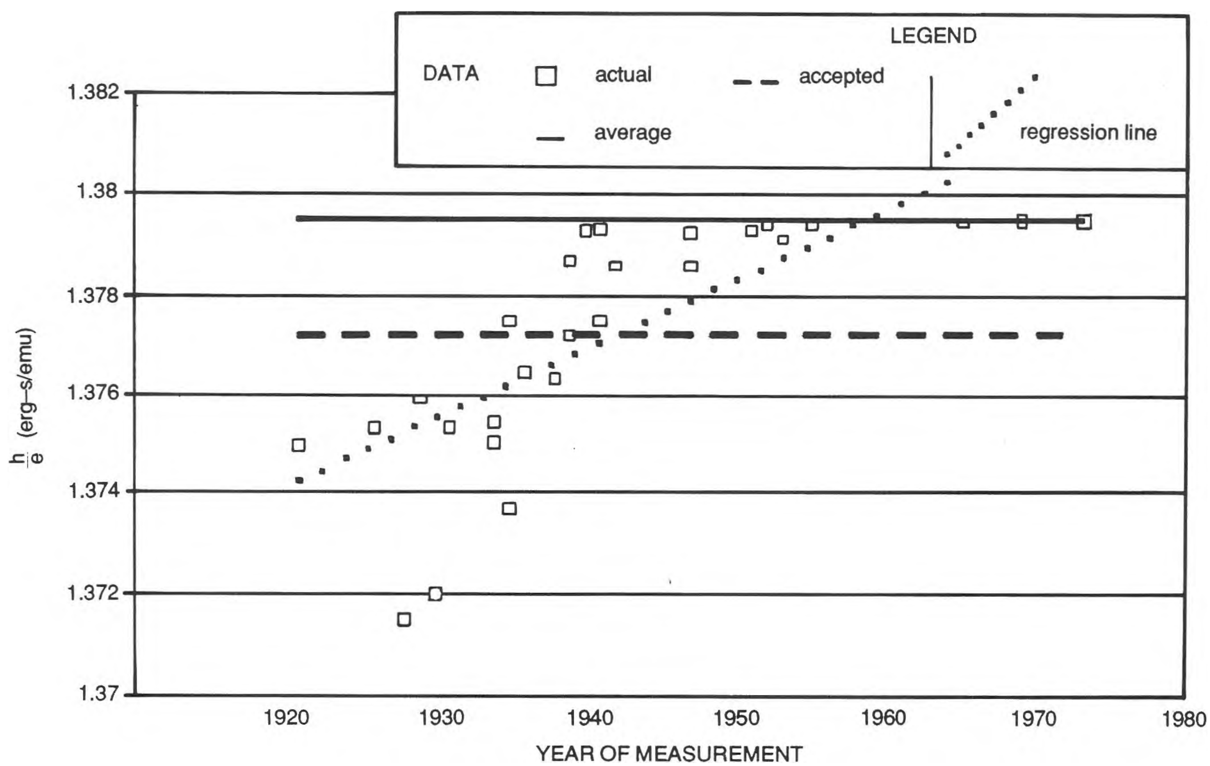

Figure 4. *Experimental values of $^{h}/e$ (1921–1973).*

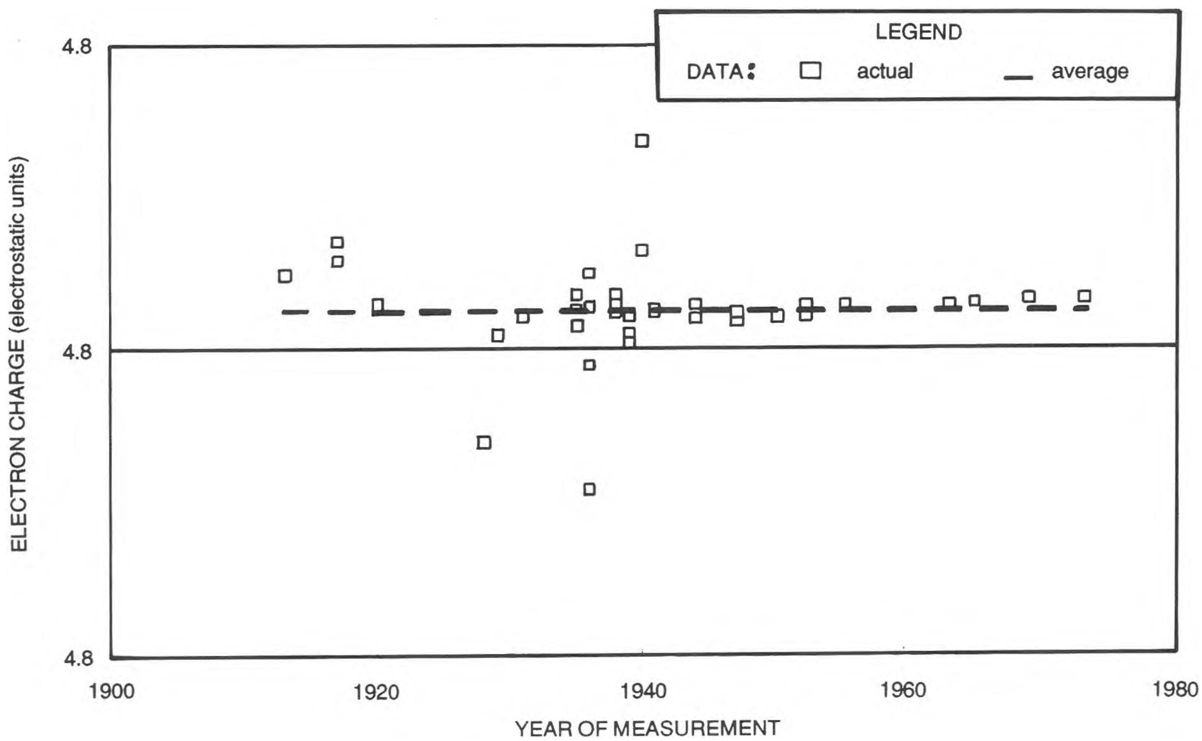

Figure 5. *Values of electron charge (1913–1973).*

A similar summary for c-dependent values is shown in Table 2 (see also Figure 4). The t-test results show support for Setterfield in 3 of 5 cases at the 95% confidence level and 5 of 5 at 91%. The MSSD and Run tests are supportive in all 9 cases, with 6 of 9 favouring Setterfield at the 99% confidence level.

The results for should be taken as tentative, as a systematic error is known in the 1930's which was later corrected to give higher values. The statistical confidence levels are likely to be overstated.

Value	Confidence Level of Test			Agreement to Theory		
	T-Test	MSSD	Runs	T-Test	MSSD	Runs
$\frac{e}{mc}$	99	99	99.9	Y	Y	Y
$\frac{h}{e}$	99.9	99.9	100.00	Y	Y	Y
Gyromagnetic Ratio	99.9	97.5	95	Y	Y	Y
Hall Resistance	91	98	–	N	Y	–
Mass of Electron	92	99.9	99	N	Y	Y
Positive Results:	T-Test MSSD	3 of 5 5 of 5		Runs Total	4 of 4 12 of 14	

Table 2. *Table of statistical test results for c-dependent data.*

Value	Confidence Level of Test			Agreement to Theory		
	T-Test	MSSD	Runs	T-Test	MSSD	Runs
Charge of Electron	55	60	60	Y	Y	Y
Boltzman Constant	94	56	82	N	Y	Y
Gas Constant R	51	89	–	Y	Y	–
Rydberg Constant	61	65	75	Y	Y	Y
Bohr Magneton	97	60	–	N	Y	–
Gravitational Constant	84	2	51	Y	Y	Y
Positive Results:	T-Test	5 of 6		Runs	4 of 4	
	MSSD	6 of 6		Total	15 of 16	

Table 3. *Table of statistical test results for c-independent values.*

Finally, one must ask if the physicists are really capable of measuring their constants in a fashion which would show them as constants. In other words, is this apparent trend real, or just a product of the way physicists do science? To answer this, I conducted these tests on those values which are constants in both conventional and Setterfield theory. Table 3 (see also Figure 5) shows these results. In the t-tests, 5 of 6 results did not reject constancy at the 95% confidence level. The Bohr magneton results were the only exception. These Bohr magneton data showed a tendency to group around two separate values. This may indicate a systematic error in the data.

The MSSD and Run tests failed to reject constancy in all 10 tests at the 95% confidence level. Only the gas constant R came even close at 89%. The extremely small MSSD value for G indicates a tendency for the data to oscillate, like a sinusoidal function. This I believe is due to MSSD's sensitivity to outliers and the relatively low accuracy of the measurements. Although only 1 outlier (Jolly, 1973) was eliminated, if others such as Cavendish (1798) and Wilsing (1889) are classed as outliers, there occurs a wide swing in the MSSD statistic up to 99%. No significant change occurs in the Run test. If this MSSD number is accepted it would indicate an increase in G contrary to both conventional and Setterfield's first explanation of gravity where G c^4.

Overall, 15 of 16 tests support constancy over trend. This would appear to affirm physicists ability to measure a constant as a constant.

FURTHER ANALYSIS

It might be claimed that the reason for the apparent decrease in c is related to decrease in the size of the error bars. Suppose then we eliminate from pre-1960 data those values which are known to be affected by systematic errors, namely Kerr Cell results and the 1932 Pease/Pearson result. The analysis of the remaining data by error bar group is summarized in Table 4. For error bars less than 100km/s down to 0.75km/s the t-test results in confidence levels of 87% to 99.5% on single-tail tests, with 5 of 6 results greater than 95% confidence levels.

The final two data sets, which contained data from 1953–60 involving 5 and 2 data points respectively with error bars 0.25km/s and 0.1km/s, yielded confidence levels in the 80–90% range. In the less than 100 km/s group no less than 15 data had error bar ranges not containing the currently accepted value of c. Fourteen (14) of these were high. The other data sets also showed that consistently 40% of the error bar ranges failed to contain today's value of c. This is not the expected distribution of a constant. It may be argued that the error bars rather than the data are at fault. However, one cannot fail to notice that only 1 error bar range was low. The 14 to 1 ratio in the less than 100 km/s group is an indication of the heavy skewing of data. If the Setterfield hypothesis is incorrect, this skew requires another explanation.

SOME COMMENTS ON THE SETTERFIELD THEORY

The 1987 monograph of Norman and Setterfield prematurely tried to answer too many theoretical considerations. Some of the conclusions in regard to the decrease in c are questionable or simply not true.

Redshift

The most obvious problem is the redshift. The

Error Bar (km/s)	No. of Data	Dates	Average Velocity c	Avg Error Bar	Average Minimum c	Error* Bars High	%	Error* Bars Low	t Stat	Conf. Level %
<100	34	1876–1960	299,813.1	15.7	299,797.4	14	41	1	3.028	99.
<60	31	1876–1960	299,806.0	9.38	299,796.6	12	39	1	2.260	98
<15	25	1876 1960	299,798.5	1.99	299,796.1	9	36	1	1.178	87
<2	18	1949–1960	299,793.0	0.85	299,792.1	7	39	1	2.282	98
<1.5	14	1950–1960	299,792.86	0.52	299,792.3	6	43	1	2.377	98
<0.75	10	1950–1960	299,792.65	0.25	299,792.4	4	40	1	2.024	97
<0.25	5	1953–1960	299,792.51	0.11	299,792.4	2	40	1	1.010	82
<0.10	2	1958–1960	299,792.55	0.08	299,792.47	1	50	0	1.840	89

* Current value of c (299792.458 km/s) not contained in Error Bar

Table 4. *Analysis of the velocity of light prior to 1966 by size of error bar.*

redshift is caused by a wavelength change between the source and the observer. From the theory

$$c_t = \lambda \nu_t \qquad (1)$$

and $\lambda = c_t / \nu_t$ (2)

where λ = wavelength,

and ν_t = frequency

Unless c_t and ν_t are different functions a redshift does not take place at the source. Next, since each wavefront travels at the same velocity, c_t , at each moment, the distance between wavefronts remains constant. So neither at the source nor during transit is there a wavelength change. These two arguments are validated by observations within our galaxy. A star at our galactic perimeter 30,000 light years away would, under the cosecant squared function, have a redshift of Z = 56. No such value exists in our galaxy. Indeed, in the entire universe the maximum Z value observed is still under 5!!

Energy Transfer

What about the energy transfer? Would not the higher energy transmission in the past lead to higher 'lethal' temperatures on Earth? The temperature rise of an object depends on the energy transmitted multiplied by the absorption coefficient.[6] The absorption coefficient varies inversely as the frequency. With a higher frequency there is a lower conversion rate to heat. Thus temperature change from solar energy is unaffected by change in c. The corollary is that conventional thermal heat would be almost ineffectual in early Earth history.

Slow Motion Effects

Should we not see very distant stars burning up

$$N_t = \frac{c_t}{c_o}$$

faster than their counterparts nearby? Consider for a moment the galaxy Andromeda 2 million light years away. In Adam's day, say 6,000 years ago, it would take but a few days for light to travel from Andromeda to Earth. Today, light would take 2 million years to reach Earth. Thus events 6,000 years apart in Andromeda are seen two million years apart on the Earth. This means we are seeing events in Andromeda in slow motion by a factor of $^1/N_t$. So when we observe atomic processes in Andromeda which are reacting at N of today's rate, we see them at

$$N_t \times \frac{1}{N_t} = 1,$$

that is, at the normal rate of nearby stars!

The corollary of this is that all gravitational motions which are not affected by decrease in c are seen in slow motion on the Earth. Thus, if seen at real or normal rate, Andromeda might measurably rotate! Furthermore, as time progresses, less and less distortion will occur, so that in 2 million years we will see Andromeda rotate at its actual rate. Thus we should observe, if we had the instrumental precision, an increase in the rotational rate of Andromeda.

This feature of Setterfield's theory provides a theoretical test. For example, can we find binary stars whose period has been accurately measured in the past and which can be remeasured for change? The binary stars must have sufficient separation that they are not exchanging material. They must be distant enough that the rate of change is significant to measure, but close enough that the measurement is not too dilated by the slow motion effect. Equation (3) represents the theoretical prediction of this experiment.

$$\frac{dP}{dt} = \frac{dN_t}{dt} \times \frac{1}{N_t} \quad (3)$$

where P = period of binary star

The slow motion effect also eliminates decreasing c as a possible explanation for superluminal velocities. Although it is possible that stars might travel at $20c_o$ when c was at $100c_o$, the slow motion effect causes us to see these stars travelling at $20c_o/100$ or $0.2c_o$ today. Thus any observed superluminal velocity requires a different explanation to avoid violating relativity.

OSBORN'S COMMENTS

Osborn makes some comments on the Setterfield theory.[7] He comments that some atomic values in the post-1966 era such as h/e , 2e/h and h^2/e show trend with time. This is a valid criticism, one which Setterfield has yet to address. Are these values measured with respect to a dynamic or atomic frame of reference? This needs some clear and documented explanation, for without it the strongest evidence for c decrease is undermined.

Osborn's comments on Dicke's Q-value and mass spectrometer values for mass may also have validity. It is not apparent either from Setterfield's or Osborn's claims what experimental accuracy or precision is involved. The precision required needs to be in the 8 digit range in the 1960–67 time frame in order for either claim to have any validity. Less precision would hide any real difference in atomic and dynamic mass in experimental errors.

Osborn, I think, is wrong in one major assumption. The chemical reaction rates are determined by reaction energies not mass. That is, a chemical reaction occurs between molecules if they have the required kinetic energy to overcome any energy barrier inhibiting the reaction. Since the current version of Setterfield's theory conserves energy this would imply stable reaction rates. Thus the biological consequences discussed in his paper must be modified and I believe would nullify his criticisms.

Osborn also makes criticisms of the theory based on arguments concerning mass and Setterfield's contention that gravitational and inertial mass are constant while atomic rest mass varies inversely with c^2. He gives an atomic explosion as an example where both inertial and atomic forces would operate simultaneously and questions how conservation laws can hold. As I understand Setterfield's positions, the two forces accelerate matter as follows:

$$a_a = \frac{F_a}{m_a}$$

so $F_a = m_a a_a$ (4)

where m_a is the rest mass measured in dynamic terms, and subscript a refers to the atomic frame of reference

$$a_d = \frac{F_d}{m_d}$$

so $F_d = m_d a_d$ (5)

where subscript d refers to the dynamic frame of reference

$$a_t = a_a + a_d \quad (6)$$

where a_t is the total acceleration

$$M = \frac{(F_a + F_d)}{a_t} \quad (7)$$

where M is the effective mass

There does not seem to me to be a violation of the laws of conservation in these equations. I may have misunderstood Osborn's argument and perhaps he can be more explicit about the violation he perceives.

EXPLANATORY VALUE OF SETTERFIELD'S THEORY

One of the purposes of a theory is to explain what otherwise would be unexplained. Can Setterfield's theory explain anything that cannot be explained by conventional theory?

Firstly, it explains how an Earth observer can see stars billions of light-years away within a young universe framework. However, since conventional theory does not postulate such youth, it is not really a scientific problem which is being explained but a biblical apologetic problem. But there is a remarkably poignant scientific mystery relevant to this topic. Why is it that all the spiral galaxies which can be seen in our telescopes are spirals with a single rotation?

The arms of the galaxies spiral around the centre only once regardless of their distance from us. If the speed of light were constant, then galaxies 200 million light years away would appear to us to be 200 million years younger. Since 200 million years is a typical rotation period in conventional thinking, these galaxies should look remarkably different from a galaxy like Andromeda which is only 2 million light years away. They are not. However, if Setterfield's theory is true, then these distant galaxies should appear to be only 6,000 to 1 million years younger. Therefore, similarly evolving galaxies should have almost identical shape regardless of distance. In addition, conventional science has yet to produce an even remotely rational explanation of the origin of galaxies, never mind spiral galaxies.

Even more remarkable is the age distribution of supernova remnants. Supernova remnants (SNR) are leftovers from gigantic explosions of large stars with runaway nuclear cores, which are bright enough for some to be seen even in daylight. Their expansion rate and radiation characteristics are well known and have been plotted by astronomers. When used to date the SNRs a remarkable surprise is discovered. All these SNRs found in the Milky Way galaxy are less than 7,000 years old![8] Furthermore, since there are approximately 5–10 supernovae per century per galaxy, the Milky Way's 240 identified SNRs are a mere 2,400–4,800 years production. These 240 are only a portion of the Milky Way's SNRs as some occupy regions of the Milky Way blocked from the view of our telescopes. Setterfield's theory would explain the dichotomy of galaxies whose atomic age is billions of years old while its SNR's ages are all less than 7,000 years.

Lastly, Robert Gentry reports[9] that zircon crystals containing radioactive uranium have retained substantial amounts of radiogenic lead and helium. While the isotope ratios indicate an atomic age of 1.5 billion years, diffusion rates of the by-products indicate an age of about 10,000 years. Under conventional assumptions these observations are irreconcilable, but under Setterfield the difference is explained by using atomic and dynamic ages.

CONCLUSIONS

Norman has reported a significant number of statistical tests which are supportive of Setterfield's claims. Professor Hasofer's results are even more impressive. However, the quadratic and tertiary functions are good as statistical models only and are not very good theoretical ones. Without an appropriate theoretical model on which a regression analysis can be done, there are still some grounds for doubting. The advantage of using MSSD and Run tests is that the hypothesis can be tested directly without knowing a theoretical basis, and therefore give impetus to the development of a theoretical model with some assurance that one exists.

But just how sure can we be that these results are firm? Suppose we examine the physical constants which have been tested. Including c, there are 12; six of these show trend and six do not. Suppose we are asked to choose 6 of these 'constants' at random. What would be the probability of choosing the 6 which are variable? The probability is 1 in 924. If we randomly choose increase or decrease for each of our six choices, what would be the probability of choosing the correct direction of change for each variable given that c is decreasing? The probability is 1 in 32. Since these choices are independent the total probability is 1 in 29,568. Therefore, Setterfield's theory has predicted a result which has 1 chance in 30,000 and which the MSSD and Run tests have supported at the 95% confidence level. This, I believe, should alleviate our fears that the ending of the decrease in c during the post-1960 era is a sign that the data is somehow spurious. For indeed, if the opponents of Setterfield have one card in their favour, it is that the decrease cannot be measured today. The failure to perform the necessary tests in the 1930's when the trend was still significant is a serious scientific disappointment.

Lastly, it is still incumbent on Norman and Setterfield to demonstrate that experiments in c-dependent values are done within the dynamic framework, as opposed to an atomic framework. The critics of Setterfield's theory have focused heavily on the c-data. The substantiation of the frame of reference of the other atomic values will provide a challenge to explain all 5 variable constants and not just one.

The critics of Norman's statistics have provided only one test with results compatible with constancy — a weighted linear regression line using a linear model. Since the models proposed for decreasing c are not linear, and since Professor Hasofer has provided other models where a weighted linear regression is significant, these tests and the conclusions drawn cannot be accepted as substantial support to deny the Setterfield hypothesis.

In evaluating the results of the above tests overall, I believe one should examine what secondary assumptions are required to defend either hypothesis. For the c-constant hypothesis, it must explain why 22 of 30 tests on six c and c-dependent values are above the 95% confidence level when the expected value should be 2 or 3. This is no small feat. For the c-decrease hypothesis, it must explain why the 1960–83 results show constancy as well as the Toothed Wheel results. No other Run or MSSD test drops below 95% confidence levels. The four t-tests below the 95% confidence level are above the 90% level. In addition the Kerr Cell results are incompatible with both hypotheses.

It would seem reasonable that the atomic clocks can explain the post-1960 data as it fits with current physical theory. There has been no good explanation for Toothed Wheel results as yet. This leaves the c-decrease hypothesis to explain 2 results out of 30 which are below the 90% confidence level. This number of erroneous tests is well within reason at that confidence level.

It would seem that accepting the secondary hypothesis that Kerr Cell results have systematic errors, and the post-1960 data are the result of atomic clocks, puts the decreasing c-hypothesis within the expected range of false results. No such statement can be made for the hypothesis of c constant at today's value. I must therefore conclude that the above tests lend substantial statistical support to the decreasing c hypothesis, provided that the data is representative and the c-dependent values have been measured dynamically.

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