Fig. 2. Same conditions as in Fig. 1 with a temperature of about 90°C.

Figures 1 and 2 show the hysteresis loops which are so oriented that the charge or polarization axis is vertical, while the voltage or field-strength axis is horizontal.

Actual jumps in the polarization are shown as if a domain which contributes a charge ΔQ were aligned only after a finite voltage increases ΔV. In Fig. 2 apparently the whole crystal is acting as a single domain which snapped into alignment for practically the maximum field strength of 2570 volts/cm. Jumps of the order of magnitude as shown in Fig. 1 occur in about 10 percent of the frames, while a jump of the type shown in Fig. 2 was observed only once in about a thousand frames. Examination of the motion picture oscilloscope records and visual examination of the oscilloscope screen shows that the jumps in slope on the hysteresis loop occur in random phase.

Phenomenologically the Barkhausen effect in the case of ferromagnetic materials is analogous to the above effect for ferro-electrics. The domains for the ferro-electric case are much larger, however.

[1] C. B. Sawyer and C. H. Tower, Phys. Rev. 35, 269–273 (1930). A. de Bretteville, J. Am. Ceramic Society 29 (11), 303 (1946); Phys. Rev. 69, 687 (1946).

A Possible New Type of Spin-Spin Interaction

E. C. G. Stueckelberg
Université de Genève, Geneva, Switzerland
February 11, 1948

IN view of the hyperfine structure difficulties brought to light by the experiments of Nafe, Nelson, Rabi[1] and others, I would like to advance a theory that might possibly have a bearing on these questions. Instead of introducing a new interaction between the electron and the electromagnetic field as Breit[2] has tried, we bring in an interaction between the electron and a new type of field. While the sources of the Maxwell field are the charges and the current densities, the sources of the new field are the spin densities. Thus the interaction between elementary particles, instead of being described by the usual charges and magnetic moments: coulomb, magnetic moment—orbit and magnetic moment—magnetic moment interaction (we avoid the term

spin to keep it for the new field) contains now another term of pure spin-spin interaction. For non-relativistic velocities, spin density and density of magnetic moment are parallel, and thus the effect of the new field is to change the usual spin-spin interaction by an arbitrary factor that experiment alone can determine.

The non-relativistic equations for the new field (it has vectorial components Q and R) are

$$\text{curl}Q = q\,\text{curl}S, \qquad \text{div}Q = 0,$$
$$\text{div}R = -p\,\text{div}S, \qquad \text{curl}R = 0,$$

where S is the spin density and q an arbitrary coupling factor. They can be compared with Maxwell's equations for B and E;

$$\text{curl}B = J + \text{curl}M, \qquad \text{div}B = 0,$$
$$\text{div}E = \rho - \text{div}P, \qquad \text{curl}E = 0,$$

and the symmetry is at once obvious except for non-existence of a convection charge current in the spin field.

I had arrived previously at this conception from the point of view of general relativity when applied to Dirac particles. Generalized relativity has, so far, only utilized space curvature, omitting a possible torsion of space. The reason for that is that a classical particle has its four momentum parallel to its four velocity, or in other words, its transported momentum is in the direction of transport. A Dirac particle, on the other hand, behaves differently because the momentum vector is different in direction from the velocity vector (and the consequence of this is that one talks about spin). Torsion of space as a field acts differently from curvature of space (gravitation) only if the direction of transport is different from the transported vector. The Q and R field introduced above is the field of this torsion of space.

[1] Nafe, Nelson, and Rabi, Phys. Rev. 71, 914 (1947).
[2] G. Breit, Phys. Rev. 72, 984 (1947).

The Growth of Barium Titanate Crystals

B. Matthias*
Laboratory for Insulation Research, Massachusetts Institute of Technology, Cambridge, Massachusetts
February 19, 1948

DURING the past year, the interest in the ferro-electric barium titanate has increased and this laboratory has received a number of inquiries concerning the growth of single crystals.

Bourgeois[1] describes a process by which he obtained microscopic crystals similar to perovskite with a stoichiometrical composition supposedly $2BaO \cdot 3TiO_2$. He used an excess of $BaCl_2$ as flux and equimolar parts of $BaCO_3$ and TiO_2 to form the compound. On repeating this process no well defined crystals resulted.

By adding an appreciable excess of $BaCO_3$, Blattner, Matthias, and Merz[2] were able to obtain well formed crystals which corresponded (except for their optical behavior) to what had to be anticipated from the polycrystalline $BaTiO_3$.

As this information, according to the inquiries, was obviously not sufficient, quantitative data for an advanced growing technique are herewith given to facilitate the investigations on barium titanate in other laboratories.

With the relative proportions of one mole $BaCl_2$ to about 0.53 mole $BaCO_3$ and 0.26 mole TiO_2, the best results were obtained by cooling the melt from 1200°C down to approximately 800°C within a few hours. Usually we used 50 grams of $BaCl_2$, 25 grams of $BaCO_3$, and 5 grams of TiO_2.

The dishes in which the growth takes place should preferably be of purest platinum or carbon crucibles used in a nitrogen atmosphere. By the first method, a certain amount of platinum is dissolved and causes a discoloration of the crystals which can be removed to some degree by tempering at 200°C for a few hours. The second method gives bluish colored crystals due to reduction of the TiO_2. On heating at 600–800°C in an oxygen atmosphere, the crystals become colorless.

Dissolving the $BaCl_2$ in water, the crystals remain with the excess $BaCO_3$ from which they are readily separated.

If one uses a comparatively large amount of alkali carbonate as melt and "dissolves" stoichiometrical amounts of $BaCO_3$ and TiO_2, hexagonal and monoclinic crystals, besides small cubic ones, are obtained.

* Now at Bell Telephone Laboratories.
[1] L. Bourgeois, Zeits. f. Krist. 14, 280 (1888).
[2] H. Blattner, B. Matthias, and W. Merz, Helv. Phys. Acta 20, 255 (1947).

The Reaction He³(n,p)H³ and the Neutrino Mass*

D. J. Hughes and C. Eggler
Argonne National Laboratory, Chicago, Illinois
February 13, 1948

KONOPINSKI[1] and Pruett[2] have shown that the ft value for H³ is much lower than would be predicted by beta-theory, but that the discrepancy can be removed if it is assumed that the neutrino emitted by H³ has a rest mass of about 0.2 that of the electron[2] (taking the H³ end point as 11 kev[3] and the half-life as 12 years).[4] Oppenheimer[5] has suggested the possibility that nuclei of the H³ type might emit neutrinos of finite mass while long-lived C¹⁴ might emit a massless neutrino. We have measured the mass of the neutrino emitted in the two disintegrations, H³ and C¹⁴, by an accurate cloud-chamber determination of the Q value for the reactions He³(n,p)H³ and N¹⁴(n,p)C¹⁴. The neutrino mass in each case involves only the n,p mass difference, the β end point (actual, not Kurie extrapolated), and the Q value.

The nitrogen reaction is well known, but measurements of its Q value have given widely discordant results.[6] We looked for the hitherto unobserved He³(n,p) in some helium enriched in He³ kindly supplied by Mr. Novick of this laboratory. With the cloud chamber filled with helium containing about 10^{-3} percent He³ we were able to observe the He³(n,p)H³ reaction along with the nitrogen reaction (from a trace of nitrogen left in the helium). Figure 1 shows examples of both the N¹⁴ and the He³ reactions in which the tracks of recoiling C¹⁴ and H³ nuclei can be seen (chamber pressure 20 cm). The "breaks" in the tracks (marked A and B in Fig. 1) are sharp enough in the negatives so that it is possible to measure the proton part of the ranges with accuracy.

In order to determine the Q values, the relative ranges of the He³ protons and the N¹⁴ protons were measured while the chamber was filled with helium. Since the stopping power of helium is not accurately known, the absolute range of the nitrogen proton was then measured with air (15-cm pressure) in the chamber. Figure 2 shows the experimental distribution of proton ranges in air (block curve) fitted to a theoretical curve including straggling and minor geometrical factors. From the mean range (R_M) determined from Fig. 1 and the stopping power of the chamber, the range in air at 76 cm and 15° is 0.991 cm, and the He³ proton range then follows as 0.980 cm. The nitrogen proton range in air was also checked by measuring the range in the chamber of Pu α's. With the known range of Pu α's (3.68 cm), this comparison method also gave 0.991 cm as the nitrogen proton range.
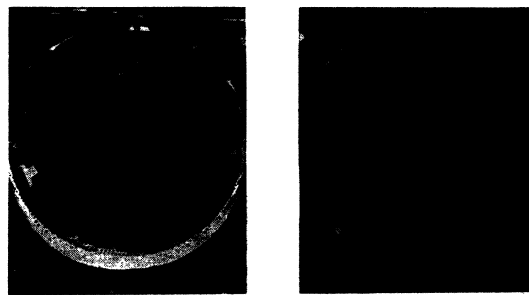
Using 751 ± 6 kev for the n,p mass difference,[7] 154 ± 7 kev for the C¹⁴ end point,[8] and 11 ± 2 kev for the H³ end point,[3] we obtain the following expected values for the Q's and proton energies, where μc^2 is the neutrino rest energy:

He³: $Q = 740$ kev; $E_p = (555 \pm 5 \text{ kev}) - 3/4\mu c^2$,

N¹⁴: $Q = 597$ kev; $E_p = (558 \pm 9 \text{ kev}) - 14/15\mu c^2$.

The present range measurements, together with the range energy curve of Livingston and Bethe,[9] give:

He³: $E_p = 552$ kev $(Q = 736$ kev$)$; $\mu c^2 = 4$ kev,

N¹⁴: $E_p = 557$ kev $(Q = 596$ kev$)$; $\mu c^2 = 1$ kev.

The error in the actual range measurement is estimated to be about 1 percent or 5 kev, but this error must be combined with the uncertainty in the range energy curve with the result that the final error is about 25 kev, which thus becomes the upper limit for the neutrino mass. However, the relative mass of the neutrino in the two cases is known much better; actually the experiment shows that the mass of the neutrino for H³ and C¹⁴ is the same within about 5 kev.

N¹⁴(np)C¹⁴   He³(np)H³

FIG. 1.