(II and III) polarized muons were stopped in argon at different magnetic fields and for case I pions were stopped. The solid curves were obtained from the analysis of the data and represent the per cent amplitude of A compared to the total counting rate. The dashed curves are theoretical line shapes centered in each case at the muonium precession frequency predicted from the measured value of the magnetic field. Resonances are clearly seen in cases II and III and indicate abundant formation of muonium in pure argon.

The general conditions required to form muonium and to retain its polarization are not well understood. From our experiments alone it is not determined whether the high purity of the argon gas is required, although if they are combined with unpublished negative results of others [2] it appears that the purity is essential. If this is indeed true, it seems quite likely that free muonium is lost in a chemical reaction in impure argon.

Our recent measurements of the asymmetry parameter, a, for various gases at high pressure, done in a free muon precession experiment [3], give :

$$a(\mathrm{A})/a(\mathrm{C}) = 0.22 \pm 0.15; \quad a(\mathrm{N}_2)/a(\mathrm{C}) = 0.13 \pm 0.15;$$
$$a(\mathrm{N}_2\mathrm{O})/a(\mathrm{C}) = 0.10 \pm 0.15; \quad a(\mathrm{O}_2)/a(\mathrm{C}) = 0.44 \pm 0.15:$$
$$a(\mathrm{SF}_6)/a(\mathrm{C}) = 0.75 \pm 0.15.$$

Since depolarization in this experiment is a necessary condition for muonium formation, it can be concluded that no more than one half of the muons stopping in SF_6 and O_2 form muonium, whereas all of the muons may form muonium in A, N_2, and N_2O.

In view of the abundant formation of muonium in pure argon, it should be possible to measure the hyperfine structure, $\Delta\nu$, of muonium with high precision. Comparison of a precise experimental value for $\Delta\nu$ with the theoretical value would provide a critical test of electrodynamics involving the muon and could reveal an anomalous structure of the muon.

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EXPERIMENTAL LIMITS FOR THE ELECTRON-PROTON CHARGE DIFFERENCE AND FOR THE NEUTRON CHARGE

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(presented by V. W. Hughes)

Although a small limit for the electron-proton charge difference has been established,[1, 2, 3, 4] the possibility of a finite difference continues to be of interest. In a recent discussion of symmetry principles, Feinberg and Goldhaber [5] have pointed out that if there were any electron-proton charge difference the conservation of baryons would follow from the conservation of charge; for example, a decay of the form $p \rightarrow e^+ + \pi_0$ would be forbidden. Lyttleton and Bondi [6] have shown that an electron-proton charge difference of 2 parts in 10^{18} may form the basis for theories of the expanding universe and of the origin of cosmic rays.

We have established upper limits to the charges of Cs and K atoms by observing the deflection of an atomic beam in a homogeneous electric field[2]. The apparatus is shown schematically in Fig. 1 where the vertical scale is exaggerated for clarity. A beam of atoms issues from the oven slit, is collimated, passes between a pair of parallel plate electrodes and strikes a hot-wire surface-ionization detector. Electric fields of up to 100 kV/cm can be applied in the 1 millimeter gap between electrodes.

Atoms which have the most probable velocity for atoms from an oven at temperature T and which have a charge q would be deflected a distance s_α in a direction determined by the field direction. A deflection due to the atomic polarizability will be independent of field direction and hence may be distinguished from a deflection due to an atomic charge q. The absence of a deflection greater than the minimum detectable deflection s_α, of about 10^{-6} cm enables us to set an upper limit for the net charge of the atom.

The results are $|q(\text{Cs})| \leq 4.8 \times 10^{-17} |q_e|$ and $|q(\text{K})| \leq 9.6 \times 10^{-17} |q_e|$ where q_e is the value of the electron charge. If the total atomic charge is assumed to be $Z\delta q + Nq_n$, where Z is the number of protons, $\delta q = q_e + q_p$, q_p the proton charge, N the number of neutrons and q_n the neutron charge, then

$$|\delta q| \leq 2.2 \times 10^{-17} |q_e|$$

and independently, $|q_n| \leq 1.6 \times 10^{-17} |q_e|$. If one assumes that $\delta q = q_n$ (an assumption required for charge conservation in beta decay), then one concludes $|\delta q| \leq 3.6 \times 10^{-19} |q_e|$. This upper limit to the electron-proton charge difference is substantially less than the value required by the theory of Lyttleton and Bondi.

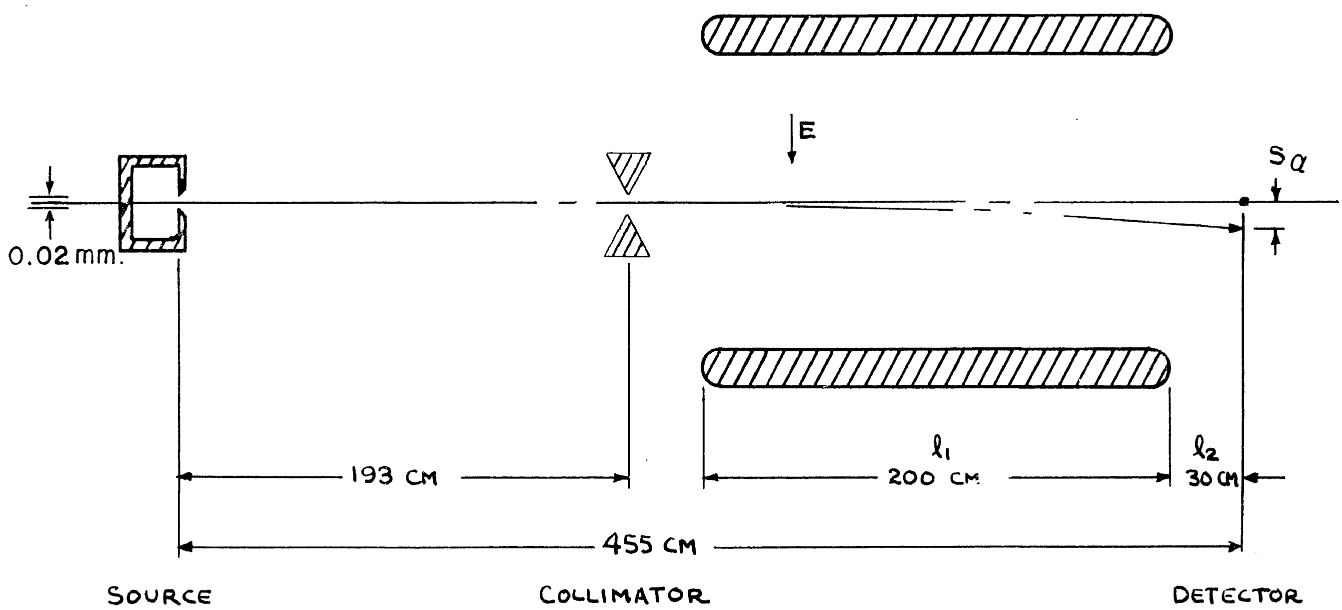

Fig. 1 Schematic diagram of the apparatus. $[s_\alpha = qEl_1(l_1+2l_2)/(4kT)]$

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DISCUSSION

PETRASCU : I want to ask Hughes whether he can say anything about experimental plans for the measurement of $\Delta\nu$?

HUGHES : Well, we hope to be able to do it very soon. This is a microwave experiment, so we are designing microwave equipment to enable us to produce the transition in the time available—which is essentially the lifetime of the μ-meson. It is an experiment much like the positronium hyperfine structure measurements which have been reported in detail [1].

GELL-MANN : I would like to make one comment on the equality of the electron and proton charges, which is a modification of a remark originating with Nambu. If the bare charges of the electron and proton are the same, then in usual electrodynamics the observed charges are also the same. There arises a suspicion that this might fail to be true theoretically if, in addition to the photon, there is another neutral vector particle which is coupled to the proton but not to the electron. It could be coupled strongly, as a vector glue to hold nucleon and antinucleon together in some people's theories, or weakly as for a possible neutral vector boson to explain part of the weak interactions (to give the $\Delta I = \frac{1}{2}$ rule). An appreciable charge difference then seems to arise between the electron and proton assuming the bare charges are the same. This charge difference comes out to be the same sort of ambiguous quadratically divergent integral that comes in when you try to calculate the mass change of the photon, and which many people have proposed to make zero on the basis of various swindles. These swindles become even more necessary if there exists a neutral vector particle other than the photon, and if we want to preserve the idea that the bare charges of the electron and proton are equal and that as a consequence the renormalized charges are also equal.

J. G. TAYLOR : I would also like to make a remark concerning the experimental result of Hughes on the difference of the charges of the electron and proton. It appears that the theory of Bondi and Littleton does not essentially depend on this difference being non-zero. It can also work, I think, if there are different numbers of electrons and protons created in a certain volume of space, even if they have the same charge. Each galaxy will then have a net charge and there will still be repulsion caused by this net charge.

HUGHES : That is completely correct. However, the version of the Lyttleton-Bondi theory that requires a charge difference would presumably have been more attractive in that one would have been able to confirm it in our experiment.

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