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Solubility and Potential Toxicity of Lead in Urban Street Dust

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The lead content of roadside and playground dust in urban areas is frequently high enough to make a major contribution to the lead intake of children through accidental ingestion of the dust (DAY et al. 1975, DAY 1977, U.K. D.O.E. 1974 and 1978). The question arises as to whether the material presents the potential toxic hazard suggested by its gross lead content (DUGGAN and WILLIAMS 1977). Although the fact of the build-up of lead from aerial deposition in surroundings frequently washed by rainwater suggests rather low lead solubility, the acidity of stomach fluids is much greater than that of rainwater, giving the possibility of a marked difference in solubility. We now report measurements of the extractability of lead at various acidities, our object being to assess the potential toxicity, following ingestion, of this form of environmental lead.

EXPERIMENTAL

Dust samples.- The material collected in previous lead surveys in Manchester, England, and Christchurch, New Zealand, was used in this investigation (respectively, DAY et al. 1975, and DAY 1977). The samples consisted of loose surface material (dust, sand, earth, etc.) collected from roadside gutters and pavements, and from paved areas in gardens, school yards and children's playgrounds. The individual samples, which had previously been dried and finely ground, were pooled to give 4 bulk samples (designated I-IV) of ca. 300 g each. These were re-ground, dried at 120°, and thoroughly mixed before analysis for total lead (Table 1), and acid extraction experiments (Table 2 and Figure 1).

Lead extraction and analysis.- Total (i.e. maximum extractable) lead was determined by boiling samples (ca. 1g) with nitric acid (2M) for one hour and measuring the lead concentrations in the filtered solution by atomic absorption spectroscopy using standard flame techniques (e.g. WELZ 1976) and a Perkin Elmer model 603 spectrophotometer with background correction. Analytical solutions were rendered 1M in nitric acid and 0.05M in EDTA to reduce interferences.

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TABLE 1

ORIGIN AND LEAD CONTENT OF MATERIAL

Bulk samples	Origin	Lead content (µg g^{-1})
I	Manchester (A-B)	940
II	Manchester (C-D)	1010
III	Christchurch (A-B)	2130
IV	Christchurch (C-D)	570

Individual samples from previous surveys in Manchester, England, and Christchurch, New Zealand, were pooled for this investigation (see text). Categories A-D refer to the type of location from which the sample originated, as follows: A, major roads; B, minor road, but with appreciable traffic; C, roads with very light traffic only; D, paved areas in gardens, school yards and children's playgrounds.

The acid-dependent extractions were carried out on larger samples (10 to 50 g), using hydrochloric acid at various concentrations from 1.0 to 10^{-5}M, by shaking the mixtures for one hour at 20°C. After filtration and washing (first extraction), the residues were re-extracted under the same conditions (second extraction). The first and second extracts were analysed separately both by atomic absorption spectroscopy, and by pulse polarography, using a Princeton Applied Research model PAR 174 pulse polarograph and dropping mercury electrode. There was close agreement between the analytical results by the two methods. However, while the spectroscopic method determines total lead (largely irrespective of chemical form), the electrochemical method determines ionic lead only, i.e. the measured polarographic wave arises from the aquated ion Pb^{2+} (PECSOC et al. 1976). The agreement between the lead analyses by the two methods establishes that all the lead extracted enters solution as inorganic lead(II), i.e. Pb^{2+}.

RESULTS AND DISCUSSION

The "total lead" analyses for the four bulk samples (Table 1) range from 570 to 2130 µg g^{-1}, depending on sample origins. The amounts of lead extracted from the samples at the various acidities, expressed as a fraction of the total lead in each sample, are given in Table 2 and Figure 1. Despite the variation in total lead content of the four samples, the proportion extracted at a given pH is reasonably constant, both for the first extract and for both extracts combined. The pattern is reasonably clear. There is a large increase in lead extractability with increasing acidity, from <10% at pH ~5 to >90% at pH ~1, under the conditions of our experiments.

TABLE 2

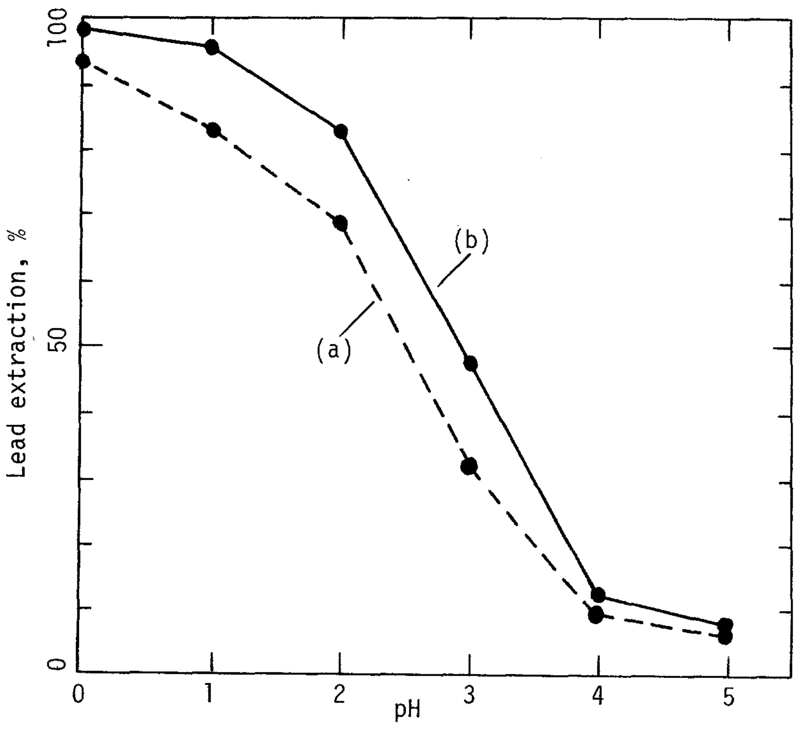
LEAD EXTRACTION FROM ENVIRONMENTAL DUST AT VARIOUS ACIDITIES AS A PERCENTAGE OF TOTAL LEAD

pH	Sample I		Sample II		Sample III		Sample IV		All Samples	
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
0	90.7	95.8	93.4	99.1	94.2	98.3	95.9	101.2	93.6	98.6
1	81.2	93.7	79.6	95.2	84.8	97.1	88.3	97.9	83.5	96.0
2	64.1	82.4	69.7	81.8	68.1	84.3	73.6	90.8	68.9	84.8
3	35.3	49.1	28.8	47.3	28.7	42.0	33.2	53.8	31.5	48.1
4	10.2	11.6	7.4	13.9	11.0	11.1	14.1	16.2	10.7	13.2
5	4.3	5.8	6.3	7.2	5.1	6.6	7.8	8.6	5.9	7.1

a: First extraction only; b, first and second extractions added together.

FIGURE 1

LEAD EXTRACTION : ALL SAMPLES COMBINED



a: First extraction only; b, both extractions added together.

We speculate that the reasons for this marked pH-dependent solubility reflect both the chemical nature of the lead-containing components of the dust, and the conditions to which the material is subjected in the environment. It may be assumed that lead generally accumulates in urban dust through aerial fall-out, and also that emissions from motor vehicles are the main source of airborne lead (NATIONAL ACADEMY OF SCIENCES 1971, EWING and PEARSON 1974). Under environmnetal conditions, the lead compounds initially emitted from motor vehicles (oxides and halides) are converted to the rather insoluble carbonate and sulphate (TER HAAR and BAYARD 1971). In addition, Pb^{2+} may be absorbed from solution by clay minerals in soil by ion-exchange processes. Urban dust is exposed to periodic washing by rainwater and surface run-off, which must steadily leach and remove components soluble above pH ~4 (the pH of unpolluted rainwater is ~5.3, the acidity arising from dissolved carbon dioxide, but in urban atmospheres a pH ~4 to 5 is often encountered, due to dissolved oxides of sulphur and nitrogen). Thus, a balance between the rate of aerial deposition of lead compounds and their rate of leaching results in the residual lead concentrations in urban dust, and furthermore, this lead component would not be expected to be readily soluble above pH ~4.

An increased lead solubility at lower pH, as we observe, is not unreasonable on chemical grounds. Both lead carbonate and sulphate increase in solubility with increasing acidity, due to the formation of bicarbonate and bisulphate ions (HCO_3^- and HSO_4^-, respectively). Also, adsorbed Pb^{2+} can be progressively released by ion-exchange with H^+ as the pH decreases.

The toxocological significance of these results is that the chemical conditions of the stomach (approximately 0.1M HCl, i.e. pH ~1, see e.g. GANARG 1971) would ensure complete extraction of lead from ingested dust, with the lead in ionic form (Pb^{2+} and derived complexes), which must present optimum conditions for absorption into the body from the gastro-intestinal tract. Therefore, it seems reasonable to classify the lead-containing components of the urban dust to the same high toxicity category as the soluble inorganic salts of lead (SAX 1975), although on a weight-for-weight basis the toxicity of typical urban dust would be about one thousandth that of, say, lead nitrate, in respect of their relative lead contents.

We turn now to possible health hazards which could arise from ingestion of lead-containing dust. The lead content of street and playground dust in cities is often *ca.* 1000 ppm, although occasionally much higher levels (up to 10000 ppm) are found, e.g. near lead industries, motorway junctions, etc. (EWING and PEARSON 1974, DAY et al. 1975, U.K. D.O.E. 1974 and 1978). Attention has sometimes been directed to the potential hazard to children with abnormal eating habits (i.e. *pica*), who may consume quantities of such dust, and cases of lead poisoning have resulted. However, even children with quite normal habits can accidentally ingest significant quantities of street dust. Direct measurements have shown (DAY et al. 1975) that children eating sticky sweets whilst playing in a city playground may contaminate the sweets with dirt from their hands, to the extent that from 5 to 50 mg of dirt, and hence *ca.* 5 to 50 μg of lead, are consumed with each sweet. These and similar considerations give rise to an estimate for the average daily intake of lead by a young child from the ingestion of street dust from 20 to 200 μg, but with the possibility of much greater quantities in some cases (DUGGAN and WILLIAMS 1977). This quantity may be compared with the amount of lead normally consumed in food, *ca.* 200 to 300 μg/day for adults and about half this for children (U.K. D.O.E. 1974). Our present finding is that dust-lead is readily soluble in stomach acid, and is presumably at least as available for absorption into the body as lead in normal food. As the currently suggested acceptable upper limits for dietary ingestion of lead by children (BALTROP 1972, U.K. D.O.E. 1974, DAY et al. 1975) are *ca.* 130 μg/day, the possible dust-lead contribution to total ingested lead is obviously significant.

We think that street dust as a potential source of lead poisoning in children has been largely disregarded. Even in cases where this source has been recognised (U.K. D.O.E. 1978), the emphasis has usually been on the possibility of children with *pica*. However, we consider that the hazard arises to a majority of normal children, interacting quite normally with their environment. It is widely recognised that a significant number of children in cities are likely to have undesirably high blood lead levels. For example, in the recent Birmingham survey (U.K. D.O.E., 1978) over 3% of the pre-school children tested had blood-lead levels over 0.35 ppm (the proposed "upper limit of normality; EUROPEAN COMMUNITIES DIRECTIVE 1977) and similar results have been obtained elsewhere. In the Birmingham survey no correlation was found between the children's blood-lead concentrations and "traditional" sources of lead, e.g. the presence of lead water-pipes in the house, or a medical history of *pica*. In our view, a major factor in the raised blood-lead levels for the under-fives could be the casual ingestion of urban dust. We consider that a reduction in environmental lead contamination should be regarded as an urgent problem in public health.

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