

# ARE THE FUNDAMENTAL "CONSTANTS" OF PHYSICS REALLY VARIABLES?

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## KEYWORDS

Constants, Aberration, Light, Halos, Nuclear

## ABSTRACT

The equations of physics contain "constants" such as the speed of light, the value of the charge of the electron or proton, the gravitational coupling constant, the weak coupling constant, the strong coupling constant, Planck's constant, and elementary particle masses. Non-trivial variations in these quantities would not just involve a change of scale caused by a redefinition of units, but would involve the variation with time of certain dimensionless ratios of these so-called "constants." I will examine the theoretical basis for possible variations in these dimensionless ratios and relate experimental and observational results to place limits on these variations. In particular, I will examine the tunnelling theory of alpha decay and relate it to the possible variation of weak and strong interaction strengths, showing that decay rates may vary without significantly changing the radii of radiohalos. Also, I will examine the data of James Bradley taken in 1727-1747 on the aberration of light from the star gamma Draconis and show that there are extra solar and lunar influences on the nutation of the earth's axis which Bradley unfortunately left out. This suggests that the speed of light in 1727 was the same as it is today. The results will also be related to the author's study of the Roemer method for determining the speed of light [7].

## INTRODUCTION

The equations of physics contain fundamental "constants." Present day physics cannot derive the values of these quantities starting from first principles, but must rely on experimental measurements. Due to the inductive nature of the reasoning which must be used in science, it is difficult to reach firm conclusions about which "constants" are truly constant. They may be constant in present day experiments but may undergo episodic variations due to the passage of a "wormhole" near to the solar system as described by Hawking [14], a phase transition of the universe as described by Crone and Sher [8], Sher [20], or Suzuki [22], or other catastrophic events which could be described as a direct intervention of God.

In general, it is necessary to formulate theories in order to have a consistent framework in which to interpret the results of experiments. For example, Canuto, Adams, Hsieh, and Tsiang [6] showed that variation of Newton's gravitational constant,  $G$ , could lead to the radius of the earth's orbit either increasing, decreasing, or remaining the same, depending on which theory was operative. This is due to the possibility of extra terms contributing to the relevant equations of motion which would be absent if  $G$  were a constant. The reasons for including these extra terms can often be quite compelling.

Bekenstein [1,2] has pointed out, on the basis of some comments of R.H. Dicke [9,10], that only the variation of dimensionless combinations of "constants" is physically meaningful. The form of physical laws should not change just because we change unit systems. It is possible to propose definitions of our units which cause some constants to vary with time. For instance, if the meter were defined in terms of the distance of the earth to the sun, then it would change with time due to the elliptical nature of the earth's orbit. But that would be a trivial variation which we do not want to be concerned with here. Hence, one should always check to see that the time variation that is examined may be reduced to a variation of a dimensionless ratio such as the fine structure constant,  $e^2/hc$ , the ratio of the mass of the electron to the mass of the proton, etc. As Bekenstein pointed out, modern scientific journals are full of errors in interpretation of the data which could have been avoided if these dimensionless ratios were used.

In the first part of this work, I will examine the effects of a possible variation of the nuclear force on the rates of radioactive decay. I will allow variation of the ratio of the depth of the nuclear potential felt by an alpha particle to the energy that the alpha particle has at infinity. As relevant experimental data we have the radii of the radioactive halos produced by minute inclusions in precambrian rocks [4,13]. I will show that standard nuclear theory allows the radii of the halos to remain the same while the radius of the nucleus and the decay constant change. Since the size of the nucleus, compared to that of the atom, is like a baseball at the center of a major league ball park, then for most practical purposes it could change size without significantly affecting atomic structure. This is because the nuclear force is short ranged and the Coulomb force is not changed by this hypothesized variation. I then also present results of a computer program showing how much the decay "constant" changes for a given change in nuclear potential. The program also shows that the expectation value of the square of the radius of the alpha particle decreases as the depth of the nuclear potential increases, in the same way that the nuclear size decreases. This makes this whole scenario plausible, but it does not prove that any changes ever occurred.

Secondly, I present some calculations to examine Bradley's data taken in the 1700's on the aberration of starlight. Bradley [3] was a pioneer in that he had to analyze his data in the era before anyone else. He showed that the stars such as gamma Draconis varied in position as the direction of the Earth's velocity changed through the year. The amount depended on the ratio of the earth's velocity to the speed of light. The value of the speed of light he obtained compared favorably with that inferred from Roemer's measurements of some forty years earlier [7]. But Bradley left out some terms for the nutation of the earth's axis. He included the largest terms due to the Moon, but left out the second order terms due to the Moon and also the terms due to the Sun [18]. Hence, the value of the speed of light inferred from his data needs to be freshly analyzed. I have written some computer programs to do that, and will present the preliminary results.

### ALPHA DECAY AND THE STRENGTH OF THE NUCLEAR FORCE

One of the best treatments of the tunnelling theory of alpha decay is by Preston [19]. In fact, his theory has become the only accurate method for treating the emission of the alpha particle with non-zero angular momentum. Experimental nuclear physics uses his approach for the calculation of "hindrance factors," which measure the probability of alpha decay to an excited state rather than the ground state of the daughter nucleus. Preston's approach starts by treating the energy of the alpha particle as a complex number. The imaginary part of the energy allows the wavefunction to represent the decay of the nucleus by emission of the alpha particle. Otherwise, a real value for the energy represents a stationary state which does not decay by alpha emission. Preston derived two simultaneous equations relating four variables. The four variables are the alpha particle energy at infinite distance from the nucleus, the radius of the nucleus, the depth of the potential well for the alpha particle, and the decay constant. Thus, on the basis of the theory, knowledge of any two of the four variables is enough to algebraically determine the other two. The equations are intractable (the solutions cannot be written out explicitly), and require iteration using a method such as Newton-Raphson iteration to solve them. But a BASIC program on a microcomputer can easily perform this task; the program requires less than forty lines of code.

Unfortunately, Preston's model is not realistic since acceptable answers are obtained only by assuming that the depth parameter,  $V_0$ , of the nuclear potential well is a positive number. This is physically unrealistic since the nuclear potential is not repulsive. A remedy for this situation was proposed by Pierronne and Marquez [17]. In this approach the potential is divided into an interior and an exterior region, with the interior being a square well of constant depth  $V_0$  and the external region being a Coulomb potential (See Figures 1,2). The parameter  $V_0$  represents the strength of the nuclear force felt by the alpha particle. The solutions for the radial wavefunctions are standard Coulomb wavefunctions on the exterior and spherical Bessel functions in the interior. Matching the real and imaginary parts of the logarithmic derivatives at the boundary gives the equations which we need for a more realistic version of Preston's method. If we also adopt the Taylor series approximations that Pierronne and Marquez made, we then obtain an algorithmic procedure which is almost as simple as Preston's approach. The main difference is that we need to be able to calculate the Coulomb wavefunctions. Fortunately, Froberg [12] did most of the work for us, publishing the expansions of the Coulomb wave functions and their derivatives. The method which he called the Riccati method converges for the region of parameter space with which we are concerned here. Hence, I wrote a Fortran program incorporating subroutines to calculate the Coulomb wavefunctions and the spherical Bessel functions needed. The algorithm accepts as input from the keyboard the depth,  $V_0$ , of the alpha particle potential well, the decay energy,  $E_\alpha$ , of the nucleus (which is the combined kinetic energies of the alpha particle and the recoil nucleus), the atomic mass number,  $A$ , of the daughter nucleus, and the proton number,  $Z$ , of the daughter nucleus. Thus, Preston would have input the values of about -50 MeV, 4.31 MeV, 234, and 90 for the decay of Uranium-238 by emission of an alpha particle ( $Z = 2$ ,  $A = 4$ ). Using an initial guess for the radius of the nucleus, taken as the radius for which the square well stops and the Coulomb potential begins, the algorithm iterates until the real part of the logarithmic derivative, which is Pierronne and Marquez's  $X$  function, matches for the interior and exterior solutions. It then uses the Pierronne and Marquez equations to calculate the "width," which is the decay constant times Planck's constant over two pi. Output includes the decay constant and the radius of the nucleus. If we set the imaginary part of the energy equal to zero, the wavefunction of the alpha particle can be used to calculate the expectation value of the radial coordinate of the alpha particle. The program also reports this value.

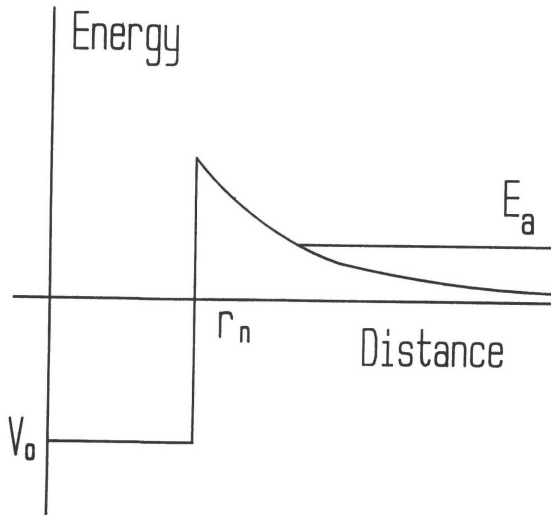


Figure 1. A graph of the potential energy of the alpha particle as a function of distance. For radial distance less than  $r_n$  the alpha particle is inside the nucleus and the potential energy is represented by a constant negative value  $V_0$ . Since the nuclear force is short ranged, the potential energy may be represented by the Coulomb repulsion outside the nucleus. This is the curve starting at  $r_n$  and dropping off to zero for larger radii. The peak at  $r_n$  is called the Coulomb barrier. Since the alpha particle reaches infinity with a kinetic energy,  $E_a$ , less than the height of the Coulomb barrier, the tunneling theory of quantum mechanics is applied.

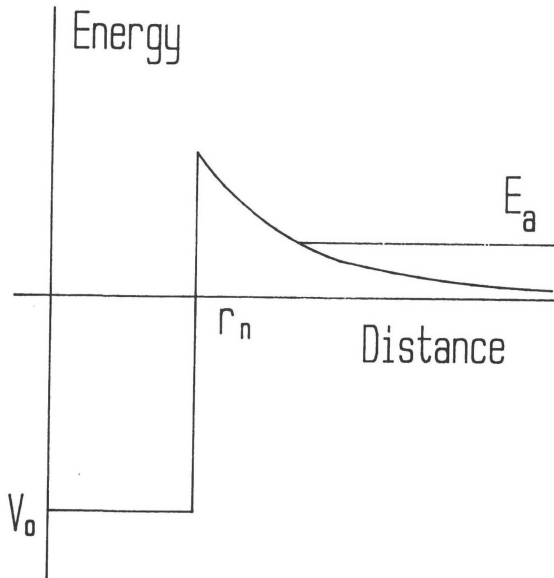


Figure 2. If the depth of the potential well is increased, the energy of the alpha particle may be held the same with only a slight change in nuclear radius.

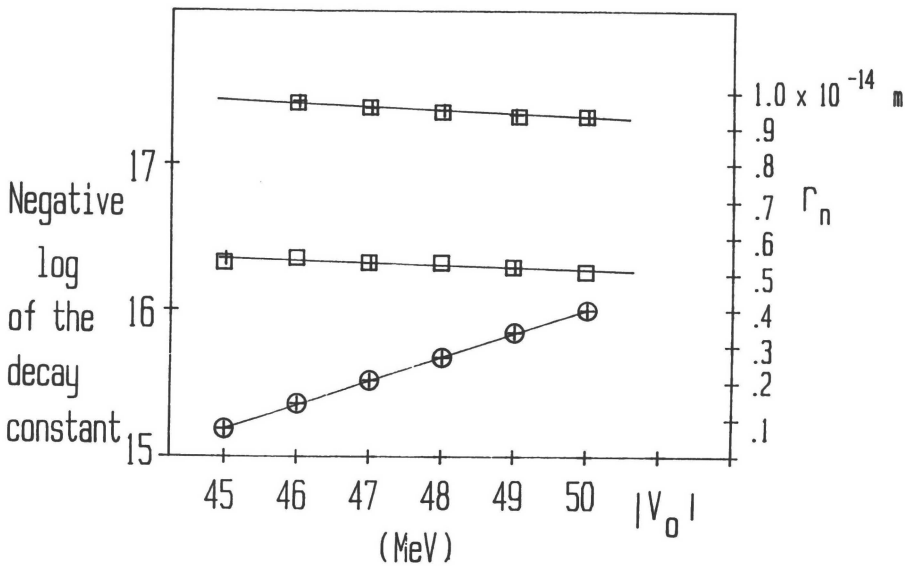


Figure 3. The results of the computer calculations as a function of the depth,  $V_0$ , of the potential well. The lines represent lines of constant decay energy. The line drawn with circles for points is the negative of the logarithm of the decay constant versus  $V_0$ . It thus shows that a change of  $V_0$  from 45 to 50 MeV changes the decay constant, and hence also the half life, by about one power decay constant. The lines drawn with squares for points represent the radius of the nucleus. The other line is the square root of the expectation value of the square of the radius, obtained by putting the imaginary part of the energy equal to zero. Roughly speaking, it is the most probable radius of the alpha particle before emission. Both radius estimates decrease slowly as the potential well gets deeper.

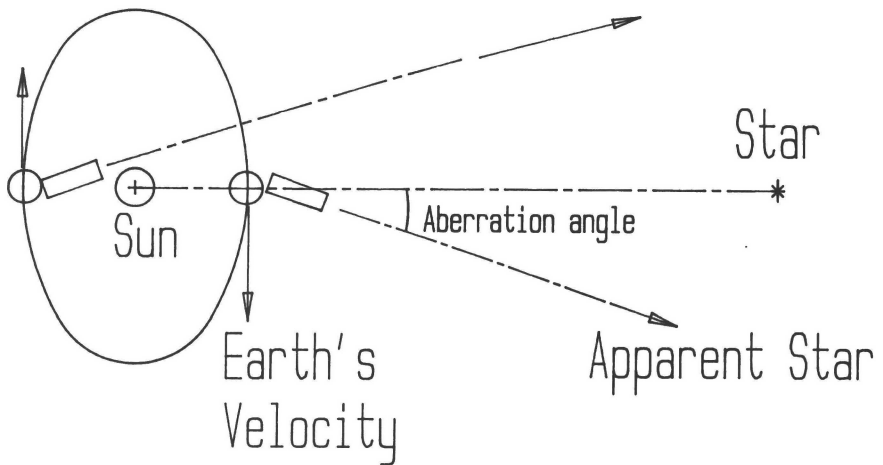
The results are presented graphically in Figure 3. The decay energy is held constant and various values of the depth,  $V_0$ , of the nuclear potential well are used to find the radius and decay constant. The graphs show how much the radius of the nucleus must decrease in order to keep the decay energy, and hence the radius of experimentally measured radioactive halos, constant.

For a given change in depth of the potential well, there is also a corresponding change in the decay constant. One should keep in mind that only a small change in decay constant may lead to a vast change in branching ratios between alpha decay, beta-minus decay, beta-plus decay, and/or electron capture decay of some nuclei. Also shown in Figure 2 is the square root of the expectation value of the square of the alpha particle radius. As expected, this also decreases as the potential well gets deeper.

This exercise shows that the radii of the radioactive halos studied by Gentry can be held constant while still changing the decay constant. But other nuclear properties would also change. This work provides a quantitative basis, a first step, for investigating what limits these other nuclear properties may place on the variation of the nuclear force strength.

#### USING BRADLEY'S DATA TO FIND THE SPEED OF LIGHT IN 1727

In the early 1700's the distances to the stars were not known accurately; the only reasonable estimates were based on the assumption of equal brightnesses. One way to find the distance to a star was to measure the parallax, which is the difference in position which it appears to have due to the finite size of the earth's orbit. Unsuccessful attempts had been made to measure the parallaxes of stars; the parallax angle is much smaller (less than one tenth of one second of arc) than the aberration of light, nutation, and precession angles. These effects had to be analyzed first and separated out before Bessel finally succeeded in measuring the parallax of 61 Cygni in 1837 to 1838. The aberration of light refers to the change in angle at which a telescope must be pointed in order to see a star at different times of the year, due to the relative magnitudes of the speed of light and the speed of the earth in its orbit (Figure 4). Stewart [21] has given a good introductory review of this subject.



**Figure 4.** *Since the Earth has a non-zero velocity in its orbit, seen here obliquely, a telescope on earth must be tilted at an angle in order to see the light from a star. Six months later the telescope must be tilted in the opposite direction. The angle of tilt is the aberration angle.*

As reported in reference [3], Bradley found a useful analogy while taking a sailboat ride on the Thames river. He noticed that the direction of a pennant flying from the mast of the ship depended on both the velocity of the boat and the momentary wind velocity. In the same way, the direction in which the telescope must be pointed in order to see a star depended on both the direction of motion of the earth as well as the direction of motion of the light from the star. Bradley and Samuel Molyneux were able to make accurate observations with two telescopes, one mounted to a chimney in Wanstead, England and the other in Kew.

In reference [3] Bradley's data for gamma Draconis and other stars are given as well as his writings on how the data are to be analyzed and interpreted. We shall see that Bradley correctly interpreted the results, but that higher order terms in the nutation were left out. This means that the last two decimal places of his results for the declination correction in seconds of arc cannot be trusted unless a more detailed analysis is made. The term "nutation" refers to a fluctuating motion of the Earth's axis of spin about the smooth precessional path. Bradley's observations of 1727-1747 were sufficient to show that the main component of nutation has a period of just over 18.6 years, and were due to the changes in the Moon's orbit which occur with the same period.

I have written a computer program to analyze Bradley's data more exactly. The reason was to see if the speed of light inferred from his data for the 1700s was different from the modern value [7]. The program incorporates orbital elements and other orientation parameters computed for the Earth for the year 1727 using the programs BRETAG.BAS and ORB.BAS described in reference [7]. The Julian dates for the first 70 of Bradley's observations of gamma Draconis were computed and inserted as data into the program. It is important to note that, in Britain, the day after September 2, 1752 was September 14, 1752 due to the decision to conform to the Gregorian calendar which had already been adopted in most European nations over 150 years earlier. Except for the first observation, Bradley did not record the exact hour and minute of observation. But the technique was to observe when the star was at the zenith, so that these times can be computed in retrospect. The Julian date of the first observation was JD2352075.3 and the 70th was JD2352432.3.

The program incorporates the right ascension and declination of gamma Draconis for the ecliptic and equinox of 1950.0, and uses that data to calculate the position for 1727. Following the same approach as in references [7] and [23], the program calculates the heliocentric equatorial coordinates and velocity components of the Earth for each date in the data set. Using the trigonometric equations given in the Explanatory Supplement [11, p. 47], the corrections due to aberration for right ascension and declination are calculated and added to the 1950.0 values. But Bradley's data are recorded with respect to the equinox and ecliptic of 1727, so that a further transformation is needed. A subroutine was written to perform this transformation using the procedure outlined by Cambell [5, pp. 47-53] but with the values of the numerical data updated using Lieske, Lederle, Fricke, and Morando [15].

Next, the correction for nutation must be computed. As noted in [3, pp. lxvii, 28], Bradley took the distance of a star's right ascension from the place of the Moon's ascending node, which he entered in a column called "argument of nutation." Then he multiplied 9 seconds of arc times the sine of this quantity to get the number which he entered in the column labelled "nutation." Plummer [18, p. 305] derived a more exact equation, including the nutation caused by the Sun and additional Lunar contributions. Using revised data provided by Mathews and Shapiro [16],

I incorporated Plummer's procedure into my computer program. This gives the correction to the declination due to nutation.

The program next reads in as data Bradley's values for the position of gamma Draconis on each of the 70 dates. These were recorded in [3] in terms of the number of seconds of arc south of  $38^{\circ} 25'$  declination (which should be  $51^{\circ} 35'$  since Bradley used a reverse coordinate system from modern conventions). To these values the program then adds the corrections for aberration, nutation, and precession. Plummer [18, p.307] derived a correction for precession. This correction changes slowly with time and is small enough that it does not play a major role in these calculations. In any case, Bradley had included his estimates of this quantity. It is not necessary to include a correction for diurnal aberration [11, p. 49], since the stars were on the zenith when Bradley observed them. We have already noted that parallax corrections are too small compared to the accuracy of Bradley's data.

The program produces a number which should, theoretically be the same for each of the 70 dates. In practice the standard deviation was found to be 0.863 with a mean of 79.736 seconds of arc (south of  $51^{\circ} 35'$  declination). As we have noted, Bradley ignored certain terms in the nutation correction. So to match the data, he had to assume a larger value for the speed of light. In this way, he obtained a mean of 79.826 and a standard deviation of 0.851. Since my program successfully calculates the mean position of gamma Draconis without assuming a different speed of light, and does so with about the same standard deviation as Bradley's calculations, this seems to show that the speed of light in 1727 was not significantly larger than today's value. However, one can run my program for other values of the speed of light to try to find the minimum standard deviation. It is found that the minimum standard deviation is 0.801 with a mean of 79.603. Figure 5 shows the results graphically. The "aberration amplitude" plotted on the x-axis is the angle of aberration which a star in the pole of the ecliptic would have if the eccentricity of the earth's orbit were zero and the earth had a mean daily motion of one degree per day. It is inversely proportional to the speed of light. The minimum on Figure 5 would correspond to a speed of light 2.4% larger than the modern value. But the difference in the standard deviations, 0.863 minus 0.801 is 0.062, is not large enough to draw firm conclusions (See Figure 5). Bradley's data are not accurate enough and there are higher order terms in the nutation that would have to be included in order to attach significance to this difference. I conclude that Bradley's data are consistent with the modern value for the speed of light.

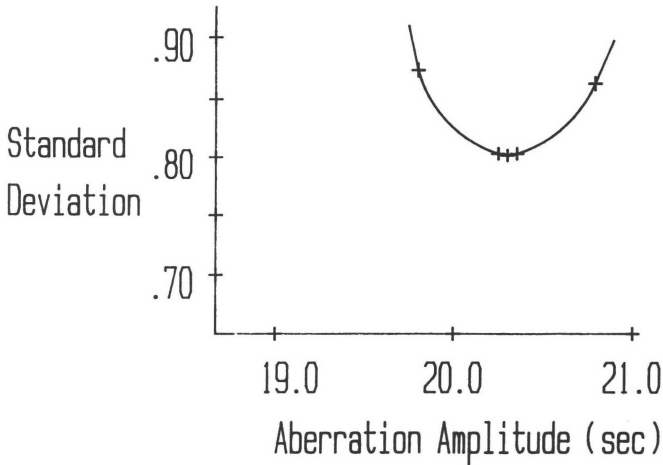


Figure 5. When all the necessary factors are included in the computer calculations, the seventy points have deviations from the mean value. The standard deviation is plotted here as a function of the assumed amplitude for the aberration of light. The minimum occurs for a value of 20.3 seconds of arc, only 2.4% different from the value of the speed of light. But the curve is shallow enough compared to the accuracy of Bradley's data that the data consistent with the modern value of the speed of light.

## CONCLUSION

This study shows that radioactive halo radii can remain the same even if the strength of the nuclear force were to change, but the half life for alpha decay would change. Further study is needed to try to find nuclear data, preserved in nature, which would contradict this hypothesis. We are concerned here with episodic changes, changes beginning at a certain point in time and ending after a short interval, not with changes in nuclear strength which are extrapolated indefinitely into the past. Hence, excess decay heat inside the Earth is not a concern of this hypothesis since nuclear decay rates would have been the same order of magnitude before this episode of change.

The study also shows that, according to data collected by Bradley in 1727-1728, the speed of light was not significantly different from the modern value. This does not contradict the alpha decay results, since theories are possible in which dimensionless ratios containing the strength of the nuclear force are not dependent on other dimensionless ratios involving the speed of light, such as the fine structure constant,  $e^2/hc$ .

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