indicate that the F_2 layer ionization also, at the time of the eclipse, was predominantly controlled by ultraviolet radiation from the sun. A comparison of the F_2 layer results of the August, 1932, eclipse with the February, 1935, eclipse indicates that the F_2 layer ionization is produced in a different manner during the summer than during the winter.

These results emphasize the importance of seizing every opportunity for ionosphere observations presented by eclipses, even though a particular eclipse may not seem entirely promising in respect to season, time of day, or latitude.

S. S. Kirby
T. R. Gilliland
E. B. Judson

Bureau of Standards,
Washington, D. C.,
March 26, 1935.

[1] Kirby, Berkner, Gilliland and Norton, Bur. Standards J. Research, **11**, 829, Dec. 1933 (RP629). Proc. I. R. E. **22**, 247 (1934).

[2] Kirby, Berkner and Stuart, Bur. Standards J. Research **12**, 15, 1934 (RP632). Proc. I. R. E., **22**, 481 (1934).

Masses of Light Atoms from Transmutation Data*

The difficulty of reconciling the stability of the Be nucleus with its high mass (9.0154) derived from the mass spectroscopic measurement of Bainbridge is well known. On the other hand, all transmutation data point to a much lower value (about 9.011). If one tries to account for the disintegrations of Be assuming the Bainbridge mass, one is forced to assume the existence of new nuclei, *viz.*, Be^8 and He^5. These present new stability difficulties; e.g., for He^5 a mass of 5.006 can be derived from transmutation data,[1] which would make Li^6 unstable against proton emission.

The difficulties are not restricted to Be. Indeed, the energy balance of the disintegration of B^{11} under proton bombardment can only be brought into agreement with nuclear masses, by making very artificial assumptions.[2] Other evidence of a wrong determination of the B mass is the transmutation $B^{10}+n^1=Li^7+He^4$ recently observed by Taylor and Goldhaber.[3]

The most striking instance seems however to be provided by C^{12}. The C^{12} nucleus is known to emit γ-rays of 5.5 MV,[4, 5, 6] therefore it must have an excited level of this energy which does not disintegrate into 3 α-particles before the γ-ray is emitted. The probability of emission of a γ-ray is about 1 in 10,000 periods of oscillation of the α-particle in the nucleus. The penetrability of the nuclear barrier for α-particles must therefore be smaller than 1/10,000 for the excited state, in order that strong γ-radiation can be observed. The energy of the excited state can, then, not be greater than that of 3α-particles +0.7 MV; and therefore the energy of the ground level must be at least 4.8 MV lower than 3α's. Hence

$$C^{12}<3\times 4.002\,16-0.005\,1=12.0014$$

as compared to Aston's value 12.0036.

On the other hand, a lower limit for the mass of C^{12} can be obtained from the γ-rays emitted by O^{16}, having an energy of 5.4 MV.[5, 6, 7] By the same reasoning as before we conclude that the excited state of the O nucleus could not emit γ-rays in appreciable amount if its energy would exceed that of $C^{12}+He^4$ by more than 1 MV. Therefore the energy of the O ground state must at least be 4.4 MV lower than that of $C^{12}+He^4$, so that

$$C^{12}>16.0000-4.0022+0.0047=12.0025.$$

This "lower" limit is thus seen to be higher than the upper limit derived above. The only possible way out is to assume that the mass of helium with respect to oxygen is completely wrong.

Such an assumption would immediately explain why all transmutations of the light elements H, He and Li among each other have energy balances fitting beautifully[1] with the mass spectroscopic values whereas for all nuclear processes in which a heavier atom (Be, B) is transformed into light ones the energy balance seems to be completely wrong. Namely, all the light atoms have been compared very accurately to He in Bainbridge's work, whereas the heavier ones have been referred to oxygen.

The change of the ratio He : O seems also to be in accord with the chemical determinations[8] of the atomic weight of H.

Consequently the derivation of atomic weights purely from disintegration data was attempted. Of the transmutations connecting the elements of the "heavier" to those of the "lighter" group the best investigated is the transformation $B^{11}+H^1=3\ He^4$. Since all considerations involving the upper limit of the α-particle energy are open to criticism,[2] we have used the mean energy of the emitted α-particles rather than the maximum energy. This is justified in the case of boron, because it is known[2] that, if γ-rays are emitted at all in the process, there must be less than one γ-ray in 50 disintegrations. Also, there is no other conceivable process which could lead to the emission of low energy particles which could falsify our mean energy: The process $B^{10}+H^1=2\ He^4+He^3$ would, even with so high a value for the B^{10} mass as 10.0146, set free an energy of only 1 MV, therefore the α-particles of this process could, even under most favorable conditions, not have more than 4 mm range. On the other hand, in the Wilson chamber measurements of Kirchner[9] which we have used for determining the energy distribution of the α-rays, no tracks under 5 mm have been measured at all. The latter fact makes incidentally our determination of the energy evolved in the process an upper limit.

The actual calculation gave for the mean energy of the α-particles observed by Kirchner 2.85±0.03 MV, corresponding to a total energy of all three particles of 8.55±0.10 MV, in perfect agreement with the value deduced from the upper limit of the α-particle energy (8.7 MV) under the assumption that the fastest α-particles get just $\frac{2}{3}$ of the total energy available which follows from momentum considerations.[10] Therefore we consider it as definitely established that the energy evolved in the disintegration of B^{11} by proton bombardment is 8.5±0.2 MV, the energy of the incident protons being about 150,000 volts in the experiments of Kirchner[9] and of Rutherford and Oliphant.[10] This makes the mass of $B^{11}=11.0078$, referred to He $=4.00216$.

B^{10} can then be immediately determined from Cockcroft's results[11, 12] on the transmutation $B^{10}+H^2=B^{11}+H^1$, which gives $B^{10}=10.0116$ in agreement with the estimate of Taylor and Goldhaber[3] from the disintegration $B^{10}+n^1=Li^7+He^4$.

C^{13} is very well connected with B^{10} by the reaction $B^{10}+He^4=C^{13}+H^1$, investigated by Chadwick[13, 14] and many others. C^{12} can then be determined from Cockcroft's[11, 12] reaction $C^{12}+H^2=C^{13}+H^1$. It is safe to assume that the γ-rays emitted[5] in the process are not connected with the observed proton group of 3 MV, but with another group of such small range that it escapes detection. There are many arguments in favor of this assumption: Firstly, the yield of protons is over 10 times the γ-ray yield.[11] Secondly, if the γ-ray was associated with the 3 MV protons, the stability difficulty for the excited state of the C nucleus pointed out above would not be solved, since the C^{12} mass would be 12.0030 referred to He (upper limit 12.0014). Thirdly, it has never been observed and is indeed very unlikely from the theoretical point of view, that a transmutation leads *always* to the excited state of the final nucleus, and even 0.2 percent of faster protons would not have escaped detection.[12] Furthermore, the energy of the neutrons from α-bombardment of Be could not be reconciled with the high C mass 12.0030, and this applies to even greater extent to the neutrons from the reaction $B^{11}+He^4=N^{14}+n^1$: Finally, the choice of the lower value of the C mass makes it possible to reconcile our masses with Bainbridge's determination of the Be mass referred to C (see below), and of the B^{11} mass referred to C and O.

C^{12} being determined, the rest is straightforward: N^{14} is obtained from Lawrence's data[15] on the process $N^{14}+H^2=C^{12}+He^4$, then O^{17} from Haxel's[16] experiments on $N^{14}+He^4=O^{17}+H^1$, and finally O^{16} from Cockcroft's[11] $O^{16}+H^2=O^{17}+H^1$. The result is

$$O^{16}=15.9952, \text{ referred to } He=4.00216.$$

The ratio He : O appears therefore to be wrong by 3.0 parts in 10,000.

Changing back to $O^{16}=16$,[17] we obtain the following values for the atomic weights of the lighter nuclei:

$$\begin{array}{ll}
n^1=1.008\,5\ \pm 0.000\,5 & Be^9=\ 9.013\,5\pm 0.000\,7\\
H^1=1.008\,07\pm .000\,07 & B^{10}=10.014\,6\pm .001\,0\\
H^2=2.014\,23\pm .000\,15 & B^{11}=11.011\,1\pm .001\,1\\
H^3=3.016\,10\pm .000\,33 & C^{12}=12.003\,7\pm .000\,7\\
He^3=3.016\,99\pm .000\,46 & C^{13}=13.006\,9\pm .000\,7\\
He^4=4.003\,36\pm .000\,23 & N^{14}=14.007\,6\pm .000\,4\\
Li^6=6.016\,14\pm .000\,50 & N^{15}=15.005\,3\pm .000\,5\\
Li^7=7.016\,94\pm .000\,48 & O^{17}=17.004\,0\pm .000\,2
\end{array}$$

referred to $O^{16}=16.000\,00$. The error in the lighter group is mainly due to insufficient knowledge of the ratio He : O, the accuracy of the determinations of the lighter elements with respect to He is much higher.[18]

It is seen that the atomic weights of the heavier group of elements (Be to O) has only been changed within the limits of error of the mass spectroscopical determinations. This applies even to Be, because this element has been measured with respect to C and CH_4 comparing the ratios Be : C and C : CH_4. The increase of the atomic weight of H brings Bainbridge's value for Be down to $9.0145\pm 0.000\,6$, which agrees with our value nearly within the limits of error.

The suggested change of the He : O ratio makes the energy balances for *all* nuclear transformations correct, including those not used in the determination of atomic weights; e.g.

$Be^9+\ \gamma\rightarrow 2He^4+n^1$	(Ref. 19)
$Be^9+H^1\rightarrow 2He^4+H^2$	(Ref. 1)
$Be^9+H^2\rightarrow Li^7+He^4$	(Ref. 1)[20]
$B^{10}+H^2\rightarrow 3He^4$	(Ref. 12)
$B^{10}+\ n^1\rightarrow Li^7+He^4$	(Ref. 3)
$O^{16}+H^2\rightarrow N^{14}+He^4$	(Ref. 11)

It also explains why no long range α-particles are observed when Be^9 is bombarded by protons (14): The reaction $Be^9+H^1\rightarrow Li^6+He^4$ should set only 1.6 MV energy free, of which the α-particle should receive 1 MV, corresponding to a range of about 5 mm. Particles of this range are observed, but the α-particles seem to be masked by the longer range (7 mm) deuterons.

The values of the above table are still somewhat uncertain because of the fact that range-energy relation of fast particles is involved. This relation is at present being reconsidered from the theoretical point of view, and there seems to be every hope of reducing the uncertainties due to this factor to a minimum. When these new data are available, it is hoped to make the fourth decimal of the atomic weight significant. The calculations will also be extended to heavier nuclei and, if possible, to some of the artificially radioactive ones. The increased accuracy of atomic weights will also no doubt be helpful in theoretical considerations on nuclear structure.

H. Bethe

Cornell University,
March 27, 1935.

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* Immediately before this note was sent to press, it came to my knowledge (Science, March 22, 1935) that Oliphant had arrived at essentially the same conclusions as pointed out here. No detailed account of Oliphant's arguments are yet available.

[1] Oliphant, Report London Conference.

[2] Lauritsen and Crane, Phys. Rev. **45**, 493 (1934).

[3] Taylor and Goldhaber, Nature **135**, 341 (1935).

[4] Bothe and Becker, Zeits. f. Physik **76**, 421 (1932).

[5] Crane and Lauritsen, Report London Conference.

[6] Crane, Delsasso, Fowler and Lauritsen, Phys. Rev. **46**, 109 (1934).

[7] MacMillan, Phys. Rev. **46**, 868 (1934).

[8] Aston, *Mass Spectra and Isotopes*, p. 101.

[9] Kirchner, Physik. Zeits. **34**, 897 (1933).

[10] Oliphant and Rutherford, Proc. Roy. Soc. **A141**, 266 (1933).

[11] Cockcroft, Report London Conference.

[12] Cockcroft and Walton, Proc. Roy. Soc. **A144**, 704 (1934).

[13] Chadwick, Constable and Pollard, Proc. Roy. Soc. **A130**, 463 (1931).

[14] Chadwick, Report to the London Conference on Nuclear Physics.

[15] Lawrence, McMillan and Henderson, Phys. Rev. **47**, 273 (1935).

[16] Haxel, Zeits. f. Physik **93**, 400 (1935).

[17] The question of changing to the scale He $=4.0000$ might be reconsidered at this moment when all atomic weights have to be changed anyhow.

[18] It is an advantage of the mass determination by transmutation data that the determination of neighboring elements relative to each other is much more accurate than that of the absolute atomic weight because the relative masses of neighboring elements are needed in predicting the energy evolved in unknown transmutations.

[19] Szillard and Chalmers, Nature **134**, 494 (1934).

[20] This process has been interpreted previously as $Be^9+H^2\rightarrow Li^6+He^5$. The assumption of the existence of He^5 is now no longer necessary.