Letters to the Editor

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The Velocity of Light

F. K. EDMONDSON[1] has recently stated that the observed values of the velocity of light are well represented by the equation

$$c = 299{,}885 + 115 \sin (2\pi/40)\ (t-1901),$$

and de Bray[2] has given a plot of this equation, together with certain experimental points. By comparing these points with the complete table of values published earlier by de Bray[3], I find that they include *each* one of the seven final declared values of c, from 1875 to the present time, as well as the preliminary value of Pease and Pearson[4]. The agreement with Edmondson's equation is so remarkable that it seems desirable to tabulate the actual figures. The first eight items in the accompanying table comprise this information[5].

Date	Investigator	Obs. Velocity km./sec.	Obs.-Calc. km./sec.
1874.8	Cornu-Helmert	299,990 ± 200	+ 10
1879.5	Michelson	299,910 ± 50	− 2
1882.7	Newcomb	299,860 ± 30	+ 5
1882.8	Michelson	299,853 ± 60	± 0
1902.4	Perrotin	299,901 ± 84	− 9
1926.5	Michelson	299,796 ± 4	− 1·6
1928.0	Mittelstaedt	299,778 ± 10	− 4·5
1932.5	Pease and Pearson	299,774	+ 0·8
1923.0	Mercier	299,782 ± 30	− 67
1906.0	Rosa and Dorsey	299,781 ± 10	− 185

In addition to Edmondson's 40-year period, Pease and Pearson[4] have found evidences of two shorter periods, one of 14¾ days, and the other of one year. Each had an amplitude of about 20 km./sec., although the shorter period fluctuation nearly vanished during December 1932 and January 1933, reappearing again in February 1933. The origin of these short period fluctuations is still obscure, but if we admit their reality, it is not improbable that a large fluctuation of the type postulated by Edmondson *may* also exist. On the other hand, it is important to notice that these apparent variations occurred only in the direct measurements of c, for which the apparatus extended over one to twenty-five miles. When we turn to the indirect methods, for which a very compact apparatus is used, there is no evidence of a variation.

One of these indirect methods is the measurement of the velocity of electric waves guided by wires (standing waves). J. Mercier[6] has carried out the latest and by far the most accurate work by this method. His result is 299,700 ± 30 km./sec., and I quoted this value in my 1929 discussion[7] of the general physical constants. N. E. Dorsey[8] has, however, recently noted that this value is for air, and when reduced to vacuum becomes 299,782, as given in the table. This revised figure agrees surprisingly well with Mittelstaedt's[5] result, which was obtained with a Kerr cell and with a base line of only 41·4 metres, and with Pease and Pearson's final *average* result. It disagrees, however, by 67 km./sec. with Edmondson's predicted value for the epoch 1923.

The second indirect method for determining c is by means of the ratio of the electrostatic to the electromagnetic unit of electricity. The best experimental value of this ratio, by E. B. Rosa and N. E. Dorsey[9], was obtained at the mean epoch 1906·0. Their direct result is 299,710 ± 10, but this is in terms of international electric units. Using $p = 1{\cdot}00051$ (one int. ohm. = p abs. ohm), I obtained[7] 299,790 ± 10 km./sec. The best value of p is, however, now[10] 1·00046, giving 299,781 ± 10 km./sec. This last value, which appears in the table, is in complete agreement with the results obtained with other relatively compact apparatus (Mercier and Mittelstaedt). On the other hand, it disagrees violently with Edmondson's calculated value for 1906.

To this last conclusion the objection may properly be raised that it is the value of p that should vary with time, rather than the experimental result in terms of international units, and that the 299,781 value properly applies to 1932, the epoch at which $p = 1{\cdot}00046$ was observed, and for which the calculated value of c is 299,773. But the experimental values of p do not show the predicted variation with time. Thus F. E. Smith[11], in 1914, obtained 1·00052, and E. Grüneiser and E. Giebe[12], in 1920, obtained 1·00051. In order to satisfy Edmondson's equation, the value of p, from 1914 to 1932, should vary by 0·00144, an amount twenty-four times the observed variation.

It is thus probable that the fluctuations observed in the directly measured value of c are related in some way to the long base-line employed in the apparatus. That such fluctuations are instrumental, rather than real, is indicated also by the evidence listed by O. C. Wilson[13] and by R. J. Kennedy[14], although the general situation outlined by them is not so clean-cut as their letters might indicate. In brief, this situation is as follows.

The apparent observed change in c is in terms of the standard metre and the mean solar day. Now if we assume the wave theory of light, and if we assume further that there is no dispersion in empty space, so that the group (that is, the measured) velocity is identical with the wave velocity, then we can write the fundamental equation $c = \lambda\nu$, where ν is the frequency of the atomic oscillator producing the light of wave-length λ. It has, however, been shown experimentally, as Wilson points out, that the length of the standard metre, in terms of λ, did not change by a measurable amount from 1892 to 1906. Furthermore, the short-period fluctuations observed by Pease and Pearson should have produced as much as one entire fringe shift per day in Kennedy's apparatus, whereas his observed shifts were always less than 10^{-4} fringe per day.

Hence if the value of c, in terms of the standard metre and mean solar day, is actually changing with time, but the value of λ in terms of the standard metre shows no corresponding change, then it necessarily follows that the value of every atomic frequency, in terms of the mean solar day, must be changing. Such a variation is obviously most improbable, but unfortunately it is not possible to make a direct test, since one cannot compare directly an atomic frequency with any macroscopic standard of time. A real variation in the measured group velocity c, if such variation exists, might then be interpreted as due to a real variation in ν, or as due to a failure of the measured c to equal the *wave* velocity $\lambda\nu$. Parenthetically, it may be noted that any such general variation in ν would not affect the value of the *non-dimensional* quantity, index of refraction, contrary to Wilson's statement.

The last four values of c given in the table represent respectively the best result by each of four quite different methods, and agree remarkably well. As a final weighted average of these results, I suggest 299,776 $\pm$ 4 km./sec.

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[1] NATURE, **133**, 759, May 19, 1934.
[2] NATURE, **133**, 948, June 23, 1934.
[3] NATURE, **120**, 602, Oct. 22, 1927. This table has been checked and republished by Mittelstaedt (*Phys. Z.*, **30**, 165; 1929).
[4] Annual Report of Director, Mount Wilson Observatory, 1930–31, p. 218; 1931–32, p. 170; 1932–33, p. 164. See also NATURE, **133**, 169, Feb. 3, 1934.
[5] The first three columns of this table differ from the data already published by de Bray[3] and by Mittelstaedt[3] only in the use of 10 in place of 20 km./sec., for the probable error of Mittelstaedt's own work (*Ann. Phys.*, **2**, 285; 1929). He states explicitly on p. 310 of his paper that 20 km./sec. is his *limit* of error.
[6] *J. Phys. Radium*, **5**, 168; 1924. In this case, also, the published $\pm$ 30 km./sec. appears to be an estimated limit of error, rather than a probable error.
[7] *Rev. Mod. Physics*, **1**, 1; 1929.
[8] Congrés International d'Electricité (Paris, 1932), **3**, p. 202.
[9] U.S. Bur. Standards, *Bull.*, 3, 433; 1907.
[10] Nat. Research Council, *Bull.*, 93, 92; 1933.
[11] *Phil. Trans.*, **214**, 27; 1914.
[12] *Ann. Phys.*, **63**, 179; 1920.
[13] NATURE, **130**, 25, July 2, 1932.
[14] NATURE, **130**, 277, Aug. 20, 1932.

β-Rays of Radium D

THERE has been much uncertainty as to the energies of the nuclear β-rays of radium D. All the expansion chamber investigations[1,2,3,4] showed, in addition to the known secondary β-rays, numerous rays of ranges around 6 mm. in oxygen at S.T.P. and therefore of energies of about 20 kilovolts. These were interpreted by Feather[3] and one of us[4] (H. O. W. R.) as due to the nuclear electrons.

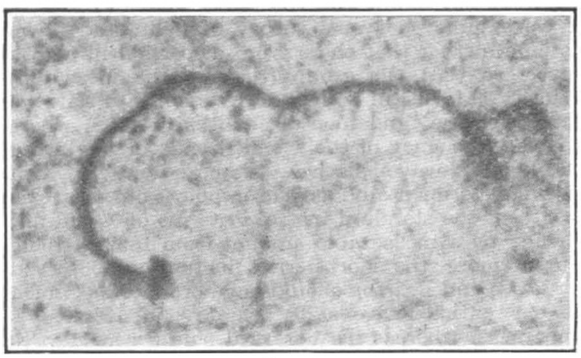

FIG. 1.

On the other hand, (1) Kikuchi[1] had failed to find pairs of secondary + nuclear tracks starting from the same atom on a weakly activated silk fibre; and (2) Stahel[5], using a counter, had failed to count more than 0·83 β-rays per disintegration through a collodion film of small stopping power, though there is evidence that the secondary electrons amount to at least 0·6 per disintegration[4,6,7].

We have obtained new evidence by photographing in the expansion chamber β-tracks coming from radium D tetramethyl. This is a vapour, and the minute quantity used is handled and introduced into the chamber by using lead-tetramethyl as a carrier. It is thus possible to observe the β-disintegration of individual radioactive atoms in the gas.

From measurements of about a hundred disintegrations, we find that the typical disintegration of radium D consists in a 47,200 volt γ-transition accompanied by the emission of a nuclear electron of small range, 0–3 mm. in air. The estimation of the high energy limit of the nuclear spectrum is complicated by the presence of occasional tertiary electrons due to the Auger effect with ranges similar to those of the fastest nuclear electrons. The limit is probably near 10 or 12 kilovolts.

The β-rays between 10 and 30 kilovolts found in previous experiments are absent, so that they must be identified as secondary electrons which had lost energy in the solid material on which the radio element has previously been mounted.

The appearance of a disintegration can be judged from Fig. 1, which is reproduced from a photograph showing three tracks coming from the same atom in air in a field of 650 gauss. They are interpreted as a nuclear ray of about 1 mm. range, a tertiary of 3 mm. and an L secondary of 2·35 cm.

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[1] Kikuchi, *Jap. J. Phys.*, **4**, 143; 1927.
[2] Petrova, *Z. Phys.*, 55, 628; 1929.
[3] Feather, *Proc. Camb. Phil. Soc.*, **25**, 522; 1929.
[4] Richardson, *Roy. Soc. Proc.*, A, **133**, 367; 1931.
[5] Stahel, *Z. Phys.*, 68, 1; 1931.
[6] Gray, NATURE, **130**, 738, Nov. 12, 1932.
[7] v. Droste, *Z. Phys.*, **84**, 17; 1933.

Effects of Cosmic Radiation in a Wilson Chamber at the Hafelekar Observatory (2,300 m.) near Innsbruck

A MAGNETIC field of 1,500 gauss was produced in a Philipp-Dörffel Wilson chamber of 12 cm. diameter and 3 cm. depth, and the effects of cosmic radiation at a height of 2,300 m. above sea-level were investigated. We obtained the following results:

On 1,200 exposures, 160 electron-tracks are visible. Those which are nearly vertical can be interpreted as 31 positive and 34 negative, if we assume that the particles have been moving downwards. The charge of the others cannot be determined, since nothing is known about the direction of their motion. On 25 exposures several simultaneous tracks are visible. A distinct shower with about seven tracks (they are not all equally distinct) was photographed. The radius of curvature could be determined for 98 tracks. The statistics show that a considerable number of soft rays is present. Half the tracks have a radius of curvature of less than 3 cm., corresponding to an energy of 500,000 e.v. 34 have a radius of more than 30 cm., corresponding to 10^7 e.v. Taking the statistics for positive and negative rays separately, we get about the same distribution. Using a strip of lead (0·6 cm. thick), laid horizontally across the chamber, only one particle penetrating it was detected. It did not show any noticeable curvature even after passing through the lead.

Beside the tracks of electrons, tracks of heavy particles were also found. We cannot assume that these rays were due to a contamination of polonium or radium (actually only polonium has to be seriously considered), as three of them had a range of 5 cm. or more (exceeding the range of polonium considerably). One ray of 4 cm. range had both ends in the chamber, which is not likely to occur with polonium. Moreover, 9 out of 15 tracks were vertical, while only 14 out of