Hydrogen Isotope Labelling of Organic Compounds catalysed by Microporous Aluminophosphates: Specificity of Tritium Gas Exchange

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Microporous aluminophosphate (ALPO) catalysts are shown to have high activity and unique specificity for exchange between elemental tritium gas and both aromatic and branched aliphatic compounds, suggesting their applicability as catalysts in a range of other reactions.

We report the high activity and very high specificity of microporous aluminophosphate catalysts (ALPOs)[1] for exchange between tritium gas and some aromatic and aliphatic compounds at temperatures as low as 100 °C. Since both elemental tritium and the organic substrate must be activated for exchange to occur, the results suggest that this new class of catalyst may have wide commercial application. Most catalytic exchange techniques involving tritium gas as isotope source lead to a compound in which the isotope is distributed among several, if not all, positions.[2] However, this new class of catalyst can yield toluene, for example, labelled almost entirely (>90%) in the single *para* position. No other known one-step tritium gas exchange procedure yields that degree of specificity in the aromatic ring.

Recent studies of tritium isotope labelling have included the development of procedures using zeolite catalysts.[3] However, zeolites such as HY, H-mordenite, and H-ZSM5, in the absence of any added catalytically active metal component, are extremely inefficient at catalysing exchange with elemental tritium gas except at relatively high temperatures

Table 1. Tritium distribution in compounds labelled over ALPO-5 catalyst with tritium gas.[a]

Compound	Time /h	Temp. /°C	Activity /$mCi\ ml^{-1}$	^{3}H distribution per H site (%)[b] *ortho*	*meta*	*para*	methyl
Toluene	24	100	48	3.6	<2	93	<1
,,	72	100	92	5.4	<1	89	<1
,,	168	100	153	4.8	3.1	84	<1
,,	72	140	115	9.7	2.2	76	<1
,,	72	180	175	18	4.1	55	<1
t-Butylbenzene	72	100	54	20	13	35	<1 (alkyl)
m-Xylene	72	100	83	38 (C-4,6), 25 (C-2), <1 (C-5), <1 (methyl)			
Mesitylene	72	100	41	100 (aromatic), <1 (methyl)			
Durene	72	100	67	100 (aromatic), <1 (methyl)			
Naphthalene	72	100	31	25 (α), <1 (β)			
Chlorobenzene	72	100	8	<1	<1	100	
Anisole	72	100	40	27	<1	45	<1 (OMe)
Furan	72	100	36	50 (α), <1 (β)			
2,3-Dimethylbutane	72	100	17	50 (methine), <1 (methyl)			

[a] *Reaction conditions*: Tritium gas (306 mCi) was added to degassed catalyst (75 mg) followed by organic substrate (0.3 ml or 0.3 g), the reaction vial sealed, then heated in an oven. Products were analysed by radio-g.l.c. and ^{3}H n.m.r. spectroscopy. Catalyst was prepared as per ref. 1 and calcined in air using a temperature ramp from 100 to 720 °C over 24 h plus 4 h at 720 °C. [b] Tritium distribution is expressed as % of incorporated tritium per H of each type in molecule.

(>150 °C).[4] These zeolites, with tritiated water as isotope source, show exchange which reflects the Brönsted acid nature of the zeolite, *i.e., ortho-para* directed in toluene.[5] Some influence of the molecular constraints imposed by the zeolite pore geometry on the exchange pattern has been noted.[6] In contrast, present results for the ALPO catalysts, even though these have similar microporous structures to the zeolites, show highly efficient activation of tritium gas and do not exhibit the simple electrophilic substitution patterns typical of acid catalysts.

The results (Table 1) show that both aromatic and branched aliphatic compounds can be labelled with the ALPO-5 catalytic system using tritium gas as isotope source. No by-products, either labelled or unlabelled, were detected, except in the case of 2,3-dimethylbutane where some active C-6 isomers were present. Exchange is also possible with tritiated water but higher reaction temperatures are necessary. The catalyst, designated as ALPO-5, was prepared by the procedure described elsewhere.[1] For calcining and pretreatment conditons see Table 1 footnote. Some variation in results was observed with changes in catalyst preparation. The detailed results for toluene at different reaction temperatures and times show, as expected, that the degree of specificity decreases with increasing reaction temperature and scrambling of the isotope begins to appear in the samples exchanged over longer times. A number of other compounds tested did not undergo appreciable exchange in this preliminary study. These included the relatively inert non-branched aliphatic hydrocarbons and substrates of larger molecular dimensions, such as the long chain alkylbenzenes, which might be expected to be excluded from access to the pores of the ALPO catalyst.

ALPO-5 has been shown[7] to have a three-dimensional structure with hexagonal symmetry, containing one dimensional channels (diameter 0.8 nm) bounded by 12-membered rings composed of alternating AlO_4 and PO_4 tetrahedra. The absence of the altervalent cations necessary for neutrality in Si/Al zeolites means ALPOs are essentially non-acidic. Other recent studies[8] have shown that ALPO-5 contains very few strongly acidic sites as measured by chemisorption of pyridine at 623 K. It is thus surprising that ALPO-5 exhibits the high catalytic activity reported in a system which requires activation of both the relatively inert elemental tritium molecule as well as an aromatic centre, a catalytic activity much higher than that reported for the 'acidic' Y-zeolites and ZSM-5.[6] These results suggest that the catalytic activity of ALPOs for other chemical systems, where reactant molecule size is such that access to the pores is possible, should be more extensively explored.

ALPO-5 appears to be an exchange catalyst capable of inducing a highly specific and unique labelling in organic compounds. Furthermore, the fact that pure tritium gas can be utilised as the isotope source means that high activity samples can be produced. A wide range of ALPOs of various pore dimensions can be readily synthesised.[7] Thus it may prove possible to select an ALPO appropriate to a particular tritium or deuterium labelling problem, such that the substrate molecule has access to the pores of the catalyst but is constrained to give high specificity of labelling.

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