the probable configuration of He^- is $(1s\ 2s\ 2p)^4P$, and that autoionization from this state is not allowed. In the absence of an electric field the lifetime of this state is known to be greater than 10^{-5} second.[7] The dissociation of this ion in the electric field may be due to breakdown of the selection rules for autoionization or due to field emission of the electron leaving the He^0 in the $(1s\ 2s)$ metastable state. Further experimental investigations are under way to elucidate this point.

The authors are grateful to Mr. R. E. Bradford, Mr. J. Coupland, and Mr. R. Webster for their help in setting up the apparatus and taking the results.

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[1] J. R. Hiskes, University of California Radiation Laboratory Report UCRL-9182, May, 1960 (unpublished).

[2] J. R. Hiskes and J. L. Uretsky, University of California Radiation Laboratory Report UCRL-8255, April, 1958 (unpublished).

[3] J. R. Hiskes, Bull. Am. Phys. Soc. 5, 340 (1960).

[4] D. R. Sweetman, Proc. Roy. Soc. (London) A256, 416 (1960).

[5] E. Holøien and J. Midtdal, Proc. Phys. Soc. (London) A68, 815 (1955).

[6] E. A. Hylleraas and J. Midtal, Phys. Rev. 103, 829 (1956).

[7] D. R. Sweetman, Proc. Phys. Soc. (London) (to be published).

SEARCH FOR A SMALL CHARGE CARRIED BY MOLECULES*

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The suggestion by Lyttleton and Bondi[1] that hydrogen atoms might carry a charge of approximately 2×10^{-18} of an elementary charge has stimulated a number of investigators to undertake experiments designed to measure this charge. At least two methods have been used: atomic beam deflection experiments,[2,3] and the method of Piccard and Kessler.[4] The results published thus far[2-6] are listed in Table I. In this paper preliminary results of a Piccard-Kessler experiment are reported in which hydrogen molecules (and also helium atoms) exhibit a charge that is approximately 40 times less than that required by the hypothesis of Lyttleton and Bondi.

In our experiment the gas whose charge is to be measured is allowed to escape from an electrically insulated metal container connected to an electrometer. While the gas is escaping, a current that can be measured will flow to the container if the gas is charged. The charge on each atom can then be computed, although it is essential to distinguish charge carried by each of the hypothetically charged atoms from charge carried by ions, electrons, and charged dust particles. By passing the escaping gas through a de-ionizer consisting of a coaxial capacitor charged by a

Table I. Upper limit on the charge carried by various molecules.

Molecule	Charge (elementary charge/molecule)	Experimental method
CO_2	$\leq 2\times10^{-19}$	Piccard-Kessler [a]
CsI	$\leq 4\times10^{-13}$	Molecular beam [b]
A	$< 8\times10^{-20}$	Piccard-Kessler [c]
N_2	$< 12\times10^{-20}$	Piccard-Kessler [c]
CsF	$\leq 2\times10^{-14}$	Molecular beam [d]
KF	$\leq 1\times10^{-13}$	Molecular beam [d]
n	$< 6\times10^{-12}$	Molecular beam [e]

[a] See reference 4.
[b] See reference 2.
[c] See reference 5.
[d] See reference 3.
[e] See reference 6.

battery within the container, ions and electrons, because of their relatively high mobilities, can be swept from the gas stream, while atoms carrying the hypothetical charge of 10^{-18} of an elementary charge will be unaffected. Dust particles, which range in size from molecules to visible grains, may be sufficiently massive to pass through the de-ionizer, but their effect is likely to be both erratic and cumulative.

By recording the pressure and the output of the electrometer, both as a function of time, on a two-channel recorder, it is not only possible to measure the total charge carried by the gas, but also to see that the potential-versus-time curve has the expected shape for the flow of a uniformly charged gas. The course to be followed by the experimenter is plain. If the atoms seem to be charged, the computed charge per atom must be independent of all parameters, such as de-ionizer potential and polarity, rate of gas efflux, pressure, bias potential of the container with respect to ground, and, of course, details of apparatus construction and gas handling. It is to be expected that the charge per atom will be different for different gases. On the other hand, if the atoms appear uncharged, it is important to make certain that the electrometer is sensitive during the gas efflux and that mechanisms that might cancel a genuine effect are eliminated. Such cancellation is most likely to occur at the end of the outlet pipe from the container.

Figure 1 is a scale drawing of the apparatus. The outer can serves both as a vacuum envelope and as an electrical shield for the container (11.2 liters) which stands on three quartz supports and is filled with gas through a quartz pipe. This quartz pipe is metalized at its ends so that it can be soft-soldered into place. Although it was designed to stand a pressure of 1000 psi, the container was usually operated at a pressure of 265 psi. The outer can was pumped to 10^{-6} mm Hg to prevent electrical leakage and to reduce undesirable thermal effects. The central electrode of the de-ionizer is maintained at ± 90 volts, or zero volts with respect to ground, as determined by the setting of a switch. The approximate contact potential to ground of the container can be determined by a movable vane. The gas that is to be investigated is admitted to the container through a porous bronze filter with 5-μ pores, an electrostatic precipitator, and needle valves for controlling the flow. A pressure transducer generates a signal proportional to the pressure in the container which can be recorded on one channel of a two-channel Sanborn recorder. The gas escapes from the container through an external regulator that maintains constant pressure on a needle valve adjusted to give the desired rate of flow. It was thus possible to obtain a nearly linear drop in pressure in the container with respect to time.

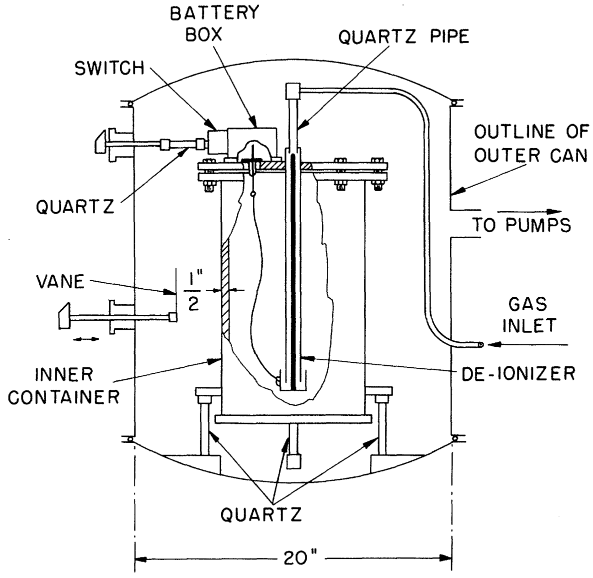

FIG. 1. Scale drawing of the apparatus.

Potential changes of the container with respect to the outer can are measured with a GL5674 electrometer whose output is amplified by a chopper amplifier and recorded on the other channel of the Sanborn recorder. Potential differences of 10^{-4} volt, or currents of approximately 10^3 electrons per second, can be detected. The time constant is 60 ± 5 sec which agrees with the time constant predicted from independent measurements of the electrometer grid resistance and capacitance, 10^{12} ohms and 60 $\mu\mu$f, respectively. The ground return of the electrometer is connected through a low-impedance voltage supply that makes it possible to place the container at different potentials with respect to the outer can. When the potential of the container was +0.01 volt, moving the vane was found to have negligible effect. Frequent calibrations of the electrometer were made with signals close to the minimum detectable signal introduced at the ground end of the electrometer grid resistor. No consistent dependence of the electrometer sensitivity on the polarity of the calibrated signal, the amount of gas in the container, the polarity of the de-ionizer, or any other parameter was found. Calibrations were also made while the gas was flowing from the container, and the sensitivity was found to be normal.

The 21 hydrogen and 19 helium runs at 265 psi and 140 sec efflux time (selected only because these parameters were the same) yielded electrometer recordings that are superimposed in Figs. 2(a) and 2(b) normalized at the start of flow. Average curves that were constructed for hydrogen and helium are plotted in Fig. 3. The shaded rectangle, 0.3 mv high and 140 sec long, represents 2.7×10^{5} elementary charges, which is the amount of charge that would be observed if each of the 5.4×10^{24} molecules carried 5×10^{-20} of an elementary charge. The apparent charge per molecule, determined from the average curves, is $(2.5\pm1.5)\times10^{-20}$ elementary charge/molecule for hydrogen, and $(-4\pm2)\times10^{-20}$ elementary charge/molecule for helium. The charge on hydrogen appears to be negative; the charge on helium, to be positive.

None of the recordings looks like the computed curve, (d) of Fig. 3, which was derived from the pressure curve, (a) of Fig. 3. The hydrogen curve goes negative and then positive, and the helium curve has a negative maximum that is too early by 30 sec. If it is assumed that the helium effect is spurious and that whatever produces it is likewise present in the hydrogen runs, the helium curve may be subtracted from the hydrogen curve. This procedure yields a curve (represented by circles in Fig. 3) that is in remarkable agreement with the computed curve. If this agreement is taken to be significant, we obtain a value of $(7\pm2.5)\times10^{-20}$ elementary charge/molecule for hydrogen, and $(0\pm2)\times10^{-20}$ elementary charge/molecule for helium.

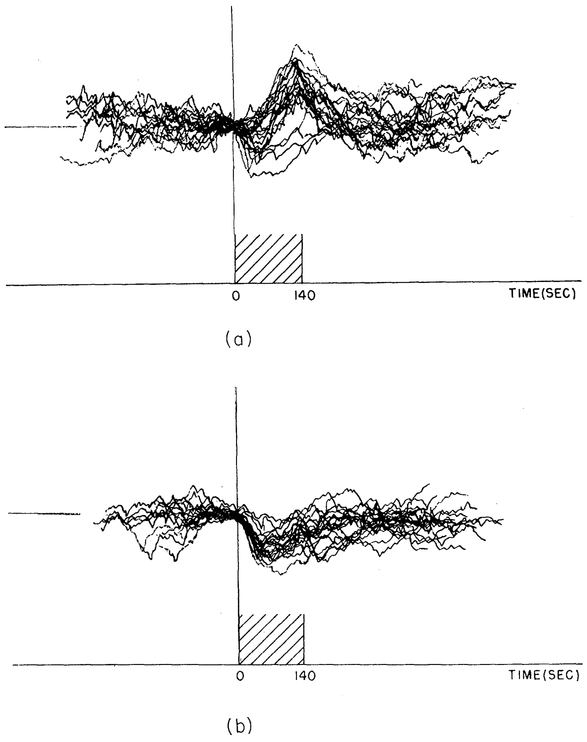

FIG. 2. (a) Superimposed electrometer recordings of 21 hydrogen runs. (b) Superimposed electrometer recordings of 19 helium runs.

The electrometer deflections recorded are still not understood; but the nature of these results, as well as the results of numerous side experiments, eliminates a few of the possible causes for the deflection, such as capacitative effects, piezoelectricity, and thermoelectricity. New and improved apparatus, use of other gases, including deuterium, and wider variations of parameters will provide the answer. In any case, the charge that we found for the hydrogen molecule, by interpreting our experiment in the obvious way, is far less than that required for the hydrogen atom by the hypothesis of Lyttleton and Bondi. A molecular-beam experiment is under way with cesium, but the difficulties of achieving sufficient sensitivity with hydrogen (and later atomic hydrogen) are considerable.

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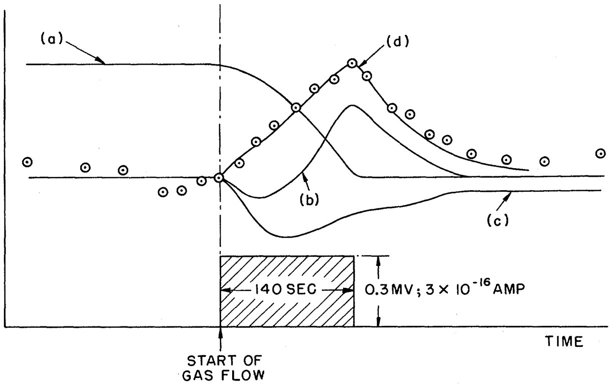

FIG. 3. (a) Observed pressure (arbitrary units) in the container as a function of time as the gas flows out. (b) Average voltage curve constructed from the data of Fig. 2(a). (c) Average voltage curve constructed from the data of Fig. 2(b). (d) Electrometer response to the flow, according to curve (a), of a uniformly charged gas from the container. Circles represent the difference between curves (b) and (c).

for much assistance with the apparatus.

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[1] R. A. Lyttleton and H. Bondi, Proc. Roy. Soc. (London) A252, 313 (1959).

[2] V. W. Hughes, Phys. Rev. 105, 170 (1957).

[3] J. C. Zorn, G. E. Chamberlain, and V. W. Hughes, Bull. Am. Phys. Soc. 5, 36 (1960).

[4] A Piccard and E. Kessler, Arch. sci. phys. et nat. 7, 340 (1925).

[5] A. M. Hillas and T. E. Cranshaw, Nature 184, 892 (1959); see also H. Bondi and R. A. Lyttleton, Nature 184, 974 (1959), and A. M. Hillas and T. E. Cranshaw, Nature 186, 459 (1960).

[6] I. Shapiro and V. Estulin, Soviet Phys.-JETP 3(30), 626 (1957).

CLUSTER MODEL INTERPRETATION OF THE ISOTOPIC SPIN SELECTION RULE IN CERTAIN NUCLEAR REACTIONS

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In this note we wish to present results concerning the operation of the isotopic spin selection rule in nuclear reactions which have resulted from a study of some lithium-induced reactions. Experimental verification of such selection rules has previously been obtained from the study of (d, α)[1] and (α, d)[2] reactions, from the study of inelastic deuteron scattering,[3] and recently from the work of Halbert and Zucker[4] on the inelastic scattering of N^{14} by C^{12}. In the present work we have been concerned with the reactions $Li^6(Li^6, d)B^{10}$ and $Li^6(Li^7, t)B^{10}$ with particular reference to the reactions leading to the $T = 1$, second excited state of B^{10} at 1.74 Mev. In the first reaction it was to be expected, since both Li^6 and the deuteron have $T = 0$, that the probability of deuteron emission leading to the $T = 1$ level in B^{10} would be reduced by virtue of the isotopic spin selection rule; the second reaction was studied for purposes of comparison.

In Fig. 1 the spectrum of deuterons observed at a laboratory angle of 9.5° from the reaction $Li^6(Li^6, d)B^{10}$ is presented. The positions of the levels in B^{10} are as calculated from the observed position of the deuterons leading to the first 1+ level in B^{10} and the variation of its position with the angle of observation. As can be seen from the observed spectrum, deuterons leading to the $T = 1$ level in B^{10} are very much inhibited, and over the angular range where one could observe this deuteron group, the situation persisted. As discussed above, this result can be interpreted as confirmation of the isotopic spin selection rule. However, it is the purpose of this note to suggest that the observed inhibition may be considered on a different basis.

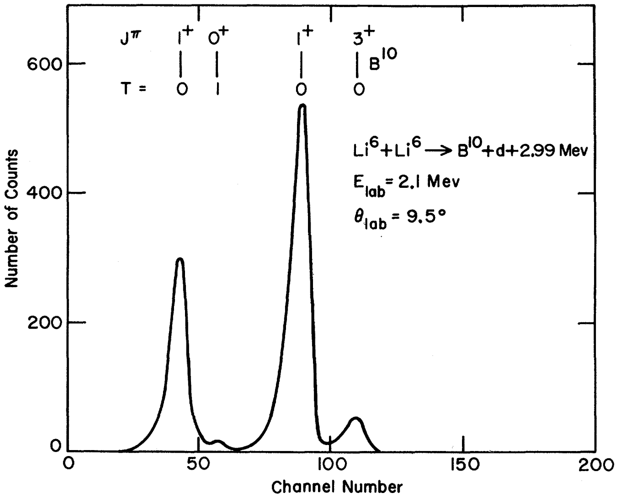

FIG. 1. The spectrum of deuterons observed in the reaction $Li^6(Li^6, d)B^{10}$ at a laboratory angle of 9.5° and incident energy of 2.1 Mev. The positions of the corresponding levels in B^{10} are indicated above.

As part of the reaction studies using lithium ions, evidence has been obtained that both the reactions (Li^6, d) and (Li^7, t) are favored and proceed in part by a stripping mechanism with capture of the alpha-particle substructure.[5] In the reaction $Li^6(Li^6, d)B^{10}$, if only the J^{π} of the final states in B^{10} are considered, there is no reason why the 0+ level should be reduced except possibly by a $(2J + 1)$ weighting factor. However, we see from Fig. 1 that the deuterons leading to the 3+ level in B^{10} are reduced also relative to those leading to the 1+ levels. If now the situation is considered from the viewpoint of B^{10}