Values of μ_p, F, and M_p/m_e Using the Omegatron

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IN an earlier note,[1] we described a method of measuring the cyclotron frequency of ions with an instrument which we called the omegatron. In illustration of the promise of this method, we presented a preliminary value of the ratio of the cyclotron frequency of the proton ν_c to its precessional frequency ν_n in the same magnetic field. Because this preliminary value has been used by others in several publications, we feel that our most recent results should be made available, although further work will probably improve the accuracy.

A careful study made it apparent that the resonant frequency could be shifted by more than 1 part in 5000 by sufficiently varied operating conditions. A consistent method of correcting for these shifts, which are attributable largely to space charge, has now been developed. Since the frequency shift is proportional to the mass, the true cyclotron frequency can be determined by using the isotopic weights of the ions. The frequency shift can thus be determined by making measurements under identical experimental conditions on several masses. Consistent results for the proton have been obtained by correcting with H_2^+, D_2^+, and H_2O^+. A detailed description will be presented later. Our result is now

$$\nu_n/\nu_c = 2.79268 \pm 0.00006,$$

where ν_n was measured in water. This ratio is μ_p, the proton moment in nuclear magnetons[2] (without diamagnetic correction). Using the gyromagnetic ratio of the proton,[3]

$$\gamma_p = (2.67523 \pm 0.00006) \times 10^4 \text{ sec.}^{-1} \text{ gauss}^{-1}$$

(no diamagnetic correction), and the isotopic weight of the proton,[4] $A_p = 1.007580$, the faraday is

$$F = 9652.03 \pm 0.3 \text{ e.m.u./g (physical scale).}$$

Combining our result on the frequency ratio with the measurement of Gardner and Purcell[5] one obtains

$$M_p/m_e = 1836.12 \pm 0.05.$$

[1] Hipple, Sommer, and Thomas, Phys. Rev. **76**, 1877 (1949).
[2] L. W. Alvarez and F. Bloch, Phys. Rev. **57**, 111 (1940).
[3] Thomas, Driscoll, and Hipple, Phys. Rev. **78**, 787 (1950).
[4] K. T. Bainbridge, "Isotopic Weights of the Fundamental Isotopes," Preliminary Report No. 1, Nat. Res. Council (June, 1948).
[5] J. H. Gardner and E. M. Purcell, Phys. Rev. **76**, 1262 (1949).

A New Method for Determining the Value of the Faraday

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IN a program on the redetermination of the value of the faraday at the National Bureau of Standards twelve determinations were made during the summer of 1949 by anodically oxidizing Bureau of Standards Standard Sodium Oxalate No. 40e in a sulfuric acid solution. As much as 12 g of oxalate was oxidized in a single determination. The average of all but the first result is 9651.93±0.26 e.m.u. Eq^{-1} (physical scale). The first result obtained is omitted from the average because it was agreed that a result obtained in a pilot run should not be averaged with the rest. Its inclusion would change the average less than 1 part in 100,000.

Final publication of the results is being delayed because the authors wish to assure themselves that the reaction,

$$C_2O_4^{--} - 2e \rightarrow 2CO_2,$$

is a pure one. All the evidence so far obtained indicates that this is so, but several additional rather difficult experiments will be required to verify the conclusions on the purity of the reaction. The final determinations are to be made by oxidizing an equivalent weight (67 g) of sodium oxalate. Tests have shown that this can be done. The purity of the sodium oxalate is taken as 99.96$_0$ percent. This value was most painstakingly established by the analytical work of H. B. Knowles and W. Stanley Clabaugh of this Bureau.

The value of the faraday determined electrolytically by the use of sodium oxalate should be of interest to those workers interested in the re-evaluation of the fundamental atomic constants[1,2] because the atomic weights of sodium, carbon, and oxygen are involved instead of the more conventional silver. Furthermore, approximately one-half of the sodium oxalate molecule, $Na_2C_2O_4$, consists of oxygen, whose atomic weight is given by definition. As far as the authors know, this reaction has never before been used to determine a value of the faraday.

Another part of the program at this Bureau is concerned with the anodic solution of pure silver and the cathodic deposition of silver in an electrolyte containing silver perchlorate and perchloric acid. The preliminary results obtained with the two methods involving silver are slightly higher than those obtained with oxalate, but the work has not progressed to the point where final values can be given. However, the average of all the results (25) obtained by the three methods is 9652.33±0.62 e.m.u. Eq^{-1} (physical scale).

In accordance with DuMond's suggestion (Phys. Rev. **77**, 411 (1950)) our values for one gram of singly charged ions of unit isotopic weight might be expressed on the physical scale as 9651.93±0.26 e.m.u./g and 9652.33±0.62 e.m.u./g, respectively. The electrochemist, however, prefers the definition in terms of an equivalent because this definition is an operational one.

[1] J. W. M. DuMond, Phys. Rev. **75**, 1267 (1949).
[2] J. A. Bearden and H. M. Watts, *A Reevaluation of the Fundamental Atomic Constants* (The Johns Hopkins University Radiation Laboratory, July 31, 1950).

Selection Rules for Closed Loop Processes

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TRANSITIONS which can be described by closed loop Feynman diagrams[1] are sometimes forbidden by the symmetry existing between particles and antiparticles. Furry[2] dealt with the case in which electrons and positrons are the particles associated with the closed loop.

A proof of Furry's theorem which can be modified easily for the nucleon case is given in this note. The proof is so modified as to apply to the case of closed nucleon loops connecting meson lines.

The existence of a matrix C such that

$$X^T = \pm C X C^{-1} \tag{1}$$

is well known.[3] Here X is a Dirac matrix and T denotes the operation of transposition. The upper sign holds for[4]

$$X = 1, \quad \gamma_\mu\gamma_\nu\gamma_\sigma (\mu \neq \nu \neq \sigma), \quad \gamma_1\gamma_2\gamma_3\gamma_4,$$

while the lower sign holds for

$$X = \gamma_\mu, \quad \gamma_\mu\gamma_\nu (\mu \neq \nu).$$

The first (second) group of matrices is called even (odd).

Consider the transition

$$\beta_1 \rightarrow \beta_2 + \beta_3 \tag{2}$$

between three neutral bosons (photons or neutral mesons), the process taking place by means of the virtual creation and annihilation of fermions. According to reference 1, the Feynman diagram will be a closed triangle of fermion and antifermion lines with boson lines at the vertices.

Let X_i ($i = 1, 2, 3$) be the Dirac matrices for the fermion-boson interactions. Suppose the fermion and antifermion are created

with the annihilation of B_1 and after the fermion has emitted B_2, the Fermi particles are annihilated with the emission of B_3. A second way in which this process can take place is obtained if the antifermion emits B_2. The triangles in the two cases differ only in the directions of the Feynman arrows.

The only difference in the matrix elements for the two transitions is that the first one contains the trace of the matrix

$$X=X_1(p_1-m)^{-1}X_2(p_2-m)^{-1}X_3(p_3-m)^{-1},$$

while the second contains the trace of the matrix

$$X'=X_1(-p_3-m)^{-1}X_3(-p_2-m)^{-1}X_2(-p_1-m)^{-1},$$

where p_i are appropriate functions of the energy-momentum four-vectors of bosons and Fermi particles combined with γ_μ according to Feynman. The minus signs of p_i in X' occur in the usual way when the behavior of fermions is contrasted with that of antifermions.

By Eq. (1)

$$X'^T=(-)^rCXC^{-1},$$

where r of the matrices X_i satisfy Eq. (1) with the minus sign. Taking the traces of the matrices makes it at once evident that the contributions of the two processes cancel each other if r is odd.

Other contributions to the total matrix element are obtained by permuting the processes involving B_i, which means orienting the triangle in different ways with respect to the time direction. These contributions can similarly be grouped into pairs.

For the sake of simplicity we have considered a triangular loop, but it is obvious that the above argument can be generalized for any closed loop. Hence, we have Furry's theorem for transitions between neutral bosons: processes associated with closed loops which can be traversed in opposite directions are forbidden if an odd number of odd Dirac matrices are associated with that closed loop.

Analogous selection rules can be formulated for the case where the bosons in Eq. (2) are neutral and charged mesons. In this case, to every way in which a transition can take place, there corresponds a second way which is obtained by replacing in the Feynman triangle, protons (neutrons) by antineutrons (antiprotons) or vice versa.

Let the contribution of the first process depend on the trace of

$$X=X_1\tau_i(p_1-m)^{-1}X_2\tau_j(p_2-m)^{-1}X_3\tau_k(p_3-m)^{-1},$$

where τ_i ($i=1, 2, 3$) are the isotopic spin matrices. The contribution from the second process then contains

$$X'=X_1\tau_1\tau_i\tau_1(-p_3-m)^{-1}X_3\tau_1\tau_k\tau_1(-p_2-m)^{-1}\times X_2\tau_1\tau_j\tau_1(-p_1-m)^{-1},$$

where the introduction of τ_1 effects the above replacements. Since

$$\tau_1\tau_i{}^T=\tau_i\tau_1 \quad (i=1, 2),$$
$$\tau_1\tau_3{}^T=-\tau_3\tau_1,$$

it follows that

$$X'^T=(-)^{r+s}CXC^{-1},$$

where r denotes the number of odd matrices among X_i ($i=1, 2, 3$), and s the number of neutral mesons.

This result can be generalized as follows for transitions between neutral and charged mesons via nucleons: Transitions between charged and neutral mesons associated with reversible closed nucleon loops are forbidden if the sum of the number of odd Dirac interaction matrices and the number of neutral mesons is odd.

The first theorem plays a fundamental role in a process like vacuum polarization. The second theorem will apply in cases where, for instance, a heavy charged meson decays into a lighter charged meson and a neutral one. Thus far no such decay process has been observed.

[1] R. P. Feynman, Phys. Rev. **76**, 769 (1949).
[2] W. H. Furry, Phys. Rev. **51**, 125 (1937).
[3] W. Pauli, Rev. Mod. Phys. **13**, 203 (1941). Our C equals Pauli's C times γ_4.
[4] The γ-matrices are defined as in reference 1.

Disintegration of He^3 by Fast Neutrons*

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THE large cross section found to exist for the $He^3(n,p)T$ reaction at thermal neutron energy[1-3] indicates that this reaction may be investigated with relative ease for fast neutrons. Such an investigation has been carried out using techniques similar to those previously described.[2]

A proportional counter having a known sensitive volume was filled with a 31.4-cc sample of pure He^3 to which was added Kr at suitable pressure. Nearly monenergetic neutrons were produced at various energies in the range from 0.4 to 3.0 Mev by use of the two reactions: $T(p,n)He^3$ and $D(d,n)He^3$. The number of disintegrations induced in the He^3 by these neutrons was measured with the counter and neutron source located in well-defined geometry.

The absolute number of neutrons entering the counter was determined by use of a "long counter,"[4] the sensitivity of which was calibrated against the half-gram Ra-Be source No. 44 whose neutron source strength has been measured by Walker.[5]

The disintegration pulses were sorted by a 10-channel pulse-height analyzer. For the determination of the total number of disintegrations the pulse-height distribution curves were extrapolated (using an estimation of "wall effect") to zero pulse height, and the area under the curve was obtained numerically. The area under the extrapolated portion ranged from 20 to 45 percent of the total. It is estimated that the uncertainty of the extrapolation may introduce errors of from 15 to 20 percent in the cross-section determinations.

Measured cross-section values are indicated by the circles plotted in Fig. 1. The estimated probable error, including a guess

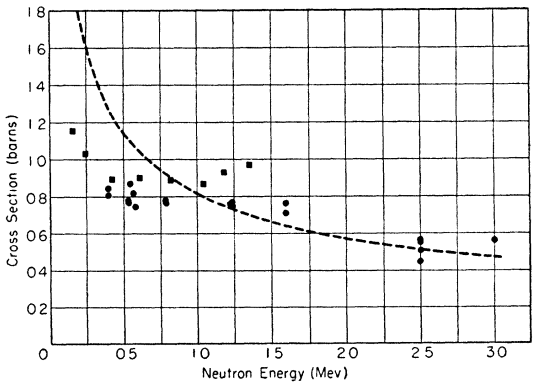

FIG. 1. Cross section for the reaction $He^3(n,p)T$ as a function of neutron energy. Directly measured values are indicated by circles. Values deduced by detailed balancing from measurements of the inverse reaction are indicated by squares. The solid curve is deduced by the $1/v$-law.

of systematic errors, is ± 30 percent. For comparison, the $1/v$-law dependence is shown as a dashed curve, though it it not to be expected that the data follow such a dependence. The results of King and Goldstein[3] for neutron absorption in the thermal region were used to deduce the $1/v$-curve.

The data of Jarvis, *et al.*[6] for the cross section of the inverse reaction, *viz.* $T(p,n)He^3$, may be compared with the present measurements by the principle of detailed balancing. The squares in Fig. 1 indicate values deduced from their data. Within experimental errors the two sets of values agree.

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[1] Batchelor, Eppstein, Flowers, and Whittaker, Nature **163**, 211 (1949).
[2] J. H. Coon and R. A Nobles, Phys. Rev. **75**, 1358 (1949).
[3] L. D. P. King and Louis Goldstein, Phys. Rev. **75**, 1366 (1949).
[4] A. O. Hansen and J. L. McKibben, Phys. Rev. **72**, 673 (1947).
[5] R. L. Walker, MDDC 414, LADC 155, October, 1946, unpublished.
[6] Jarvis, Hemmendinger, Argo, and Taschek, Phys. Rev. **79**, 929 (1950).