Search for structural effects in π^- meson capture by hydrogen in complex molecules

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The effect of molecular structure on the probability of negative pion capture by bound hydrogen is investigated. It is shown that the capture probability for aliphatic hydrocarbons does not depend on the length or spatial structure of the carbon chain. The lower capture probability observed in benzene hydrocarbons is apparently due to modification of orbital hybridization. Of all compounds studied, only in inorganic bases is the identical-group effect observed.

It was established earlier [1] that nuclear capture of π^- mesons by hydrogen in molecules of the $R(Z_mH_n)_q$ type is suppressed by a factor q in comparison with the predictions of the model of large mesic molecules. It was natural to assume that this suppression $\epsilon = q$ is connected with the presence of q identical hydrogen-containing groups in the molecule. It was proposed that this effect always appears whenever the molecule contains identical hydrogen-containing groups [1].

The present study was undertaken for the purpose of determining the effect of the molecular structure on π^--meson capture by bound hydrogen, and in particular to determine the region where the effect of identical groups comes into play. The measurements were performed with the 80-MeV beam of the JINR synchrocyclotron. The experimental setup was described by us earlier [2].

Table I gives the experimental values of the probability W_e for π^--meson capture by hydrogen in organic molecules and, the values of the coefficients a_C which are defined the general case, for a molecule $Z'_kZ_mH_n$ with covalent hydrogen bond, by means of the formula [3].

$$W=\frac{a_{z'}\nu'(Z')^{-2}+a_z\nu Z^{-2}}{kZ'+mZ+n},\quad \nu'+\nu=n, \tag{1}$$

where ν' and ν are the number of the bonds of atoms with charges Z' and Z with hydrogen.

As seen from Table I, the conditions for π^--meson capture by hydrogen in aliphatic compounds do not change when the length of the linear molecule is increased, or on going over to a cyclic molecule. In C_6H_6 the capture is suppressed by an approximate factor of two in comparison with the C_6H_{12} molecule, which also has a cyclic structure; this is apparently due to the change in the type of hybridization of the C–H bond on going from the aliphatic to the aromatic compounds. The more complicated aromatic structure leads to an increase of the suppression ϵ (a decrease of a_C). The equality of the values of W_e of propyl ether and its isomer indicates that there are no large isomer effects in the capture of π^- mesons (see the first two lines of Table III).

TABLE I

Compound	$W_e \cdot 10^3$	a_C	Compound	$W_e \cdot 10^3$	a_C
Linear molecules			Cyclic molecules		
C_5H_{12}	15.90±0,55	2,00±0.07	C_6H_{12}	14,30±0.55	2.06±0.09
C_6H_{14}	16.60±0,54	2,13±0.07	C_6H_6	3,90±0,30	0,98±0.08
$C_{12}H_{26}$	15,20±0.70	2.06±0.10	$C_{12}H_{10}$	2.76±0.31	0,82±0,09
$C_{17}H_{36}$	14,00±0,52	1.95±0,07	$C_{18}H_{14}$	2.76±0.31	0,88±0,09
			$C_{10}H_8$	2,00±0,15	0.61±0.05

TABLE II

Compound	$W_e \cdot 10^4$ [1]	q	$\epsilon' = W'/W_e$ [1]	$\epsilon = W/W_e$
$Cd(CH_3COO)_2$	8.7±1.3	2	2.2±0.3	3.6±0.5
$Ba(CH_3COO)_2$	10.5±1.4	2	1.7±0.3	2.8±0.4
$Pb(CH_3COO)_2$	6.0±2.0	2	2.0±0.6	4.0±1.3
$Ca(CH_3COO)_2$	5.5±1.6	2	4.2±1.3	7.6±2.2

TABLE III

Compound	$W_e \cdot 10^4$	q	$\epsilon = W/W_e^*$	Compound	$W_e\ 10^4$	q	$\epsilon = W/W_e^*$
$(C_3H_7)_2O$	106,0±5.0	2	1.28±0.08	$C_2H_4Cl_2$ [1]	13±2	2	3,5±0.5
n-$(C_3H_7)_2O$	113.0±5.0	2	1.21±0.07	$(NH_4)_2Cr_2O_7$ [1]	6.0±1.1	2	2.2±0.4
$(CH_3)_2S$	61.0±4.0	2	1.52±0.11	$(NH_4)_2TiF_6$[1]	7,0±1.4	2	2,4±0.5
$(C_2H_5)_4NI$	42.0±4.5	4	2,08±0,24	$(NH_4)_2C_2O_4$	15.5±1.2	2	1.6±0.1
$(C_2H_5)_3N$	123,0±13.0	3	1.17±0.13	$(NH_4)_2SO_4$	13.2±0.7	2	1,7±0.1
$(CH_2OH)_2$	44.3±2.5	2	1.71±0.12	NH_4NO_3	8.1±0.6	1	2.4±0.2
$C_{12}H_{10}N_2$	16.0±2.0	2	2.22±0.26	$(NH_4)_4[Fe(CN)_6]$	14.0±1.1	4	1.6±0.1

*In the calculation of W we assumed $a_C = 2.05 \pm 0.04$ for derivatives of the aliphatic series, $a_C = 0.98 \pm 0.08$ for aromatic derivatives, and $a_N = 1.0 \pm 0.1$ for nitrogen in ammonia salts.

TABLE IV

Compound	$W_e \cdot 10^4$	q	$\epsilon = W/W_e^*$	Compound	$W_e \cdot 10^4$	q	$\epsilon = W/W_e^*$
KOH	6.7±2.1 [1]	1	1.1±0.3	$Al(OH)_3$	6.3±1.8 [1]	3	2,4±0.6
$Ca(OH)_2$	5.7±1.4 [1]	2	1.9±0.4	$Al(OH)_3$	5.6±1.0	3	2.7±0.6
$Cd(OH)_2$	3,3±1.2 [1]	2	1.8±0,6	$Zr(OH)_4$	2.2±0.8	4	4.8±1.6
$Ba(OH)_2$	2,5±0.7 [1]	2	2,2±0.6	$Ba(OH)_3$	5.6±1.0	3	3.3±0.6

*In the calculation of W we assumed $a_0 = 1.28 \pm 0.15$ for oxygen.

The effect of identical groups was observed earlier [1] in bases and in salts with general formula $R(Z_mH_n)q$, where R is the core group of the atoms (atom). If, however, we assume in the reduction of the results of [1] the value $a_C = 2.05 \pm 0.04$ for saturated carbon compounds (Table I), we can conclude that the effect of identical groups does not take place in the investigated salts. Table II duplicates part of Table II of [1]; the next to the last columns give the values of the suppression ϵ' of the π^--meson capture probability in bound hydrogen, obtained in [1] with $a_C = 1.28 \pm 0.15$, while the last column gives the values of ϵ obtained with $a_C = 2.05 \pm 0.04$.

Table III lists the measured values of W for various types of organic molecules containing identical groups, and for ammonium salts. An analysis of these results indicates that the identical-group effect does not occur in organic molecules and ammonium salts. The observed capture suppression ϵ differs strongly from q in most cases, and in the case of organic molecules it is apparently due to inductive influence of the substituents R [4]. It is possible that the suppression in the ammonium salts is due to the polarizing action of the acid anions.

At the same time, our new measurements confirm the conclusion that the identical-group effects does occur in bases [1]. Table IV lists all the available data on this effect in bases. It includes the results of our measurements with $Al(OH)_3$, $B(OH)_3$, and $Zr(OH)_4$ targets and the data of [1]. As seen from Table IV, the effect is quite convincingly in evidence for bases. A statistical analysis of the data of Table IV yields the relation $\epsilon = (0.99 \pm 0.07)q$. Thus, the effect of identical groups is observed for bases and is not observed for salts and for organic molecules containing identical hydrogen-containing groups.

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