with increasing temperature as in the Stasiw and Pohl experiments, but on the contrary decreases with increasing temperature; (2) sensitization does not necessarily result merely from the passage of a dark current through the crystal but commences only when the dark current begins to decrease with time; (3) the dark current does not decrease exponentially with decreasing temperature but remains comparatively large at low temperatures.

In conclusion we wish to thank Dr. K. K. Darrow and Mr. E. J. Murphy for many stimulating and helpful discussions during the preparation of this manuscript.

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Time Lags in Magneto-Optics

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A modification has been introduced in the apparatus usually employed for the time lag experiments, thereby enabling photometric measurements to be made. Minima were observed, but they were not confined to definite trolley positions. This apparatus has served to emphasize the variations in the exciting magnetic field, but has not disclosed evidence to support the view that sharp minima due to other causes are present.

THE problem of the time lag in the Faraday effect and of other possible related effects has been under examination for a long time, but within the past few years the results of Beams and Allison,[1] and particularly of Allison and his students,[2] have aroused much interest. The whole problem obviously demanded the attention of workers in numerous other laboratories, in order that the results might be checked, and if possible enough material obtained for a satisfactory basis to a theoretical treatment of the subject.

To assist in the study of this problem, the work reported in this article was begun about three years ago with the installation of apparatus substantially in accord with the descriptions in the references cited. On the first apparatus constructed the results were largely qualitative, and completely negative so far as sharp minima were concerned.

The qualitative results of the original set-up may be summarized in this way: First, the existence of the broad minimum for CS_2 in both cells was readily shown, and a satisfactory explanation in terms of the electrical constants of the circuit was demonstrated. This is in agreement with the findings of Slack and Breazeale[3] and of Webb and Morey.[4] Second, it was shown that temperature effects in the CS_2 cells were apt to be troublesome. Because of this water-cooled cells have been used since that time whenever measurements have been made. In addition the variability of the spark was clearly another hindrance to satisfactory observation.

Having failed to note definitely any sharp minima, one of us (H. W. F.) visited Dr. Allison's laboratory in August, 1933, where every courtesy was shown, and every opportunity given to study the apparatus, method of observing, as well as other details of the work. On the second day minima of the sharp type were seen in his apparatus. Minima were also seen a few days later in the laboratory of Professor F. G. Slack at Vanderbilt University.

Apparatus

Our apparatus was then completely rebuilt in a larger room, reproducing with extreme care every essential of the apparatus seen in Alabama. In some respects minor changes were introduced. For example the sliding bridge or "trolley"

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[1] Beams and Allison, Phys. Rev. **29**, 161 (1927).

[2] Allison *et al.*, J. Chem. Ed. **10**, 2 (1932).

[3] Slack and Breazeale, Phys. Rev. **42**, 305 (1932).

[4] Webb and Morey, Phys. Rev. **44**, 589 (1933).

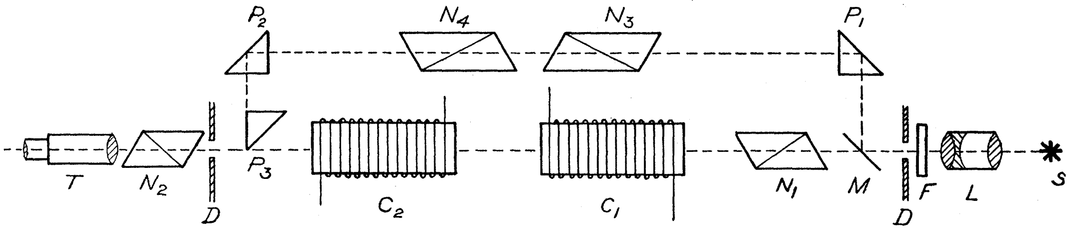

FIG. 1. Optical system used to give a comparison field. S, magnesium spark; L, lens; F, filter; D, diaphragms; N_1, polarizer for direct beam; C_1, C_2, Faraday cells inside coils; N_2, analyzer; T, telescope; M, cover glass at 45° to axis of system; P_1, P_2, P_3, right-angle prisms; N_3, polarizing Nicol in comparison train, set parallel to N_2; N_4, rotating Nicol from which scale angles are read for measuring intensities.

which moves over the long wires seemed in some of the set-ups to fail occasionally to make positive contact, and we had demonstrated that a minimum could be simulated by a contact variation. Our bridge therefore was designed to prevent such difficulty.

The hand wheel which operates the trolley by means of cords and pulleys was purposely arranged to facilitate slow motion of the trolley and no observer has been permitted to check the relation between the motion of the trolley and that of the periphery of the wheel.

After construction, the next task was to set our scale, and it was thought best to locate first the CS_2 minimum as accurately as possible and then to work from that to locate the HCl minimum generally used for setting the scale. The general region of the CS_2 minimum was found, but when HCl was used in the second cell, minima similar to those seen in Alabama were observed for many different trolley positions. Records of these minima failed to indicate any definite or favorite location and finally an attempt was made to locate them by having one of us observe while the other moved the hand wheel. The same sort of results as before were obtained, the observer at last reporting minima while the assistant had, without the observer's knowledge, ceased moving the trolley.

This led to the adoption of the arrangement shown in Fig. 1 for providing a comparison field. The light for the comparison field is thus a certain fraction of that passing through the experimental cells. Since the plane of the reflecting surface, M, is vertical, the first Nicol, N_3, in the "shunt" path was set to pass the vertical component. The second Nicol in the shunt path, N_4, has a circular scale and is initially set with its principal plane at right angles to that of N_3. The Nicol, N_4, is capable of rotation by turning either fast or slow motion knobs within easy reach of the observer. Since the analyzer, N_2, is set with its principal plane parallel to that of N_3, it follows that on rotation of N_4 through an angle θ there passes N_2 from the shunt path a horizontal component of magnitude $K \sin^2 \theta$, the value of K of course depending not only upon the source, but upon the number of reflecting surfaces and the characteristics of the media involved. Furthermore the amplitude of the light pulse passing N_2 from the direct path, as well as that from the shunt path, is directly related to the intensity of the original light from the spark, and if the optical paths are identical, the comparison of the two fields is independent of the intensity of the light from the source. (Actually in our arrangement the shunt path was about 20 cm longer, but this remained constant, and therefore introduced no great error.) As a result the rotation of N_4 is a measure of whatever takes place in the direct beam during the passage through the Faraday cells.

The angular aperture of the field observed was actually about five degrees, thus being sufficiently large to make proper comparison. While we took no measurements of field brightness, it should be stated that no measurements were taken on the apparatus until the observers had been in the dark for at least fifteen minutes. At the lowest intensities measured, the field could not be seen before fifteen or twenty minutes of dark adaptation.

If the adjustment is properly made, this arrangement should eliminate trouble caused by spark variation whether that variation is in actual brightness or in position between the

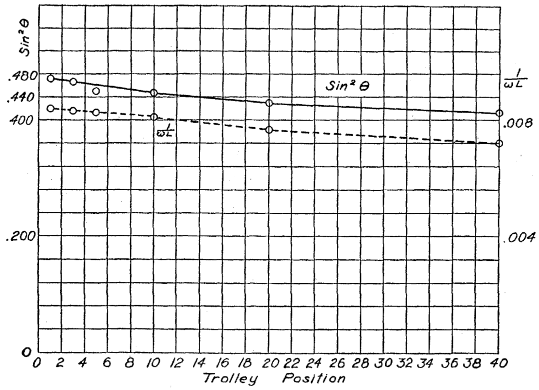

FIG. 2. Trolley position and light passed through cell C_2.

faces of the electrodes. Study of the change produced in the fields at the separating lines showed that change of spark position did not produce any abrupt change in the fields. We believe that this procedure is essential in such experiments as the one under discussion, whether the visual method or the photoelectric cell method of observation be used. Actually we used the visual method for two reasons, it was the one used by others in this work, and it is probably more satisfactory at the extremely low intensities involved. If further work on the problem is carried out, the two beams need not be brought into a single field but each may be passed through an analyzer and into a photoelectric cell, the two photo-cells being connected to oppose each other in feeding into the detector system.

TEST OF THE PHOTOMETER

Having a suitable measuring tool we first showed that the rotation produced in the Faraday cells was definitely related to spark gap width, increased intensity resulting from increased gap. An illustration of this is found in Fig. 5. Hereafter all readings were taken with gap adjusted to the same width after every two observations, the practise being to set Nicol N_4 for a match first from one side, when the comparison field was too bright, then from the other, when the comparison field was too dark. The mean of these two settings represented one reading for a photometric match.

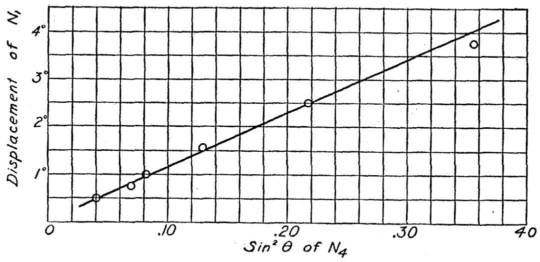

FIG. 3. Calibration of Nicol N_4.

To test the method more definitely we measured the amplitude of the light passing through cell C_2, whose coil was in series with the movable trolley, when cell C_1 and its coil were not used. The variation in the amplitude with trolley position is shown in Fig. 2 where the ordinate represents the square of the sine of the angle as read from the scale of N_4. The unit for the trolley scale is that usually employed and is equal to 15 cm, so that a change of position of the trolley a distance of 1 scale division means a change in electrical path amounting to 10^{-9} second. The zero on our scale is arbitrary, but very roughly, 10 on this scale corresponds to 15 on Allison's scale. Since the intensity of the light passing the analyzer N_2 is a function of the current in the coil, it should therefore be closely related to the impedance of the circuit. We have computed from our wave meter readings the values of $1/\omega L$ for different trolley positions. For the sake of comparison these are also shown in Fig. 2.

While this procedure is not quite rigorous, it is at least a very good approximation and it justifies the conclusion that the measuring apparatus is sufficiently reliable and sensitive for the purpose in hand. Further measurements with reference to electrical constants of the circuit have been quite in accord with the findings of Slack and Breazeale.[3]

A further test of the photometer consisted of a measurement of the intensity of the light passing N_2 when N_1 was set at various small angles to its normal position. This is in effect a calibration of the scale of N_4 for measuring rotation angles in the cell system. The result of this calibration is set out in Fig. 3.

MEASUREMENT FOR THE CS_2 MINIMUM

Then followed the resumption of tests to locate as accurately as possible the position of the minimum for CS_2 in both cells, since this has

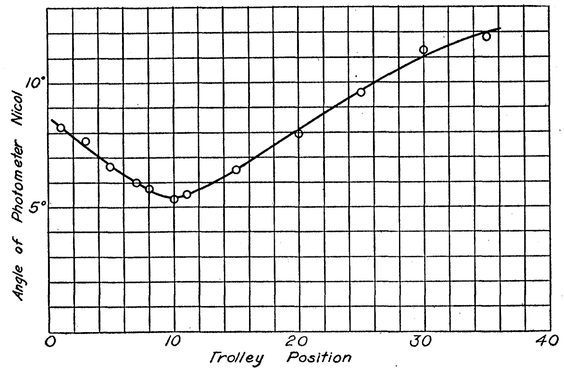

FIG. 4. Minimum observed for CS_2.

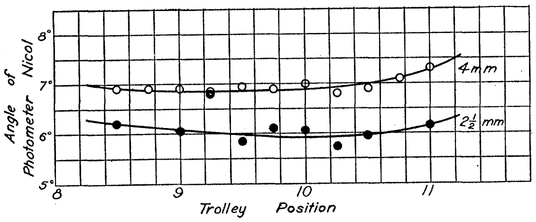

FIG. 5. Minimum observed for CS_2, enlarged scale.

been used by other observers as the standard reference point. The results of these tests are given in Figs. 4 and 5, where Fig. 4 gives a view of the test over a wide range, and Fig. 5 the results of two attempts to get more definite location. The data shown by Fig. 4 together with those from many similar runs indicate that the minimum is at 9.6±0.5 scale divisions. The results shown in Fig. 5 indicate that the bottom of the curve is very flat and that this method will not give a more exact position than the one stated. Many attempts to observe fine detail in the intensity variation demonstrated only the considerable variation in the effective light, minima being frequently measured at points where later maxima appeared. Sets of observations over the same range served to average out these minima, thus proving that they represented only temporary effects. This result gave a fairly definite reference point from which the approximate position of reported minima could be calculated. This limitation of range seemed to be necessary in view of the somewhat laborious method we were using. In addition to these definite measurements we have carefully swept the region by moving the trolley slowly and watching

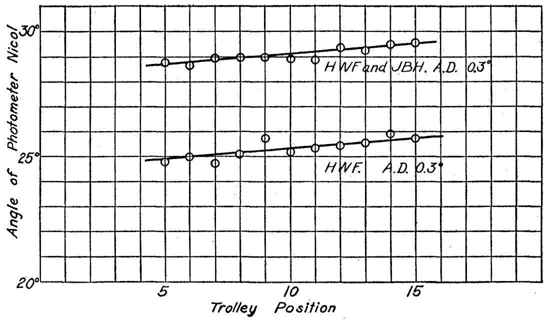

FIG. 6. Observations on HCl.

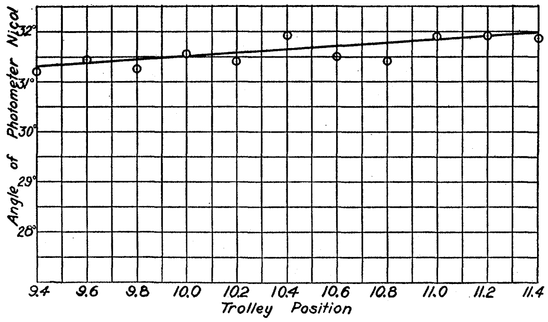

FIG. 7. Observations on HCl, enlarged scale.

for a change in the direct field after having set the comparison field for a match at the start. This procedure failed to indicate anything different from the results shown in our curves. It is our belief that this sweeping with the use of a comparison field is far more reliable than in the case with no comparison field.

OBSERVATIONS TO LOCATE THE HCl MINIMA

Since the sharp minima due to HCl have been given as perhaps the most pronounced and hence the most readily observed, and as located at +0.75 and +0.85 scale units from the CS_2 minimum, we felt justified in searching carefully in that region with our photometer. We have used various concentrations, but most of our measurements, including those of the diagram, were made with a concentration of HCl about 1/300 normal in the second cell. The results of various runs are given in Fig. 6 for a wide range, and in Fig. 7 for a detailed short run in the region where the minimum might be expected. Minima are thus observable, but all sharp minima fail to maintain their identity when the

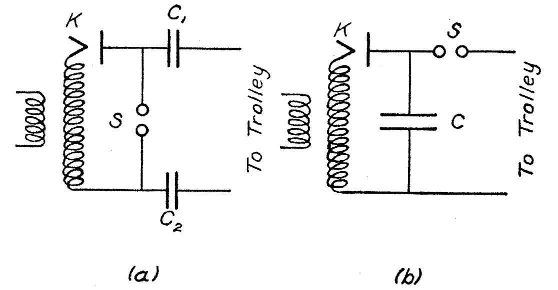

FIG 8(a). Circuit used for most of observation; 8(b). circuit commonly used.

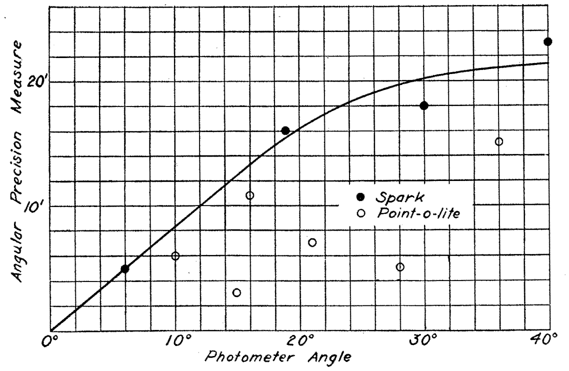

FIG. 9. Comparison of observations with different light sources.

results of repeated runs are averaged, leaving only the general form of curve to be expected from the difference in Verdet constants and the electrical constants of the circuit. No sharp minima at any characteristic trolley position were found when sweeping was employed. We are then obliged to conclude that on our set-up there are no permanent sharp minima for HCl.

FURTHER OBSERVATIONS TO CHECK RESULTS

For much of our work we used the circuit indicated in Fig. 8(a) instead of that of Fig. 8(b) which is commonly used in this experiment, but as far as our results go, the same conclusions hold with respect to both circuits.

Our condensers were normally mica condensers with small leakage and low dielectric loss, but the general results were the same with these as with glass plate condensers. The readings with the glass plate condensers were more irregular showing the influence of the factors mentioned.

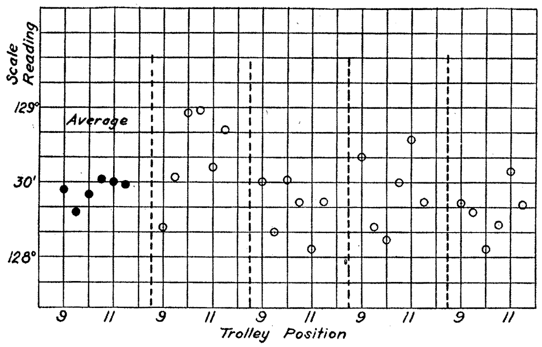

FIG. 10. Four sets of readings showing variations in Nicol readings in matching halves of the field.

Measurements on faint illuminations from a Point-o-lite lamp were compared with those taken on the spark. Fig. 9 shows the variation in precision with the magnitude of the angle N_4, the curve for the spark settings being the average of a considerable number. The points plotted for the observations on the Point-o-lite source are from a normal run. This shows that the settings were more reliable if the source were constant. Since the personal errors are the same in the two cases it follows that the variations in the magnetic fields in the coils are responsible for some of the observed peculiarities.

Observation of the voltage across the primary of the high potential transformer at the time photometer settings were made indicated no changes in voltage sufficient to account for the intensity variations observed.

In practically every case our setting was made at the position where the two halves of the field showed the same general brightness, but seldom were conditions sufficiently steady to enable us to do better than to set at such a point that the direct beam was sometimes brighter and sometimes darker than the comparison beam. It is an open question as to the disadvantage suffered thereby but in view of various reports[5] on comparisons of steady fields at low illumination it seems probable that the accuracy of setting was not any the less on this account.

To illustrate further the sort of change observable we include in Fig. 10 the results of four individual runs made by the same observer. Each point is the mean of his two settings, and at the time of setting he was confident that any

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[5] Blanchard, Phys. Rev. **11**, 81 (1918).

one setting was not in error by as much as 10 minutes. While the personal error is certainly present, the sensitivity is such that variations greater than 15 minutes can hardly be ascribed to personal error, but to variations for which the spark is responsible.

Our measurements further frequently show decided differences not only from day to day, but from hour to hour. For example, the first run in Fig. 10 shows most of the readings above those of later runs. We have tried to connect this with other known variables, the relative humidity for example, but so far as our records go the relation is not obvious. Careful watch of the magnesium electrodes shows that their behavior is not uniform, they wear away at a different rate at one time than another; sometimes the spark is held for quite a period at one local spot, and then it seems to wander more or less uniformly over the face of the gap. We are of the opinion that at least a portion of this difficulty can be ascribed to lack of homogeneity in the electrodes.

Further study of the temperature effects already mentioned in connection with our first set brought out some interesting facts. Part of the disturbance was clearly due to heat developed in the wire of the coils and conducted through the cylinder walls to the liquids in the cells, CS_2 being particularly sensitive on account of the large temperature coefficient of its index of refraction. The distortion observed did not occur as soon as the current began to pass through the coil, as would have been the case if eddy currents caused by impurities had produced the heating, but only after a time interval which could be prolonged by blocking the cell up a trifle from the bottom. The water-cooled coil has eliminated this difficulty.

Still another temperature effect was caused by evaporation of the CS_2 from the opening used for filling. This effect was quite distinct from the other, in that the conduction of heat to the cell was possible over a considerable area and hence caused a gradual wandering and distortion of the beam. The evaporation was of course quite local, and produced some fairly sharp contrasts in the field of view, at times making it impossible to get satisfactory photometer settings. This difficulty was remedied by sealing up completely all tubes containing liquids with large vapor pressures.

The contrast between the success in discovering the cause of such disturbances when a comparison field was used and the failure properly to diagnose disturbances of one sort or another without it has been so marked that it would be a serious oversight not to emphasize the fact.

Consideration of Subjective Effects

Slack[6] has called attention to the very considerable influence of subjective reactions in all work of this sort. It is of course not to be expected that our work is free from such difficulties, but comparison between our attempts to locate, for example, the CS_2 minimum by observing the single direct beam and by comparing the direct beam with the comparison beam, show that the latter method is far more successful. During the course of our experiments we have been aware of numerous subjective effects, such as change of size of field, pseudocolor differences and general fatigue.

In the matter of suggestion we have been most careful to keep the observer in ignorance of the trolley position, the order in which readings were taken, and the values of the readings on the scale of N_4. For example, it has not been possible for him to know on any given trial whether he was taking an observation with the same or a different trolley position. Until the run was completed, the sole task of the observer has been to match the two fields in front of him.

A peculiar result which, however, does not seem to bear upon our conclusions is the fact that almost invariably one of us sets the Nicol, N_4, at larger angles over a given run than does the other. Since the work is practically all done with filters there is no clear-cut explanation on the ground of color difference, and at present we have no suitable answer, but suggest that it will be found in physiological or psychological terms.

Conclusions

Our experiments warrant the support of the following conclusions:

(1) Observations of a single low intensity op-

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[6] Slack, Phys. Rev. **45**, 126 (1934); J. Frank. Inst. **218**, 445 (1934).

tical field produced by a spark are unreliable not only on account of physiological and psychological effects, but also because of variations in the spark discharge itself, those variations being due to numerous causes.

(2) In our apparatus the intensity of the beam transmitted by the Faraday cells is consistent with predictions from the Verdet constants of the liquids used and the constants of the electrical circuit.

Acknowledgments

In the course of these experiments we have enjoyed the cooperation of various members of the departments of chemistry and electrical engineering as well as of our own, and we wish particularly to thank Professor H. T. Beans of the chemistry department for his able advice and assistance and Messers. Arthur Roberts, E. H. Green and G. L. Buc for ready assistance in some of the darkest hours.

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On Nuclear Moments

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The magnetic moments of nuclei, most of them known only roughly, and their more accurately known ratios, can be fairly well explained quantum mechanically on the basis of the following assumptions: Nuclei are built of protons whose spin is 1/2 with a gyromagnetic ratio -5 (the magnitude 5/2 of the magnetic moment agreeing with deflection experiments) and of neutrons whose spin is 1/2 with a gyromagnetic ratio -1.1; according to atomic number and mass at most one of these particles with a possible "orbital" angular momentum exists outside of "closed shells" and in addition possibly two neutrons *without* "orbital" moment. The coupling scheme is selected according to physical considerations analogous to those of atomic theory, and consistent with the importance of the proton-neutron bond. Only states of lowest spin-orbit coupling energy of the proton are realized.

Nuclei with even atomic number Z and even mass number A have no observed magnetic moment. In the light of this and other evidence for the existence of "closed shells" of protons and neutrons in nuclei, attempts have been made by Landé,[1, 2, 3] by Tamm and Altschuler[4] and by Schueler[5] to interpret observed nuclear magnetic moments as resulting from the spins and "orbits" of the few particles not in closed shells. While it is not yet clear that the interactions between particles in the nucleus are of such a nature that the magnitude of the orbital angular momentum of a single particle is conserved, there seems to be enough of value in the results[3] that the basic assumptions should be tested in as unobjectionable a manner as possible.

In several nuclei with A odd Z odd, one proton with spin and orbital momentum suffices to correlate the observed moments. It we invoke in addition to the proton two "free" neutrons (as for other nuclei it seems we must), the simplest assumption is that the extra neutrons have no orbital angular momenta, but only spins, s_ν. The only orbital moment is that of the proton, l_π. Tamm and Altschuler allowed also a neutron orbital moment l_ν, limited by a condition that had only an empirical meaning, their complete coupling scheme being $\{(l_\pi s_\pi)[l_\nu(s_\nu s_\nu)]\}$ for A odd Z odd. The strong coupling between the spins of two electrons (familiar as Russell-Saunders coupling) depends on the identity of the two particles and should not exist between the spins of a proton and a neutron. The spin-orbit coupling arises from the motion of the particle in a radially non-uniform electric field, and may be very strong for a proton (*or neutron*) in the nu-

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[1] Landé, Phys. Rev. **44**, 1028 (1933).

[2] Landé (erroneously signed "Inglis and Landé") Phys. Rev. **45**, 842 (1934); **46**, 76 (1934).

[3] Landé, Phys. Rev. **46**, 477 (1934).

[4] Tamm and Altschuler, Acad. U. S. S. R. **1**, 455 (1934).

[5] Schueler, Zeits. f. Physik **88**, 323 (1934).