STATISTICAL ANALYSIS OF *THE ATOMIC CONSTANTS, LIGHT AND TIME*

R. H. BROWN*

Received 25 November 1987; Revised 23 January 1988

Abstract

A statistical analysis of the data presented in The Atomic Constants, Light and Time *indicates that a significant change in the velocity of light has not occurred in recent years.*

Introduction

The Atomic Constants, Light and Time represents an immense amount of literature search, mathematical analysis, and creative thought. The authors are to be commended for their contributions in each of these areas. The scientific community is indebted to them for their compilations of data and literature references. Many readers will be stimulated by the provocative views on cosmology presented in this report.

After reading the Foreword by Lambert T. Dolphin and the first few pages of introduction by the authors, I looked forward to finding, in succeeding pages, clear and statistically well-supported evidence for a continuing decrease in the propagation speed of electromagnetic radiation. My subsequent disappointment provides the motivation for preparing this review.

After writing the following paragraphs I read the supplement to *The Atomic Constants, Light and Time*, entitled "Geological Time and Scriptural Chronology" and written by Barry Setterfield. In this supplement it is apparent that Mr. Setterfield is motivated to produce a model in which the physical universe has been in existence for less than 10,000 years. Efforts to harmonize the data obtained from scientific investigation with the data contained in the Bible are commendable, since the testimony of a competent and dependable eyewitness provides a better basis for reconstructing a singular event than does only analysis of after-the-event consequences. But when an interpretation of testimony given by an eyewitness, by an external observer, (whether direct or through an intermediary) requires unreasonable or highly questionable interpretation of the after-the-event consequences, there is need for careful investigation of the possibility that the eyewitness, external-observer testimony has been misinterpreted. There is danger that some discerning minds will incorrectly conclude that the authority cited for eyewitness, external-observer testimony is neither competent nor dependable. These considerations have provided additional motivation for sharing this review.

Difficulties

My first difficulty came from an attempt to evaluate the two empirical equations for the speed of light given on p. 7. Not until p. 55 did I discover that t in the first is calendar years AD, t in the second is 1961 minus calendar years AD, and both yield reasonable values only over the relatively narrow range of time associated with the experimental determinations that have been made.

My second difficulty, which was magnified throughout subsequent pages, came on p. 8 where six determinations of the speed of light were claimed to provide 98.2% confidence for rejecting the hypothesis that the speed of light was constant from 1879.5 to 1926.5. The mean and standard error for these six determinations are 299,845.5 and 41.5 km/s. According to a Student's t-distribution, 5% of such data should lie beyond 83.5 units away from the mean either above or below. The 1926.5 value of 299,798 km/s is 47.5 units below the mean, only 57% of the distance to the 5% point; and the present value is 53.0 units below the mean, only 63% of the distance to the 5% point. It is true that these six measurements declined monotonously during the time interval over which they were made, but the maximum difference is only 112 and the observers claimed standard errors ranging from ± 15 to ± 90 km/s for their reported means. How can one claim 98.2% confidence that this set of data represents measurement of a steadily decreasing quantity, rather than the influence of subjective factors and normal error of measurement on the determination of a constant quantity?

On p. 9 a statement made in 1931 is quoted which affirms that new values for the speed of light are "invariably . . . lower than the last one obtained." In the *selected* listing on p. 26, 21 examples out of 56 succeeding measurements are greater than the preceding, five of which were made prior to 1931. On p. 11 the authors point out that Aslakson's determination of c in 1949 was *higher* than all measurements made between 1928 and 1940 (5 as listed on p. 26).

Statistical Analysis

Citing the Roemer-type (observational delays in the eclipse of Jupiter's satellite Io) determinations of c as tabulated on p. 12, the authors state (p. 11) "On this basis, the hypothesis that c has been constant . . . can be rejected at the 96.5% confidence interval." Using the following symbols

M = mean speed of light in km/s
S = square root of the variance, in km/s
N = number of samples in the data set
T(.05) = T-value beyond which 5% of the data may be expected to lie, km/s from the mean; table t(.05) value multiplied by S
D = difference between the mean and the most recently accepted value

the six high precision values (omitting the 1675 and 1693 "estimates") from Table 1, p. 12, may be summarized:

M = 301,494; S = 1,697; N = 6; T(.05) = 3,419; D = +1,702.

*R. H. Brown, Ph.D., Geoscience Research Institute, Loma Linda University, Loma Linda, CA 92350.

One of these data is an increase over its predecessor, five are decreases, but the total characteristics of the set hardly seem to give 96.5% confidence for rejecting the hypothesis that c has been essentially constant from 1738 to 1983, since the significance of T(.05) is that in a large number of similar sets of data 5% of the values may be expected to be more than T(.05) units remote from their respective mean either above or below. T(.05) as defined above and used throughout this review differs from the usage on which Norman and Setterfield's conclusions are based. They divide by SQRT(N) to obtain a predictor for mean values. My objective is to evaluate their conclusions from the perspective of a broad view of each data set they use.

Data from Bradley-type (star aberration angle) determinations are claimed to provide 93.9% confidence for rejection of the hypothesis that c has been constant from 1740 to 1983 (p. 13). For the tabulation given on p. 14,

M = 299,869; S = 386; N = 63; T(.05) = 635; D = +77.

For the Pulkova observatory values only,

M = 299,776; S = 282; N = 13; T(.05) = 503; D = -16.

Figure 1 on p. 15 lists as Pulkova items two which are not so designated in Table 3 on p. 14. Is the error in Table 3 or in Figure l?

Splitting the data of Table 3 into three segments of 50 year duration yields the following:

Date	M	S	N	T(.05)	D
1765 ± 25	300,555	134	2	846	763
1865 ± 25	299,942.5	424	16	743	150
1915 ± 25	299,812	348	45	585	20

Values greater than the two in the 1765 group are found in the 1865 and the 1915 groups. In my judgment, these data provide a stronger basis for rejecting the hypothesis that c has declined significantly from 1740 to 1983, than for rejecting the hypothesis that c has been essentially constant throughout this interval.

The 14 values for c as determined by the toothed-wheel method (Fizeau) tabulated on p. 16 yield the following summary analyses.

Selection	M	S	N	T(.05)	D
A	299,974	697	10	1,278	182
B	299,818	522	9	971	26
C	299,910	48	5	102	118
D	299,885	19	4	45	93

A — Precision values 1872-1902.4 (1849.5-1855 omitted)
B — Same as for A, but low precision 1880 value omitted
C — Values considered by the authors as most reliable
D — 1900.4-1902.4 highest precision values

The mean of selection D is 15 km/s below the value obtained in the final evaluation of Cornu's 1874.8 determinations, 1/3 the range to the 5% region of the D set. Furthermore, a standard error of ±200 was assigned to the "Cornu" value of 299,900. Yet the authors claim "a confidence interval of 99.4% that c was not constant at the current value during these experiments" (p. 17).

The nine values tabulated on p. 18 for c as determined by the rotating mirror (Foucault) method provide the following summary analyses.

Selection	M	S	N	T(.05)	D
A	299,661	632	9	1,176	-131
B	299,833	50	6	101	+41
C	299,845	46	5	98	+53

A — All values
B — Values considered by the authors as most reliable
C — Same as for B, but omitting 1932.5 short baseline determination (has lowest standard error among the B group and D = -18), as suggested by the authors

The authors claim significance for decreased values for c obtained in succeeding years with the same rotating mirror equipment [p. 19]. One example is an 1882.8 determination 57 km/s lower than an 1879.5 determination. The standard error reported for these measurements is ± 60 and ± 50 km/s, respectively. The other example is a 4 km/s lower value in 1926.5 than was obtained in 1924.6. The respective reported standard error values are ± 15 and ± 30.

The authors state that "a decay is still apparent" (p. 19) in determinations made 1928-1940 using a Kerr Cell shutter. The data they quote on p. 20 yield

M = 299,776; S = 7.07; N = 4; T(.05) = 16.64; D = -16.

These data might be taken to provide over 90% confidence for a hypothesis that c *increased* between 1935 and 1983.

Unquestioned measurements of c made between 1947 and 1960 by cavity resonator, radar, geodimeter, radio interferometer, spectral line, and tellurometer techniques are tabulated on p. 21. These data yield the following summary analyses.

Selection	M	S	N	T(.05)	D
A	299,793.18	1.46	23	2.51	0.72
B	299,792.96	1.04	22	1.79	0.50

A — All values
B — Omitting 1947 preliminary 299,798 value

In both selections A and B only two of the items fall outside the 90% confidence range specified by ± T(.05), as predicted by statistical theory, but I cannot see in the positive values for D "a confidence level of 99.0% in the data showing c as higher than now during those 15 [14] years" (p. 19).

Determinations made from 1966 to 1983, mainly with lasers, are tabulated on p. 20, and may be summarized as

M = 299,792.470; S = 0.033; N = 11; T(.05) = 0.060; D = 0.011.

Regarding these measurements, the authors state:

> The only conclusion to be drawn from these figures . . . is that any decay during this period would have occurred at a very low rate, perhaps may have ceased altogether, or c may have begun to increase at some time in this period (p. 22).

The speed of light may be determined from the ratio of electrostatic units to electromagnetic units for electric charge. Values obtained in this manner from 1856 to 1906 are tabulated on p. 24. These values yield the following summary analyses.

Selection	M	S	N	T(.05)	D
A	297,340	5,311	23	9,119	-2,452
B	297,383	5,432	22	9,348	-2,409
C	299,982	561	8	1,063	+190

A — Omitting the imprecise early determinations in 1856 and 1868
B — Omitting in addition an imprecise determination in 1883
C — Values considered most accurate

In group C, determinations made in 1890 are lower than those made in 1891 and 1897. Of the seven succeeding values in the series of eight, four are lower and three are higher than the immediate predecessor. With D only 18% of T(.05), there is little basis for confidence that these data "exhibit a decay trend" (p. 25).

Measurement of standing electromagnetic wave patterns on wires may yield values for c. A tabulation of determinations made in this way from 1891 to 1923 is given on p. 24. For these data

M = 299,716; S = 1,626; N = 6; T(.05) = 3,276; D = -76.

A refined summary of all data on the speed of light is tabulated on p. 26. This tabulation yields the following summary analyses.

Selection	M	S	N	T(.05)	D
A	299,845	150	57	247	53
B	299,803	32	50	52	11
C	299,791.2	6.5	41	10.9	-1.3
D	300,178	302	6	609	386
E	299,865	43	10	79	73
F	299,783	13	7	25	-9
G	299,793.15	1.44	24	2.47	0.69
H	299,792.473	0.033	10	0.060	0.014

A — All data from Table 11
B — Determinations since 1879 (Michelson)
C — Determinations since 1921 (Michelson higher precision)
D — 1740-1875
E — 1876-1923
F — 1924-1940
G — 1941-1966
H — 1967-1983

For all selections in these analyses the US NBS 1983 value is less that T(.05) away from the mean—less than about 1/3 of T(.05), except for selections D and E.

The fact that D > 0 in most of the preceding examples appears to support the hypothesis that c has been decreasing. For a generalized series of numbers a(b + id), i = 1, 2, 3, . . . , n, scale factor a, displacement factor b, and increment factor d, the average value is a{b + [(n + 1)/2]d}, and the standard deviation is given by the expression ad{SQRT[(n^2 - 1)/12]}. The difference between an extreme value and the mean is ad[(n - 1)/2]. The ratio of this difference to the standard deviation is SQRT[3(n - l)/(n + 1)]. This expression ranges from 1.00 for one degree of freedom (n = 2) to 1.73 for infinite degrees of freedom (n = infinity). Multiplying by t(.l6) for a test value of greater statistical significance, the range goes from 1.4 for one degree of freedom to 1.7 for infinite degrees of freedom. [For infinite degrees of freedom t(.l6) is 1.00]. Practical measurements of a steadily changing quantity may be expected to yield D/S values that scatter above and below these values, but the average D/S for a large number of sample sets should be in the vicinity of 1.4-1.7 if the data represent a quantity that has changed continuously and significantly throughout the time over which measurements were made. If D is taken for a more remote point in time than that of the limiting value for the range over which the standard deviation is computed, the D/S ratio average for a large number of sample sets will be greater than 1.4-1.7

In only six of the cases discussed above (paragraph five, laser data, and selections A, B, C, and H from the authors' refined summary in Table 11, p. 26) was D computed against the most recently determined member of the set. In all other cases it was computed against the US NBS 1983 value. For the six exceptional cases D/S = 0.46 with a standard error of ± 0.34. Eliminating the 1.14 ratio for the paragraph five data, D/S = 0.33±0.08. For the 18 cases in which D was computed against the remote 1983 value the range of D/S is from 0.050 to 5.69, with a mean 1.35±1.60. Eliminating the 5.69 value for the N = 2 data in the 1765±25 years range for the Bradley aberration method, the range of D/S is from 0.050 to 4.89, with a mean 1.10±1.21. Among these 17 cases only four have D/S greater than 1.3 — 4.89 for the Fizeau method data 1900.4-1902.4, with N = 4; 2.46 for the Fizeau method data selected by Norman and Setterfield as most reliable; 2.63 for the N = 4 Kerr Cell data, the mean of which is 16 km/s *less* than the 1983 value; and 1.70 for the 1876-1923 range of the summary data (Table 11, p. 26). These observations provide strong evidence that within the precision and accuracy of measurements made up to the middle of this century the speed of light has been essentially constant.

Norman and Setterfield base their confidence in the hypothesis that the speed of light has been monotonously declining over the last three centuries on regression analysis and statistical comparison of averages for small samples of data. Should success in fitting sets of data against time of acquisition, or subsequent reporting, to a line with negative slope override the basic statistical considerations on which the preceding analysis in this review has been developed? Investigation of physical constants which are related to the speed of light may provide some clarification. The last half of the monograph is devoted to such investigation.

From data tabulated on p. 30 the authors conclude that there is no experimental evidence for variation in the electrical charge carried by an electron. The data were collected between 1913 and 1973. Following the analysis pattern I have used for speed of light data, and using the 1973 determination as the reference for calculating D, the following summary analyses were obtained for the 37 items of Table 13, omitting three "pioneer results" considered of doubtful accuracy.

Selection	M	S	N	T(.05)	D	D/S
A	4.8042	0.0080	34	0.0135	0.0010	0.12
OD	4.8101	0.0170	7	0.0330	0.0069	0.41
OM	4.8036	(0.0048)	1	------	0.0004	----
XR	4.8019	0.0007	4	0.0016	-0.0013	1.86
XM	4.8024	0.0013	7	0.0025	-0.0008	0.61

A — All 34 items
OD — Oil drop method
OM — Oil drop mean
XR — X-ray method
XM — X-ray mean

On the basis that the electron charge has been constant, the authors claim 99.17% confidence for the hypothesis that the product mc, electron mass times the speed of light, has varied from 1910 to 1973. Using the 1973 value for calculating D, the following analysis was obtained for the data in Table 14, p. 32, for e/mc.

Selection	M	S	N	T(.05)	D	D/S
A	1.7600	0.0027	33	0.0046	0.0012	0.44
CF	1.7613	0.0052	4	0.0122	0.0025	0.48
FS	1.7604	0.0033	8	0.0063	0.0016	0.48
ZE	1.7591	0.0020	4	0.0047	0.0003	0.15
DV	1.7600	0.0014	2	0.0088	0.0012	0.86
MD	1.7593	0.0005	3	0.0015	0.0005	1.00
XR	1.76006	(0.0004)	1	------	0.0012	----

A — All data
CF — Crossed field technique
FS — Fine structure technique
ZE — Zeeman effect
DV — Direct velocity measurement
MD —— Magnetic deflection
XR — X-ray refraction

On the basis of the D/S ratio data, I see no basis for confidence in a hypothesis that mc has been time dependent.

Constants Variable?

Planck's constant h is expected to increase with time if c decreases. For the data on h/e in Table 15A, p. 34, with D calculated on the latest (1973) value

M = 1.37724; S = 0.00238; N = 28; T(.05) = 0.00405; D = -0.0023; D/S = 0.97.

The authors state that "the data . . . does not negate the proposition" (p. 33). Although $D < 0$, with the 52 year time interval involved and D/S = 0.97 for N = 28, I would not expect D = -0.0023 to support the proposition any better than D = +0.0023.

Measurements of 2e/h from the a.c. Josephson effect are considered to give 96.2% confidence that h was not constant, assuming e to be constant (p. 35). Using the 1972.38 value for determining D, the following analyses were obtained for the composite data and for individual laboratories involved (Table 15B, p. 34). The time range for these data is *only two years.*

Selection	M	S	N	T(.05)	D	D/S
A	483593.798	0.235	11	0.426	0.192	0.82
NBS	483593.584	0.137	3	0.400	-0.022	0.16
NPL	483594.117	0.104	3	0.304	0.510	4.90
NSL	483593.791	0.054	3	0.156	0.185	3.43
PTB	483593.653	0.066	2	0.417	0.047	0.71

There is no justification from these data for a time dependency of h.

The quantized Hall resistance, h/e^2, provides another approach to determining if h has been time dependent. The authors claim 92.9% confidence that h/e^2 has not been constant (p. 35). The data on which they base this conclusion is given in Table 15C, p. 36. Using the 1985 value for reference, the data collected over five years yield

M = 25812.8257; S = 0.0335; N = 6; T(.05) = 0.0675; D = -0.0212; D/S = 0.63.

All the data in this set fall within the 80% confidence range [T(.10) = 0.0494]. Of the four values which have an order of magnitude higher precision than the other two, the highest was determined in 1984.5, the second highest in 1983.5, the third highest in 1985.0, and the lowest in 1984.0. This pattern, together with the associated statistical analysis, provides no basis for asserting that h increased significantly over the five years of data collection.

Determinations of the Rydberg constant made between 1890 and 1981 are listed in Table 16 on p. 36. For these data

M = 109,737.310; S = 0.071; N = 24; T(.05) = 0.122; D = -0.005; D/S = 0.07

and all but one datum is within the 90% confidence range [T(.10) = 0.094]. I agree with the authors that "This strongly suggests that the Rydberg constant has not varied" (p. 37).

The authors claim 99.9% confidence that the gyromagnetic ratio of the proton has changed over the time interval 1949-1981. Their data list in Table 17, p. 38, yields

M = 26751.779; S = 0.803; N = 30; T(.05) = 1.364; D = 0.551; D/S = 0.69.

The 1981b value is only 40% of the T(.05) distance from the mean, and the 1962b, l962c, 1966, and 1978 values are each lower than the 1981b value. Again I do not see evidence for a significant change over time.

Radioisotope Half-Lives

In harmony with their line of thinking, the authors take the position that radioisotope half-lives have increased over time. They tabulate data which they claim "support the contention of increasing half-lives by an almost two-thirds majority . . .. The most pessimistic conclusion is that they do not invalidate the proposal" (p.41). Their Table 19 (p. 40) lists half-life values for 35 radioisotopes, as published in 1904, 1913, 1930, 1936, 1944, 1950, 1958, 1966, and 1978. Unfortunately, many of these values are only restatements of previously published values, and do not represent an additional independent determination. To reduce the hazard of using imprecise or inaccurate values which were determined before techniques and instrumentation were well developed, my analysis covers only the values published in 1930 and afterward. This selection eliminates consideration of Pb-214, Po-218, Ra-224, and Ac-228, for which the same half-life value is repeated from 1930 to 1978. Using the 1978 value for reference, the following analyses were obtained for the significant figures of the half-lives.

Isotope	M	S	N	T(.05)	D	D/S
Tl-207	4.754	0.032	7	0.062	-0.016	0.5
Tl-208	3.108	0.044	7	0.085	+0.055	1.25
Tl-210	1.314	0.010	7	0.019	+0.014	1.40
Pb-210	20.67	2.29	7	4.45	-1.63	0.71
Pb-211	36.07	0.04	7	0.08	-0.03	0.75
Pb-212	10.62	0.02	7	0.04	-0.02	1.00
Bi-210	4.97	0.06	7	0.12	-0.04	0.67
Bi-211	2.156	0.005	7	0.010	+0.006	1.20
Bi-212	60.57	0.11	7	0.21	-0.030	0.27
Bi-214	19.73	0.076	7	0.15	+0.03	0.39
Po-210	138.51	1.61	7	3.13	+0.13	0.08
Po-216	0.152	0.0075	7	0.015	+0.002	0.27
Rn-219	3.937	0.031	7	0.060	-0.023	0.74
Rn-220	54.73	0.43	7	0.84	-0.87	2.02
Rn-222	3.8235	0.0018	7	0.0035	0.000	0.00
Ra-223	11.34	0.19	7	0.37	-0.095	0.50
Ra-226	1603	17	7	33	+3	0.18
Ra-228	6.43	0.46	7	0.89	+0.67	1.46
Ac-227	21.11	0.86	6	1.73	-0.66	0.77
Th-227	18.72	0.27	7	0.52	+0.002	0.01
Th-228	1.905	0.006	7	0.012	-0.008	1.33
Th-230	7.97	0.29	7	0.56	-0.03	0.10
Th-231	24.99	0.52	7	1.01	-0.53	1.02
Th-232	1.47	0.12	7	0.23	+0.06	0.50
Th-234	24.17	0.25	7	0.49	+0.07	0.28
Pa-231	2.69	1.00	7	1.94	-0.59	0.59
Pa-234	6.70	0.03	5	0.06	-0.05	1.67
Pa-234m	1.156	0.018	7	0.035	-0.019	1.06
U-234	2.49	0.12	5	0.26	+0.04	0.33
U-235	7.08	0.035	5	0.075	+0.042	0.20
U-238	4.493	0.049	7	0.095	+0.025	0.51

There are 16 negative D, 14 positive D, and one zero D. For only one isotope, Rn-220, is D greater than the T(.05) value—0.87 versus 0.84. Since there seem to be only three independent values in the 1930-1978 citations for Rn-220, a correct value for T(.05) would be larger than 0.84. The apparent conclusion is that these data provide no evidence for a significant change in nuclear half-lives over the last 50 years.

Gravitational Constant

The authors and I are in agreement with our conclusions regarding the Newtonian gravitational constant—"invariant" (p. 44). From their Table 20, p. 42, covering data from 1798 to 1981 one can derive the following analyses, with D computed against the 1981 value.

Selection	M	S	N	T(.05)	D	D/S
A	6.657	0.053	25	0.091	-0.016	0.30
B	6.653	0.050	24	0.086	-0.020	0.40
C	6.674	0.027	20	0.047	+0.001	0.04

A — All values
B — Uncertain 1798 determination deleted
C — Low precision items deleted

Conclusion

The authors may be convinced that "The above data presentation indicates strongly that both light speed and atomic processes, including atomic time, are undergoing a uniform decay process" (p. 51) and I am certain that many of their readers will agree. To both those who agree with the authors and those who intuitively question their thesis and mode of defense, I recommend a thorough consideration of the analysis in this review.

ARTICLE REVIEW

Hot gas in the universe by Roger A. Chevalier and Craig L. Sarazin. 1987. *American Scientist.* 75:609-18.
Reviewed by Paul M. Steidl*

This article, by two experts in the field of interstellar and intergalactic matter, is a review of hot gas in the universe, from supernovae to superclusters. At each level they describe the hot gas observed and attempt to account for its properties. Their basic premise is that hot gas can be accounted for by matter ejected from supernovae on a small scale, and galactic infall on a large scale. Hot gas in this context refers to highly ionized gas at millions of degrees.

Their discussion of the causes of supernovae is of necessity highly theoretical, but the description of supernova ejecta was well-founded in observation. Highly ionized elements have been observed spectroscopically in both Type I and Type II supernovae. The problem occurs when they say that the even distribution of heavy elements in interstellar matter is a result of the mixing of supernova ejecta with the interstellar medium. This is because of their assumption that the interstellar medium started as pure hydrogen and helium, a consequence of the big bang theory. Without that assumption, neither mixing is required, nor are the large time scales over which the mixing must operate.

Evidence for hot has in the interstellar medium is not nearly as strong as for supernova ejecta. At present it rests primarily upon the observation of the ions C^{+3}, Si^{+3} and N^{+4}. Hot hydrogen, which must constitute the bulk of any hot gas, is not directly observable. Ionization by extraglactic radiation and by stars might account for at least some of these ions, meaning that there may not be a large amount of hot gas at all. This must be left to further observations. If it is not there, then eons of supernovae are not required to supply it. But even if it is there, the cooling time for million degree gas is 100 million years, so no continuing source is required to account for it in the creationist time frame.

Elliptical galaxies were long thought to be devoid of dust and gas. More recently it was discovered that they are strong x-ray sources, implying that they contain large amounts of very hot gas, around 10 million degrees. The amount, they say, is comparable to the amount of gas ejected by all the galaxies stars over the period of their lifetimes. If the heating had been done by supernovae, these energetic explosions would have blown the gas away from the galaxies entirely, so the heat source must lie elsewhere. One mechanism they suggest is the motions of the stars themselves, whose speeds reach 300 km/s. For a hydrogen atom, this corresponds to 10 million degrees,* so no other mechanism is required. Since the gas being added to the medium

*Paul M. Steidl, M.S., receives his mail at 17126 11th Place, West, Alderwood Manor, WA 98037.

*From setting $1/2\ mv^2 = 3/2\ kT$.