The Spectroscopic and Free Electron Values of e/m

In a recent letter[1] on the present status of the value of e/m a conclusion is reached that the spectroscopic and free electron methods yield values of e/m which differ by only 0.0006×10^7 abs. e.m.u. or just the average deviation to be expected from the assigned probable errors. This conclusion is reached by including the writer's[2] x-ray refraction value of e/m with the spectroscopic results. The classification of the x-ray refraction value as a spectroscopic result was made by the writer[2] in discussing bound and free electron values of e/m and this has been followed in the above letter.[1] This value of $e/m=1.7601\pm 0.0003$ is not only much higher than any of the spectroscopic but also has the smallest probable error of any values in this group. The high weight thus accorded this value has the effect of raising the general average of the spectroscopic results into approximate agreement with the free electron values.

The x-ray refraction measurement, however, is in reality a free electron result and should not be averaged with the spectroscopic results. The refracting electron is bound to a particular atom during the entire process of refraction, but the frequency of the forced vibration is so much greater than the natural frequency of the electron that it acts almost completely as a free electron. The x-ray refraction process is thus entirely different from that involved when one evaluates e/m spectroscopically by atomic energy level transitions.

If we use the recalculated[1] values and divide them into two groups, the results are given in Table I.

TABLE I.

SPECTROSCOPIC RESULTS	
Separation of He and H lines	$1.7601_5\pm 0.0008$[3]
“ “ $H\alpha$ and $D\alpha$ “	$1.7581_4\pm 0.0004$[4]
“ “ “ “ “ “	$1.7579_3\pm 0.0004$[5]
“ “ “ “ “ “	$1.7592\ \pm 0.0005$[6]
Zeeman effect	$1.7569\ \pm 0.0007$[7]
Weighted average	$1.7583_1\pm 0.0002_8$
FREE ELECTRON RESULTS	
Direct velocity measurement	$1.7610\ \pm 0.0010$[8]
“ “ “	$1.7588\ \pm 0.0009$[9]
Magnetic deflection	$1.7597\ \pm 0.0004$[10]
Crossed fields	$1.7581\ \pm 0.0013$[11]
X-ray refraction	$1.7601\ \pm 0.0003$[2]
Weighted average	$1.7598_8\pm 0.0001_7$

The discrepancy between the free electron and the spectroscopic values is 3.5 times the sum of the probable errors and statistically there is less than one chance in 10^9 of the free electron value being as low as the spectroscopic. The ratio of the external to internal consistency for the spectroscopic results is 1.24 and for the free electron 0.77. Both of these indicate a reasonable estimate of probable errors, and consistency of results in each group. By considering the two weighted averages, the situation is found to be just as serious as that which led Birge[12] in 1929 to retain two values of e/m.

In seeking a cause for the discrepancy, one is impressed by the consistency (0.77) of the free electron results which are obtained from four entirely different experimental and theoretical methods. The spectroscopic result obtained by means of Houston's new method of analysis[13] is higher than is obtained by the usual spectroscopic method of analysis, but is still considerably lower than seems consistent with the free electron value. The Zeeman effect gives a very low value. The need for further experimental work on the value of e/m and a critical analysis of the theories involved is apparent.

As long as we have no direct evidence for rejecting one or the other of these results, the value of e/m that should be recommended for use in calculation is the average of the two results. In such a case the probable error should be sufficient to include both spectroscopic and free electron results. This value of e/m is

$$e/m=(1.7591\pm 0.0008)\times 10^7 \text{ abs. e.m.u.}$$

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February 25, 1939.

[1] R. T. Birge, Phys. Rev. **54**, 972 (1938).
[2] J. A. Bearden, Phys. Rev. **54**, 698 (1938).
[3] W. V. Houston, Phys. Rev. **30**, 609 (1927).
[4] C. D. Shane and F. H. Spedding, Phys. Rev. **47**, 33 (1935).
[5] R. C. Williams, Phys. Rev. **54**, 568 (1938).
[6] W. V Houston, see reference 1.
[7] L. E. Kinsler and W. V. Houston, Phys. Rev. **46**, 533 (1934).
[8] C. T. Perry and E. L. Chaffee, Phys. Rev. **36**, 904 (1930).
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[10] F. G. Dunnington, Phys. Rev. **52**, 475 (1937).
[11] A. E. Shaw, Phys. Rev. **54**, 193 (1938). Shaw's published value 1.7571 was calculated on the basis of international units. The present value is recalculated using absolute units.
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[13] W. V. Houston, Phys. Rev. **51**, 446 (1937).

The Actinium Series of Radioactive Elements and Their Influence on Geological Age Measurements

A. O. Nier has just published the results of his excellent investigations of the isotopic composition of uranium[1] and radiogenic leads[2] of different geologic origin.

His results completely and finally disprove the evidence, based on chemical atomic weight determinations, against the actino-uranium theory and the necessity of correcting geologic age measurement for the actinium series. They fully support the conclusions drawn in the author's paper,[3] presented before the Geochemistry Symposium at the Rochester Meeting of the American Chemical Society (September, 1937), that the reliability and accuracy of orthodox chemical atomic weight determination is substantially below those based on mass-spectrographic measurements and is insufficient to show the spread in atomic weights of leads expected from theory. In particular the "puzzling" Bedford crystalline lead proved to be in full accord with the predictions of theory.

Only two discrepancies, stressed by Nier, need be discussed here: The *first* is the extremely old (age $1.5–2.10^9 a$) Manitoba uraninite lead, which shows an AcD : RaG ratio far above our theoretical curve. However, this possibility was envisaged in our 1933 paper[4] in the following paragraph:

"Data on the oldest obtainable uranium leads from minerals unaltered as far as possible are especially desirable, to test the applicability of the actinium D: radium G ratio formula beyond a billion years. (The Manitoba uraninite, for instance, discovered by H. V. Ellsworth, with a lead/uranium = 0.27 should prove worth while.) They might also be interesting in another respect: In case the experimental curve should deviate in that range from our theoretical it might indicate the existence of a second actino-uranium isotope (still a possibility as we mentioned in paper 1), not yet in equilibrium with our present isotope. The Rutherford-Soddy disintegration theory allows one to calculate in a simple way the ratio of actinium D to radium G for different possible cases; it would be, however, premature to discuss these points at the present time."

Assumption of the genetic scheme:

$$\mathrm{AcU}^{239} \xrightarrow{\alpha,\ \beta,\ \beta} \mathrm{AcU}_{\tau}{}^{235} = 7.10^8 a$$

with a half-life value of the order of 10^8 years for AcU^{239} and a reasonable concentration in uranium during the early history of the earth's crust would account for the observed facts, i.e., the present absence of AcU^{239} and an excessively high Pb^{207} : Pb^{206} ratio in very old minerals.

The *second* discrepancy is between the activity ratio, R, of Nier = 4.6 percent and the directly determined values of 4.0–4.1 percent (Grosse (1932) = 4.0, E. Gleditsch and Foyn (1934) = 4, Francis and Da Tchang (1934) = 4.1) from the Pa : U ratio. However, the magnitude of this disagreement, i.e., $\simeq 10$ percent of the actual value, is not discomforting if one remembers that in a number of careful investigations previous to 1932 a much greater spread (B. B. Boltwood (1908) 8 percent; O. Hahn and L. Meitner (1919) 3 percent; G. Kirsch (1920) 4.2 percent; W. G. Guy and A. S. Russell (1923) 3.1 percent; A. S. Russell and W. P. Widdowson (1923) 2.9 percent; A. Piccard and E. Kessler (1923) 5 percent) was observed.

Although in a number of cases the errors were due to incomplete separation of protoactinium, we are reasonably sure this was not the case in our own $\mathrm{Pa-ZrP_2O_7}$ precipitations, which were checked for quantitative separation. Errors may have also been introduced by the different corrections required, such as range of particles or thickness of film. In our own measurement inaccuracies *may have* been introduced by inadequate correction for the self-absorption of α-particles in the $\mathrm{ZrP_2O_7}$ film. It is perhaps significant that the results in Mme. Curie's laboratory average 4.0 percent for the tantalum method and 4.2 percent for the $\mathrm{ZrP_2O_7}$-method. Further careful determinations will be required to decide the best value, but we believe no fundamental disagreement with Nier's value exists.

If Nier's value is correct it follows that the AcU^{235}-content of uranium equals 0.7_1 percent by weight and the weight of protoactinium associated in any uranium mineral with 1 g of Ra is increased to 0.9_3 g.

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[1] A. O. Nier, Phys. Rev. **55**, 150 (1939).
[2] A. O. Nier, Phys. Rev. **55**, 153 (1939).
[3] A. V. Grosse, see Abstracts of Rochester or 94th Meeting of the American Chemical Society, page 23.
[4] A. V. Grosse, J. Phys. Chem. **38**, 487 (1934).

On the Mass of the Mesotron

Since we published[1] the results of mass determination of the mesotron, the existence of which had theoretically been foreseen by Yukawa, we have been continuing the same experiments with the Wilson cloud chamber.

During last September we obtained a photograph shown in Fig. 1. A lead bar 5 cm thick was mounted in the middle of the chamber 40 cm in diameter, which is filled with air and alcohol vapor, and placed in a magnetic field of about 12,600 oersteds. The operation of the chamber was controlled by two Geiger-Müller tube counters mounted immediately above the chamber. The distance between the counters was about 15 cm. Above the counters was placed a lead block 20 cm thick.

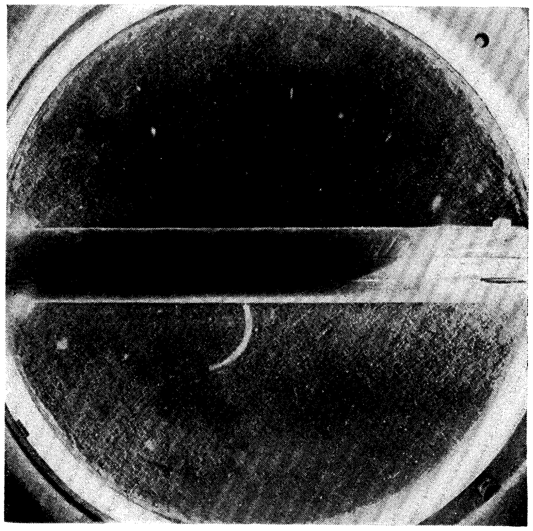

FIG. 1. Wilson track of a mesotron. $H = 12{,}600$ oersteds. $H\rho = 3.88 \times 10^4$ oersted·cm. Observed range = 6.15 cm.

A negatively charged particle of $H\rho = (3.88 \pm 0.08) \times 10^4$ oersted-cm seems to have been created within the lead bar by a certain non-ionizing agent and was brought to rest in the gas of the chamber, the observed range being 6.15 cm. By taking into account the pressure of the gas, which was between 1.23 and 1.30 atmospheres at 25°C, and a possible inclination of the track with respect to the plane of the chamber, we estimate its range in air of 15°C and 760 mm to lie between 7.3 and 8.1 cm. According to the range-energy curve for the proton given by Livingston and Bethe[2] we calculate the mass of the particle by using the above values of $H\rho$ and range and obtain

$$M_m = (170 \pm 9) m, \tag{1}$$

where m is the mass of the electron.

At the end of the range the photograph shows no sign of an electronic track, which would prove the disintegration of the mesotron.

We have recently re-examined the old photograph mentioned in our preceding paper[1] and obtained the following values. A positively charged particle of $H\rho = (7.4 \pm 0.1)$