scalar units in desired combinations. The H_1 intensity of the square wave is constant throughout a T_1 measurement, giving $n_i=k(H_1)n_0$ where $k(H_1)$ is a proportionality factor which is constant for H_1 constant. In Fig. 1, n corresponds to the measured height of the inverted signal occurring at the time t chosen; n_0 corresponds to the measured height of the positive signal at $t=0$. For distilled water (not in vacuum) the data illustrated in Fig. 2 give $T_1=2.33\pm0.07$ sec. as compared with 2.3 ± 0.5 sec. measured by Purcell *et al.*[1] For this particular case, five measurements were made per point. The method permits even higher accuracy if more measurements per point are taken. The single signals seen here are much larger than ordinary periodic resonance signals, and signal to noice ratio is high. Shorter values of T_1 can also be measured by subjecting the sample to higher frequency H_0 field modulation.

* This work was supported in part by ONR contract N6-ori-71.
[1] Bloembergen, Pound, and Purcell, Phys. Rev. **71**, 466 (1947).
[2] This method appears to be similar to one reported by H. C. Torrey, Phys. Rev. **75**, 1326 (1949).
** This effect will be discussed in a paper to be published on the nutation of the nuclear magnetic moment.

An Error in a Paper by Landau on Coulomb Interactions in a Plasma*

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May 20, 1949

LANDAU[1] attempts to show that the Coulomb interactions of electrons and ions in a plasma can be represented as the divergence of a flow vector in momentum space. To obtain this result he expands the probability w of scattering through a small angle in powers of that angle without properly taking into account the singularity of w at zero deflection. Fortunately this expansion is avoided by reversing the integration by parts. Landau's Eq. (1) is

$$\int [n(p)n'(p')-n(p+\Delta)n'(p'-\Delta)]w(p-p',\Delta)d\tau' d\tau_\Delta. \quad (1)$$

The distributions n, n' are continuous and can be expanded in powers of Δ

$$n(p+\Delta)=n(p)+\frac{\partial n}{\partial p_i}\Delta_i+\frac{1}{2}\frac{\partial^2 n}{\partial p_i\partial p_k}\Delta_i\Delta_k,$$

$$n'(p'-\Delta)=n'(p')-\frac{\partial n'}{\partial p_i'}\Delta_i+\frac{1}{2}\frac{\partial^2 n'}{\partial p_i'\partial p_k'}\Delta_i\Delta_k.$$

Substituting in (1) the zero order terms cancel and the first order terms vanish on integration, leaving

$$\int\left[\frac{\partial n}{\partial p_i}\frac{\partial n'}{\partial p_k'}-n'\frac{\partial^2 n}{\partial p_i\partial p_k}+\frac{\partial n}{\partial p_i}\frac{\partial n'}{\partial p_k'}-n\frac{\partial^2 n'}{\partial p_i'\partial p_k'}\right]w\frac{\Delta_i\Delta_k}{2}d\tau' d\tau_\Delta. \quad (2)$$

This expression is correct. The last two terms are now integrated by parts, and use made of the relation

$$\partial w/\partial p_k' = -\partial w/\partial p_k,$$

giving

$$\int\left[\left(\frac{\partial n}{\partial p_i}\frac{\partial n'}{\partial p_k'}-n'\frac{\partial^2 n}{\partial p_i\partial p_k}\right)w+\left(n'\frac{\partial n}{\partial p_i}-n\frac{\partial n'}{\partial p_i'}\right)\frac{\partial w}{\partial p_k}\right]\frac{\Delta_i\Delta_k}{2}d\tau' d\tau_\Delta. \quad (3)$$

This is Landau's result on page 156 *except for the sign before the second parenthesis.* Unfortunately this expression does not reduce to a divergence.

There is a further error in Landau's method, which I have followed in going from (2) to (3) in order to point out the error in sign. The vector $(\mathbf{p}+\mathbf{p}')/2=\mathbf{g}$ represents the motion of the center of gravity and the conservation laws require $\mathbf{p}$, $\mathbf{p}'$, $\mathbf{p}+\mathbf{\Delta}$, and $\mathbf{p}'-\mathbf{\Delta}$ to terminate on a sphere about $\mathbf{g}$. The integration by parts was done holding $\mathbf{p}$ and $\mathbf{\Delta}$ constant. This obviously restricts $\mathbf{p}'$. To be correct the integration should be at constant scattering angle, in which case the quantity $\Delta_i\Delta_k$ occurs with w in the derivative $\partial(w\Delta_i\Delta_k)\partial p_k$.

Unless the second half of (3) can be shown to be small, these errors will affect the results of Cahn[2] in two recent papers on the velocity distribution in a plasma.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and ONR.
[1] E. Landau, Physik Zeits. Sowjetunion **10**, 154 (1936).
[2] J. H. Cahn, Phys. Rev. **75**, 293, 838 (1949).

Proton Range-Energy Relation

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May 10, 1949

RECENT experiments have provided several points for the proton range-energy relation at low energies. We wish to report two more points and review the available data. The review is limited to data from cloud chambers since these experiments give mean ranges directly. The results of these determinations are shown in Fig. 1. The experimental points are numbered to correspond to paragraphs in the text. The Livingston and Bethe[1] (hereafter L & B) and the Cornell revised 1938[2] range-energy curves are included for comparison. All data are at S.T.P. (15°C, 76 cm Hg).

Point I: Twenty-eight tracks, equivalent in weight to fourteen tracks of good quality were obtained from the $H^2(\gamma,n)H^1$ reaction using Ga^{72} γ-rays in a cloud chamber filled with D_2 and D_2O vapor.* The expansion ratio was 1.36, the average temperature was 26.2°C and the total pressure was 65.1 cm before expansion. The mean range in deuterium was 0.53 ± 0.03 cm which, using the differential stopping powers of Blackett and Lees,[3] is equivalent to 0.18 ± 0.01 cm in air. Using $E_\gamma=2.250\pm0.05$ Mev[4] and a deuteron binding energy of 2.237 ± 0.005 Mev[5] E_p becomes 0.13 ± 0.03 Mev.

Point II: A similar experiment was performed using the γ-rays from ThC″. Thirty-five tracks of good quality were obtained at an expansion ratio of 1.33 at an average temperature of 21°C and

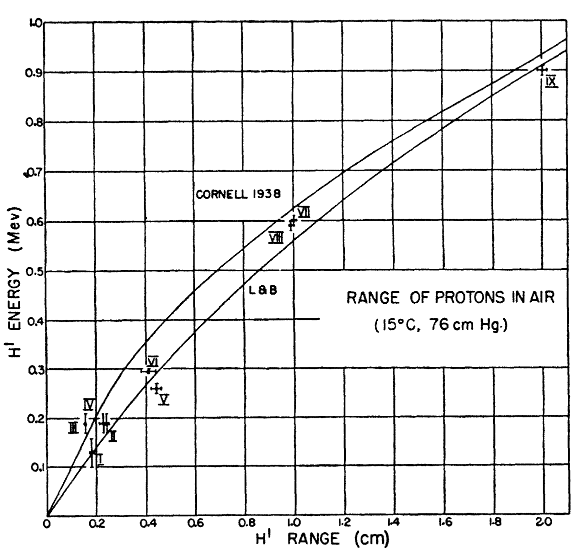

FIG. 1. Range of protons in air (15°C, 76 cm Hg).

a total pressure of 69.5 cm before expansion. The mean range in deuterium was 0.74 ± 0.03 cm which is equivalent to 0.24 ± 0.01 cm in air. Using $E_\gamma=2.620\pm0.006$ Mev, E_p becomes 0.19 ± 0.02 Mev.

In the following review the differential stopping powers of Blackett and Lees are used for protons in H_2 and He. In applying these stopping powers the L & B range-energy relation is used as a close approximation. Only a negligible change would result if the Cornell 1938 curve were used. The carbon stopping powers are those listed by L & B. The value 2.237 ± 0.005 Mev is used as the binding energy of the deuteron. The $n-H^1$ mass difference is taken as 0.803 ± 0.005 Mev, the mean of the values of Elliott and Bell[5] and of Tollestrup *et al.*[6]

Point III:[7] Protons from $H^2(\gamma,n)H^1$ using γ-rays from ThC″.

Fifteen tracks were obtained in an atmosphere of D_2 and D_2O vapor at a total pressure of about 8.0 cm, of which about 2.7 cm was due to D_2O. The range in the gas was 2.9 cm, which is equivalent to 0.155 cm in air. No error was assigned to this measurement.

Point IV:[8] Protons from $H^2(\gamma,n)H^1$ using γ-rays from ThC″.

Sixty-two tracks having an average length of 0.613 cm were obtained in an atmosphere of 40 percent CH_4 and 60 percent He. For α-particles of 2 cm residual range, a mica foil of 0.902 cm air equivalent corresponded to 2.91 cm of gas. The corresponding range in air was 0.23 ± 0.02 cm.

Point V:[9] Protons from $H^2(\gamma,n)H^1$ using Na^{24} γ-rays.

The chamber was calibrated with an α-particle source whose range was determined in a separate experiment. The reduced air range was 0.36 cm. The corresponding true air range is 0.44 cm. The error is estimated here to be 0.02 cm. Using $E_\gamma=2.76$ Mev,[10] E_p becomes 0.26 ± 0.01 Mev.

Point VI:[11] Tritons from $H^2(d,n)H^3$.

The energy of the tritons from this reaction is computed from the $Q(4.04\pm0.02$ Mev[6]) to be 0.89 ± 0.01 Mev. The range is given as 1.31 ± 0.10 cm of air, of which an estimated 0.50 cm was due to an aluminum foil. The remainder of the range was in a He filled cloud chamber, and has been changed from 0.81 to 0.83 cm to take account of the change in stopping power. Determinations of the stopping power of aluminum show poor agreement. From the range in aluminum given by Parkinson *et al.* and Wilcox,[12] the air equivalent of the foil has been changed to 0.40 ± 0.07 cm. The final range in air becomes 1.23 ± 0.10 cm. For the equivalent proton the energy and range are 0.296 ± 0.003 Mev and 0.41 ± 0.03 cm, respectively.

Point VII: Protons from $N^{14}(n,p)C^{14}$.

The range of the protons is 1.00 ± 0.01 cm.[13] The proton energy may be calculated from the $n-H^1$ mass difference and the C^{14} β-end point (0.154 ± 0.007 Mev)[14] to be 0.60 ± 0.01 Mev.

Point VIII:[15] Protons from $He^3(n,p)H^3$.

The range of the protons was obtained by comparison with the proton range from $N^{14}(n,p)C^{14}$ and hence is not an independent measurement. From the range assumed for Point VII the range for Point VIII becomes 0.99 ± 0.01 cm. The proton energy may be calculated from the $n-H^1$ mass difference and the H^3 β-end point (18.9 ± 0.5 kev)[16] to be 0.59 ± 0.01 Mev.

Point IX:[17] Tritons from $Li^6(n,\alpha)H^3$.

The chamber was calibrated with the α-particles from ThC. The triton mean range was 6.00 ± 0.06 cm.** The range of the equivalent proton is then 2.00 ± 0.02 cm.

Following Bøggild and Minnhagen, the Q of this reaction has been estimated from mass values and reaction cycles to be 4.74 ±0.06 Mev. This estimate takes account of the more recent $n-H^1$ mass difference and the H^3 β-end point. The lack of agreement between this value and the measurement of Bøggild and Minnhagen (4.56 Mev) may be due to uncertainties in the range-energy relation,[18] and possibly due to the method of calibrating the chamber for α-particles. The equivalent proton energy is then 0.90 ± 0.01 Mev.

The data favors the curve of Livingston and Bethe, although there is some indication that this curve may be about 20 kilovolts low in the region of 0.5 Mev.

The experimental work for Points I and II was performed by the authors in the Radiation Laboratory of McGill University, and was supported by scholarships from the National Research Council of Canada.

* A similar experiment using the γ-rays from La^{140} yielded a mean range of 0.52 ± 0.03 cm in D_2. The γ-ray energy is not known with sufficient accuracy for the purposes of this Letter.

** We are indebted to Dr. J. K. Bøggild for informing us that this is the range at S.T.P.

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The Actinide Series and the Periodic Table

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SEABORG and Wahl[1] have recently published an article on the chemical properties of elements 94 and 93, indicating again that the transuranic elements are members of a group of atoms similar to the rare earths. This opinion was already put forward theoretically in relation to the arrangement of the electrons in atoms. The calculations of Wu and Goudsmit[2] as well as of Goeppert Mayer[3] showed the filling up of the 5f level at U or at Pa. They declare, however, that inaccuracies of a few units in Z are to be expected as their calculations concerning the starting of the group are of approximate character.

The author believes that chemical investigations can also contribute to the elucidation of this problem. The established regularities of the periodic system and the similarities of analogous compounds indicate sufficiently that Ac and the following elements belong to a group similar to the rare earths. Thus Th, Pa, and U as well as Np and Pu can by no means be considered as higher homologues of the Ti, V, Cr, Mn groups, respectively of Ru and Os. They are members of the Al group just as well as the lanthanides. The main property functions supporting our suggestions are as follows:

Apart from the single boron, the specific weights show a monotonous change in the columns of the system. Th and U would represent the only exceptions, if they were to remain in the IV resp. VI column.

The same can be said of the melting points. These do not show such a strict change, as the specific weights do, however, within each column the variation is monotonous, or if in a few cases a discrepancy occurs, it is not significant. On the other hand in the columns accepted up to date the melting point of Th sinks back to about 500° and that of U to about 2000°. On comparing with the elements of the III column, the melting points of Th and U fit into the regular change.

The third striking property of the homologous series in the system is the variation of the ionization potentials. These sink gradually in the main groups—apart from slight deviations which are without meaning in the case of determining such subtle data—whereas they rise in the by-groups.[4]