below 100 kev measured by Meinel[2] by the H_α doppler shift in the auroral spectrum.

We must therefore account for the presence in the auroral beam of particles much greater in velocity than the beam itself. If these particles are protons then they must be approaching the earth in very flat spirals in magnetic fields locked in the solar gas cloud. It should be noted that such protons of 120 Mev are not inconsistent with Meinel's Doppler shift, as the H_α line is emitted only near the end of their range. However, an analysis of Meinel's H_α line shape and the angular distribution of incident auroral protons by Chamberlain[3] seems more consistent with protons of much lower energy than can be reconciled with the present observation. We rather favor the assumption that the observed effect originates from 60-kev electrons, and if these electrons cannot be contained in the auroral beam itself some mechanism must be devised for transferring energy from the auroral protons to the electrons. Kellogg[4] has suggested the charge separation of the neutral beam on entry into the earth's magnetic field as a means of accelerating the electron component from its beam-velocity energy of 30 ev to the observed 60 kev.

Extensive observations of soft radiation above the atmosphere in the auroral zone have been made by Van Allen and co-workers.[5] The authors conclude that the radiation consists of x-rays in the range 10–40 kev and is probably from electrons of auroral origin. However, the radiation was not observed as deep as 8 g/cm^2 in the atmosphere. We believe that the present observation is possibly the same phenomenon as Van Allen's soft radiation, but for the first time is directly correlated with visual aurora, and in addition appears to be a more energetic process. This is in agreement with evidence that auroral displays like the one on July 1st which exhibit zenith arcs which occur well below the auroral zone, and in which H_α radiation is observed, are a higher energy phenomenon than the more abundant aurorae at higher latitudes where H_α emission is not observed.[6]

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Time-Reversal Invariance in Beta Decay*

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Several experiments have been suggested[1] which, in principle, lead to a test of time-reversal invariance (hereafter abbreviated as TRI) in beta decay. These experiments were designed to measure a quantity which depended on Im $C_XC_Y^*$. Recent experiments indicate a complete (i.e., $\pm v/c$) polarization of electrons in pure Fermi and Gamow-Teller transitions,[2] which implies that S-V, T-A, S-A, and V-T interferences do not occur. Since this eliminates many of the simpler tests of TRI, it becomes appropriate to test TRI in experiments which measure Re $C_XC_Y^*$. It is the purpose of this letter to consider one example of this type, based on the beta spectrum of RaE.

Terms involving Re $C_XC_Y^*$ appear, for example, in the beta spectrum, beta-gamma directional correlation, beta-gamma circular polarization correlation, and in the beta-nuclear polarization correlation. The principal difficulty involved in this means of testing TRI, is that in the absence of a reliable means of calculating nuclear matrix elements, we must treat them, as well as the coupling constants, as unknown parameters. The experiments then must give sufficient information to determine *both* matrix elements and coupling constants, and in particular must prove unambiguously that matrix elements from different forces are present, since only then does a test of TRI arise. One easily sees that the beta-gamma directional correlation and the beta-gamma circular polarization correlation experiments alone do not determine enough information to provide a test. For example, measurement of the circular polarization of a gamma gives, together with the lifetime, only two parameters, while there are three unknowns, M_F, M_{GT} and Re $C_XC_Y^*$. Here, and in the following, we treat $|C_F|^2$, $|C_{GT}|^2$ as known,[3] and assume the validity of TRI for the strong forces,[4] which fixes the relative phase of the nuclear matrix elements.

On the other hand, experiments with polarized nuclei provide enough independent experiments to determine all the unknowns, in an allowed transition.[5] Experiments with Co^{58} are an example[6]; when analyzed with an S-T interaction, there are three unknowns (M_F, M_{GT}, and Re $C_SC_T^*$), and there are three (or more) experiments which can be done. Unfortunately, the results are all consistent with $M_F=0$, which means that no test of TRI is possible. Other nuclei, notably Mn^{52}, may provide a test along these lines.

Lastly, we wish to consider the evidence from the shapes of beta spectra. Allowed spectra, and most first forbidden spectra, do not determine the matrix elements, since all matrix elements give rise to the same (allowed) shape. Only spectra showing deviations from this shape give a means of determining the matrix elements. We shall consider in detail the well-known example of RaE, and show that if the transition is analyzed in terms of an S-T combination, the shape of the spectra implies that TRI holds quite accurately.

The beta spectra of Bi^{210} (RaE) has been carefully studied both experimentally and theoretically.[7] In a theory with real coupling constants, there are only two unknown parameters (the ratios of three real matrix elements). Previous analyses[7] have concluded that for a wide range of values of the first parameter, the second can be chosen so as to fit the observed spectrum. However, a fit with pure tensor force is *not* possible; this conclusion is vital to our argument, since only with both forces acting can we test TRI.

With complex coupling constants, we have three unknown parameters, which can be conveniently introduced as follows: by appropriate choice of the over-all phase we can make C_T real, and bring the scalar coupling constant to the form $C_S(1+iF)$, with real C_S and F. Our three unknown parameters are then the original matrix elements, plus F. The correction factor

$$C(W)=|C_T|^2H_T(W)+\mathrm{Re}(C_TC_S^*)H_{TS}(W)+|C_S|^2H_S(W) \quad (1)$$

can then be written

$$C(W)=\{C_T^2H_T(W)+C_TC_SH_{TS}(W)+C_S^2H_S(W)\}+F^2C_S^2H_S(W). \quad (2)$$

Here $H_X(W)$ are the correction factors for the individual forces.[8] The first three terms in (2) are the correction factor appropriate for real coupling constants, and the last term is present only when TRI is violated. We note that while strong cancellation can occur among the first three terms to give the observed shape, the last term is positive-definite, and is large and energy-independent:

$$H_S(W)\cong\left|\int i\beta\mathbf{r}\right|^2(\alpha Z/2R)^2. \quad (3)$$

The magnitude and energy independence of the last term enable us to conclude that it is present only in a very small amount, thus setting limits on the magnitude of F.

If we factor out $C_T^2|\int\beta\boldsymbol{\sigma}\times\mathbf{r}|^2$, the first term is brought to the form used by Plassman and Langer; we find, using their notation,

$$C(W)\sim C_0(W)+F^2\xi_1^2(\alpha Z/2R)^2. \quad (3)$$

The largest upper bound of F is implied by the *smallest* value of ξ_1 consistent with the shape,[9] which is $\xi_1=0.17$. For this value of ξ_1, $C_0(W)$ has values ranging between 2 and 0.6, and we can conclude that the additional term must certainly be less than about 0.2, which leads to $F\lesssim\frac{1}{5}$. A shell model analysis[7] of Bi^{210} implies the larger value $\xi_1\sim 1$, and therefore a smaller bound on F: $F\lesssim\frac{1}{10}$.

Analysis of the spectrum with a V-A combination is essentially the same, and leads to the same conclusions; the analysis with a V-T combination contains no interference, and so does not test TRI. More complicated force laws probably contain too many parameters to establish the existence of interference between different forces.

The only other first-forbidden transition known to show such deviations from allowed shape is Pr^{144}, which may provide similar information for the T-P combination.[10] There are several second-forbidden transitions which could be used[11]; however, their spectra can all be fit with tensor force alone, and it is only by the use of *calculated* matrix elements that the analysis can be carried out.

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Pion-Electron Decay*

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EXPERIMENTALLY the decay of π^+ into e^+ has not yet been observed. For instance, Lokanathan and Steinberger[1] gave an upper limit to this mode of decay as

$$(\pi\rightarrow e)/(\pi\rightarrow\mu)\leq 5\times 10^{-5}. \quad (1)$$

If one combines the strong pion-nucleon interaction with the beta-decay interaction, the electron decay of the pion is expected to occur through

$$\pi^+\rightarrow p+\bar{n}\rightarrow e^+ +\nu, \quad (2a)$$

$$\text{or} \quad \rightarrow e^+ +\nu+\gamma. \quad (2b)$$