

AAIH SEMINAR No. 8

ODORS: HELPFUL WARNINGS AND HARMFUL EFFECTS

Tuesday, October 22, 1985

Seminar Director:

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	Page
1:30 p.m. FUNDAMENTALS OF ODOR SCIENCE	6
2:15 p.m. Demonstration of olfactory threshold testing	12
2:30 p.m. ODOR AS AN AID TO CHEMICAL SAFETY	17
3:15 p.m. Intermission to visit the exhibits	-
3:45 p.m. EFFECTS OF CHEMICAL EXPOSURE ON THE SENSE OF SMELL	31
4:30 p.m. Questions, comments, and review of test results	-

Objectives:

There is a large and scattered literature on the chemistry of odorous substances and the physiology of the sense of smell. This review is designed for maximum relevance to industrial hygiene. The presentation will be in three sections:

1. **Fundamentals of Odor Science:** Discusses the physical chemistry of odorants, measurement of odor detection threshold, odor intensity and odor quality. Describes the phenomenon of specific smell-blindness, and its value in suggesting a fundamental classification of primary odors.
2. **Odor as an Aid to Chemical Safety:** Develops a quantitative evaluation of the warning thresholds for 214 industrial odors, in relation to their TLVs. Analyzes the potential for worker education on hazard recognition by odor, and for odorization of hazardous products that lack adequate warning properties.
3. **Effects of Chemical Exposure on the Sense of Smell:** Considers the normal, and abnormal, ranges of human olfactory sensitivity. Surveys the literature on temporary and permanent loss of the sense of smell caused by chemical exposure, usually chronic, but sometimes acute. Over 100 chemicals can have these effects, belonging to six major divisions of the chemical industry.

Illustrative materials will be provided, and a hands-on demonstration of olfactory threshold testing will be available.

American Academy of Occupational Medicine
American Academy of Industrial Hygiene
Joint Conference on Occupational Health
Orlando, Florida, October 21-25, 1985

Key References (review articles):

Fundamentals of Odor Science:

Odor theory and odor classification. J. E. Amoore. In "Fragrance Chemistry," 1982, 27-76. E. T. Theimer, Editor. Academic Press, New York.

Olfactory Threshold Testing:

The pyridine scale for clinical measurement of olfactory threshold: a quantitative reevaluation. A. H. Sherman, J. E. Amoore and V. Weigel. Otolaryngology and Head and Neck Surgery, 1979, 87, 717-733.

Odor as an Aid to Chemical Safety:

Odor as an aid to chemical safety: odor thresholds compared with threshold limit values and volatilities for 214 industrial chemicals in air and water dilution. J. E. Amoore and E. Hautala. Journal of Applied Toxicology, 1983, 3, 272-290.

Effects of Chemical Exposure on the Sense of Smell:

Effects of chemical exposure on olfaction in humans. J. E. Amoore. In "Toxicology of the Nasal Passages," 1985, 155-190. C. S. Barrow, Editor. Hemisphere Publishing Corp., New York. (in Press)

Useful Formulae:

$$\text{At } 25^{\circ}\text{C: } \frac{\text{ppm} \times \text{mol. wt.}}{24.4} = \text{mg/m}^3 \text{ (European practice).}$$

$$\text{Air/water partition coefficient at } 25^{\circ} \text{ (w/v) } = \frac{\text{vapor press. (mm Hg)}}{\text{solv. (g/l)}} \times \text{mol. wt.} \times 5.38 \times 10^{-5}$$

To prepare water or air dilutions from the pure odorant (solid or liquid):

$$1 \text{ ppm (w/v)} = 1 \text{ mg (or } 1/D \text{ } \mu\text{l)} \text{ per liter of water}$$

$$1 \text{ ppm (v/v)} = \frac{\text{M.W.}}{24.4} \text{ mg. (or } \frac{\text{M.W.}}{24.4 \times D} \text{ } \mu\text{l)} \text{ per cubic meter of air}$$

Avogadro's Number: Mol. wt. in gm of a pure compound contains:
 6.02×10^{23} molecules

Effect of pH on ionization of weak acids and bases:

$$\text{acid: } \frac{\text{concn. of acid}}{\text{concn. of anion}} = \text{antilog}_{10} (\text{pK}_a - \text{pH})$$

$$\text{base: } \frac{\text{concn. of base}}{\text{concn. of cation}} = \text{antilog}_{10} (\text{pH} - \text{pK}_b)$$

where K_a and K_b are the acid and basic dissociation constants, respectively.

Quantity of odorant adsorbed =

$$\text{mass of adsorbant} \times k \times \text{concn. of odorant}^b$$

where k is a constant, and exponent b is less than unity.

Formulae (continued):

Stevens' (1960) Power Law for odor intensity:

$$\text{intensity} = k \times \text{concn. of odorant}^n$$

where k is a constant, and exponent n is in the vicinity of 0.6

$$\text{or: } \log \text{ intensity} = n \times \log \text{ concn.} + \log k$$

Hence, perceived intensity of odor increases about 1.5 times for each doubling of the odorant concentration.

Conversions in the binary step ($\log_2$) concentration scale for odorants:

$$\text{concentration ratio} = \text{antilog}_{10} (\text{binary steps} \times 0.301)$$

$$\text{binary steps} = \frac{\log_{10} \text{ concn. ratio}}{0.301}$$

$$\text{Odor Units (U)} = \frac{\text{actual concn. of odorant}}{\text{threshold concn. of odorant}}$$

Guadagni's (1966) Rule of Additivity:

Odor Units of a mixture is the sum of the odor units of all its components:

$$U_m = U_1 + U_2 + U_3 + \dots$$

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Volatilities of Odorous Compounds at 25° C

Odorant	Vapor pressure (mmHg)	Molecular weight	Concentration in air		
			(g/liter)	(mg m ³)	(ppm, v/v)
Trimethylamine	1700	59	5.4×10^{-2}	5.4×10^2	2,200,000
Pyridine	20	79	8.5×10^{-2}	8.5×10^4	26,000
Isobutyl isobutyrate	4.2	144	3.3×10^{-2}	3.3×10^4	5500
<i>l</i> -Carvone	0.12	150	9.7×10^{-4}	9.7×10^2	160
Phenyl ether	0.022	170	2.0×10^{-4}	2.0×10^2	29
α -Chloroacetophenone	0.0075	155	6.3×10^{-5}	6.3×10^1	9.9
α -Pentadecalactone	0.00045	240	5.8×10^{-6}	5.8×10^0	0.59
Musk ketone	0.0000021	294	3.3×10^{-8}	3.3×10^{-2}	0.0028

Calculated air/water partition coefficients of normal 5-carbon compounds at 25°.

Compound	Vapor pressure (mm Hg)	Solubility in water (g/l)	Molecular weight (g)	Partition coefficient (calculated)
Pentane	520	0.038	72.1	52
Propyl ethylene	640	0.11	70.1	22
Propyl acetylene	440	1.0	68.1	1.6
Pentyl chloride	33	0.20	106.6	0.93
Pentyl mercaptan	15	0.16	104.2	0.55
Methyl butyl ether	170 ^a	8.9	88.1	0.091
Methyl butyrate	32	15	102.1	0.011
Nitro pentane	1.7	1.3	117.1	0.0085
Pentyl aldehyde	16 ^a	12	86.1	0.0063
Butyl cyanide	7.6	13 ^b	83.1	0.0026
Methyl propyl ketone	16	54	86.1	0.0013
Pentyl amine	28	∞	87.2	0.0013 ^c
Pentyl alcohol	2.5	23	88.1	0.00052
Pentanoic acid	0.29	50	102.1	0.000031

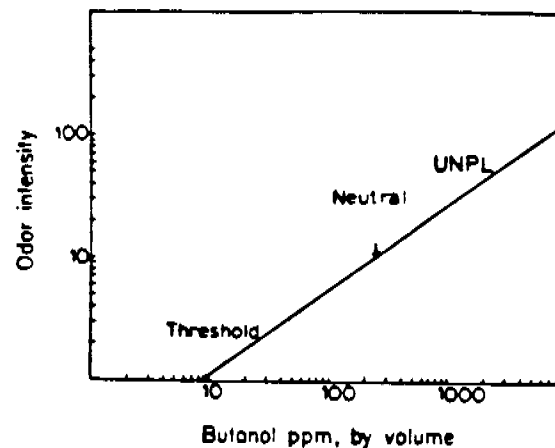
Odor Detection Thresholds of Selected Compounds

Compound	Odor threshold concn in air	
	(mg m ³)	(ppm, v/v)
Ethane	1.5×10^5	120,000
Methanol	6.6×10^2	500
Chloroform	3.2×10^2	65
Benzene	1.7×10^1	5.2
Camphor	1.1×10^0	0.17
Furfural	2.3×10^{-1}	0.059
Isoamyl acetate	3.8×10^{-2}	0.0071
5 α -Androst-16-en-3-one	2.1×10^{-3}	0.00019
2-Methoxy-3-isobutylpyrazine	3.6×10^{-6}	0.0000054

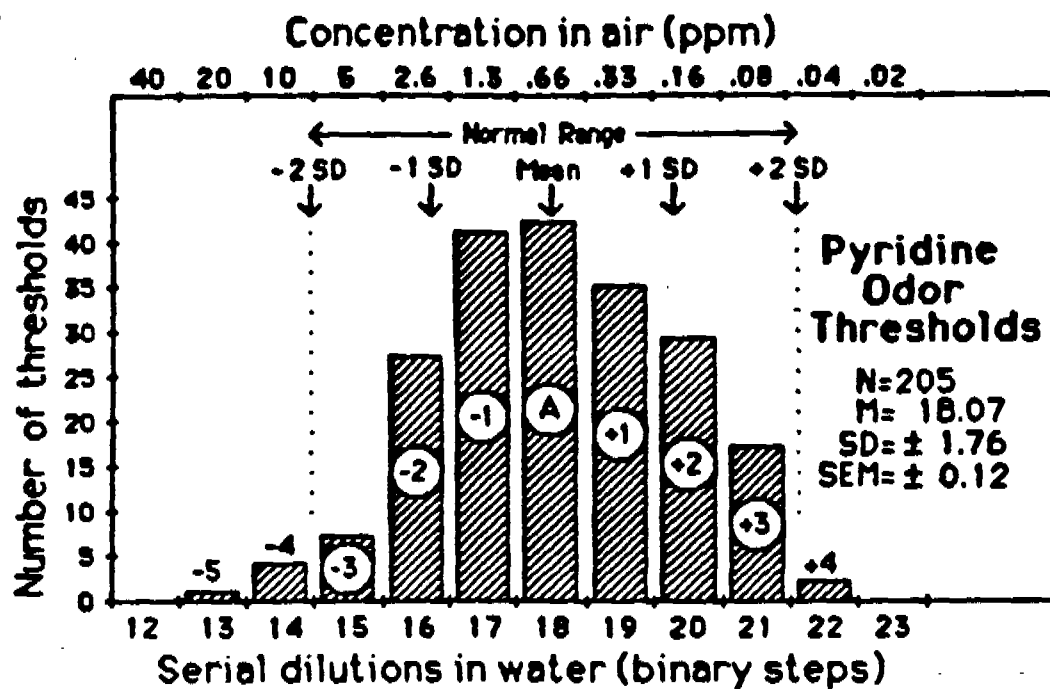
stale wine

green pepper odor

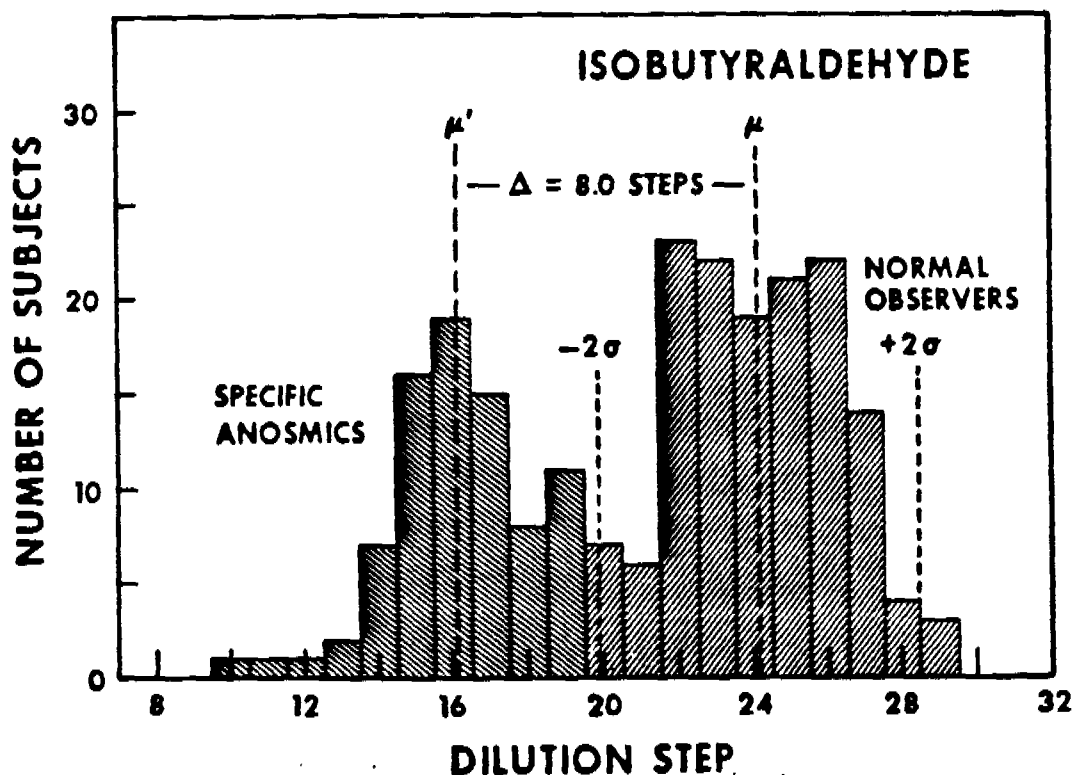
vitamin B when stale gives off odor
~100 times lower than lowest in the table.



The butanol reference scale for odor intensity, plotted in log log coordinates (Reprinted from Moskowitz *et al.*, 1974).

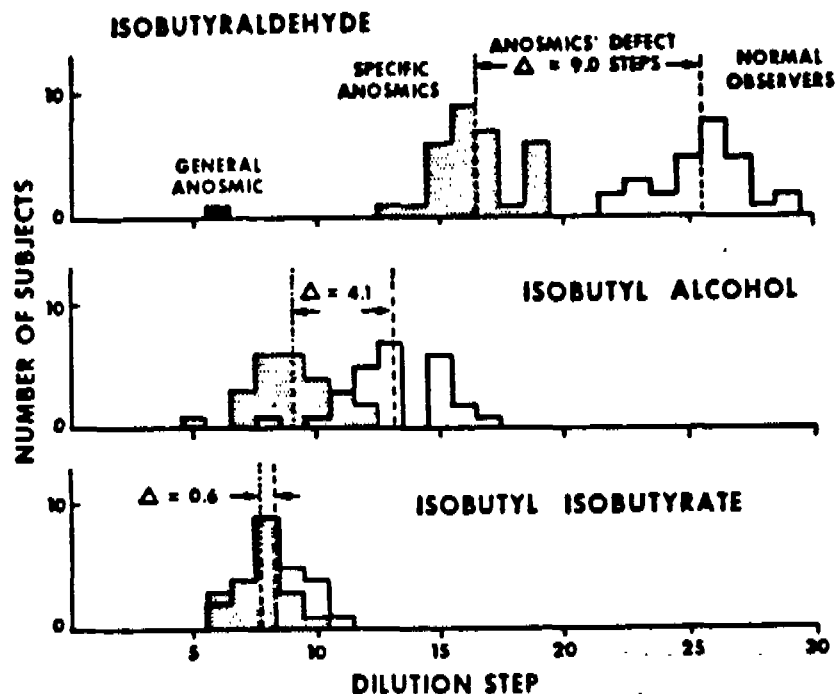


Normal distribution of olfactory threshold sensitivities in the human population.



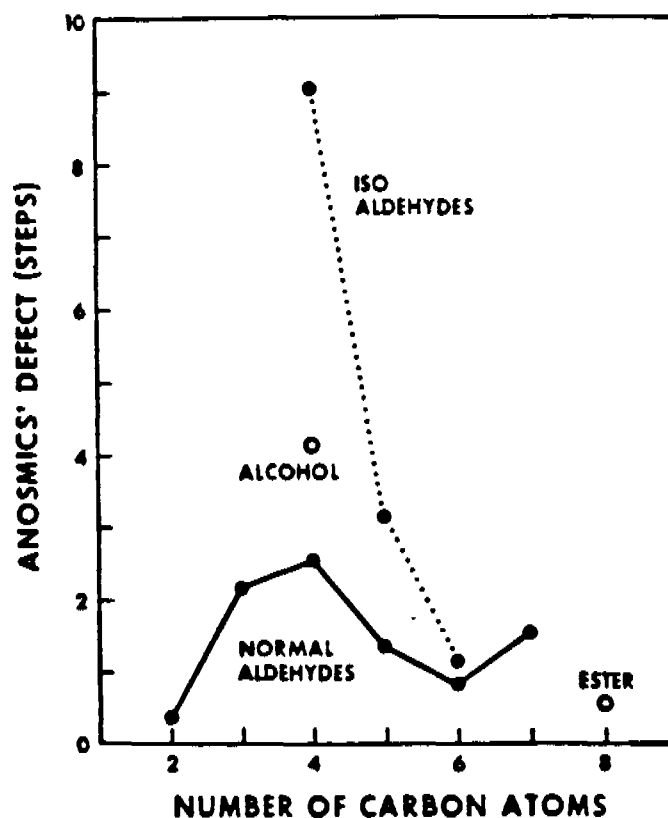
Bimodal distribution of olfactory thresholds to isobutyraldehyde.

$\mu' \gg \mu$, 8 steps lower $\Rightarrow 2^8 = 256$ times higher conc. to smell it



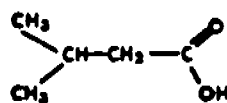
best example

Thresholds of a panel of specific anosmics (stippled) compared with a panel of normal observers (outlined).

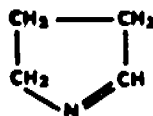


Mapping the range of the specific anosmia to aliphatic aldehydes.

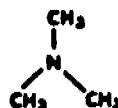
lack of sense of smell



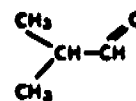
ISOVALERIC
ACID



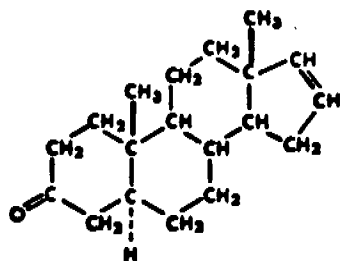
1-PYRROLINE



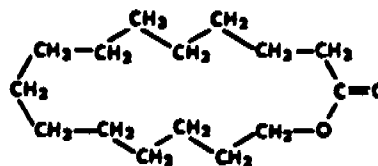
TRIMETHYL-
AMINE



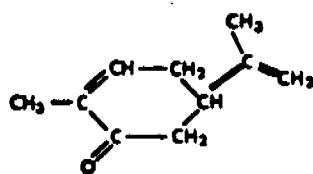
ISOBUTYR-
ALDEHYDE



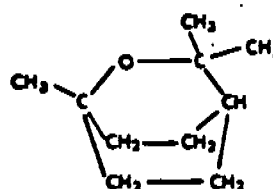
5 α -ANDROST-16-EN-3-ONE



ω -PENTADECALACTONE



l-CARVONE



1,8-CINEOLE

Structural formulas of eight of the
primary odorants.

Olfactometric properties of eight of the
primary odorants.

Primary odorant	Primary odor	Normal threshold		Anosmics' occurrence (%)	Anosmics' defect (factor)
		In air (ppm, v/v)	In water (ppm, w/v)		
Isovaleric acid	Sweaty	0.0010	0.12	3	42
1-Pyrroline	Spermous	0.0018	0.020	16	39
Trimethylamine	Fishy	0.0010	0.00047	6	830
Isobutyraldehyde	Malty	0.0050	0.0018	36	340
5 α -Androst-16-en-3-one	Urinous	0.00019	0.00018	47	770
ω -Pentadecalactone	Musky	0.018	0.0018	12	13
<i>l</i> -Carvone	Minty	0.0056	0.041	8	13
1,8-Cineole	Camphor	0.011	0.020	33	56

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quite small
at all

number of times higher conc
must be for some to smell

GENERAL ODOR CLASSIFICATIONS											SPECIFIC ANOSMIA ANALYSES					
LINE NO	2000-1999 34 (300) CLASSES	1900-1700 7 CLASSES	1600-1500 8 CLASSES	1400-1300 4 CLASSES	1200-1100 7 CLASSES	1000-900 9 CLASSES	800-700 8 CLASSES	600-500 44 CLASSES	400-300 10 CLASSES	200-100 ADDITIONAL	DETAILED SPECIFIC ANOSMIAS				ESTABLISHED PRIMARY ODORANT	PRODUCT PRIMARY ODOR
1	FOURTY						HEXYL ACETATE	FOURTY			7-HEXYL N-ACETATE	HEXYL ACETATE				
2	HEXY							SOFTY								
3	ETHYRICAL				ETHYRICAL	ETHYRICAL		ETHYRICAL SOLVENT CAMPHOR METHANOL			ETHYRICAL DICHLOIDE	ETHYRICAL ETHYLENE	HEXYL	HEXYL (2)		
4	CAMPOR				CAMPOR						1,3-ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE	CAMPOR
5	SOFTY	AROMATIC						AROMATIC			ETHYRICAL	HEXYL ALCOHOL	HEXYL ALCOHOL			
6	CAMPOR		SPICY				SPICY	SPICY			CAMPOR ALCOHOL	HEXYL ALCOHOL	HEXYL ALCOHOL			
7	HEXYL						HEXYL ETHYLENE									
8	HEXYL				HEXYL			HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE
9	HEXYL										HEXYL	HEXYL ETHYLENE	HEXYL ETHYLENE			
10	HEXYL										HEXYL	HEXYL ETHYLENE	HEXYL ETHYLENE			
11	CITRUS		FOURTY				CITRUS	CITRUS			HEXYL	HEXYL ETHYLENE	HEXYL ETHYLENE			
12	ALCOHOL					SPICY		ALCOHOL								
13	ALCOHOL		FLOWERY		FLOWERY			FLOWERY			HEXYL	HEXYL ETHYLENE	HEXYL ETHYLENE			
14	HEXYL ETHYLENE	FRAGRANT		FRAGRANT		FRAGRANT		FRAGRANT								
15	HEXYL										HEXYL	HEXYL ETHYLENE	HEXYL ETHYLENE			
16	HEXYL										HEXYL	HEXYL ETHYLENE	HEXYL ETHYLENE			
17	HEXYL				SWEET			HEXYL SWEET			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
18	HEXYL										HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
19	HEXYL	AROMATIC			HEXYL			HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
20	HEXYL	ALCOHOL						HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
21	HEXYL							HEXYL ETHYLENE			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
22	HEXYL										HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
23	HEXYL		HEXYL	HEXYL	HEXYL	HEXYL	AFFECTIVE	HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
24	HEXYL							HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
25	HEXYL	HEXYL		HEXYL				HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
26	HEXYL										HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
27	HEXYL	HEXYL									HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
28	HEXYL							HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
29	HEXYL	HEXYL						HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
30	HEXYL							HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
31			HEXYL				HEXYL	HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
32			HEXYL		HEXYL	SOLVENT	HEXYL	HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
33				HEXYL				HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
34								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
35								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
36								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
37								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
38								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
39								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
40								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
41								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
42								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
43								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
44								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
45								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
46								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
47								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
48								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
49								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			
50								HEXYL			HEXYL ETHYLENE	HEXYL ETHYLENE	HEXYL ETHYLENE			

PYRIDINE DILUTION SERIES

DILUENT → Binary step #	WATER Concentration (percent)	MINERAL OIL Concentration (percent)	AIR Concentration (ppm, v/v)	CLINICAL SIGNIFICANCE OF THRESHOLD
0	100	100	27,000	<u>Complete anosmia.</u> (no I, V, IX or X nerve function)
1	50	Henry's Law <u>not</u> obeyed in this concentration range		<u>Hyposmia type I.</u> (no Ist nerv function but Vth nerve is functional)
2	25			
3	12			
4	6			
5	3	3	2,700	
6	1.5		1,400	
7	0.8		700	
8	0.4		340	
9	0.2			
10	0.1	0.2	170	<u>Hyposmia type II.</u> (abnormally weak Ist nerve function)
11	0.05	0.1	80	
12	0.025	0.05	40	
13	0.012	0.025	20	
14	0.006	0.012	10	<u>Normal range.</u> (Average = 16.0 st p S.D. ± 2.0)
15	0.003	0.006	5	
16	0.0015	0.003	2.6	
17	0.0008	0.0015	1.3	
18	0.0004	0.0008	0.66	
19	0.0002	0.0004	0.33	
20	0.0001	0.0002	0.16	
21	0.00005	0.0001	0.08	
22	0.000025	0.00005	0.04	<u>Hyperosmia.</u> (abnormally sensitive Ist nerve function)
23	0.000012	0.000025	0.02	
24	0.000006	0.000012	0.01	
25	0.000003	0.000006	0.005	
26	0.0000015	0.000003	0.0025	
27	0.0000008	0.0000015	0.0012	
28	0.0000004	0.0000008	0.0006	
29	0.0000002	0.0000004	0.0003	

TEST PROCEDURE

Select the pair of bottles for step #14. Flip open the spouts, and swirl the contents to hasten equilibration. Instruct the patient to direct the spout closely towards the nostril, then to squeeze the bottle while inhaling through the nose. Ask the patient to pick out the odorous, or most odorous, bottle. Extra sniffs are permitted, before making the choice. Detection only is required, not recognition of the odor. Raise bottle above eye level to see the label on bottom of bottle. If the patient's choice is correct (PYR-14) enter "C" in 1st. test column for step #14. Swirl the bottles again, and randomize their positions until neither the tester nor the patient remembers which is the odorous bottle. Ask the patient to repeat the test a 2nd. and a 3rd. time at step #14. A wrong selection (BLA-14) is indicated by "X" in the appropriate column. In order for the patient to pass a given sensitivity step, the correct selection must be made all three times. Flip the air-spouts closed, and replace the bottles in the carton. Proceed to the next higher, or lower, sensitivity step, as required to establish the patient's threshold olfactory sensitivity to pyridine on this occasion. At least two consecutive concentration steps should be passed, in order to establish a valid threshold, which is defined as the highest sensitivity step yielding all-correct responses.

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SCORE-SHEET

OLFACTORY SENSITIVITY TEST (PYRIDINE SCALE)		SENSI- TIVITY STEP #	TESTS		
			1st	2nd	3rd
<u>Questionnaire</u>		29			
Patient's name: _____		28			
Referring M.D.: _____ Date: _____		27			
In order to avoid permanently contaminating the bottles with foreign odors, and to obtain a reliable test result, it is essential that:-		26			
Patient has not smoked in last 15 min.? _____		25			
No food, beverage or candy in last 15 min.? _____		24			
No perfume or hand lotion used today? _____		23			
Not suffering from a cold or influenza? _____		22			
Not experiencing a nasal allergy (hay fever)? _____		21			
At least one nostril is clear right now? _____		20			
<u>Precautions</u>		19			
The bottles are one-quarter filled with mineral oil, and must not be knocked over, shaken or inverted, because oil may enter the air spout. If this accidentally occurs, the dispenser cap should be unscrewed, any oil inside the cap and air delivery tube removed with twists of clean tissue, and the cap tightly replaced. Each test odor bottle should always be compared with its own matched blank bottle. Pyridine in the strongest concentrations (step #6 contains 3% in the oil) may be caustic or irritating. Each successive higher sensitivity step contains pyridine at one-half the concentration of the preceding step. This clinical olfactory test kit must be used only by trained personnel, and kept out of the reach of children.		18			
		17			
		16			
		15			
		14			
		13			
		12			
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		8			
		7			
		6			

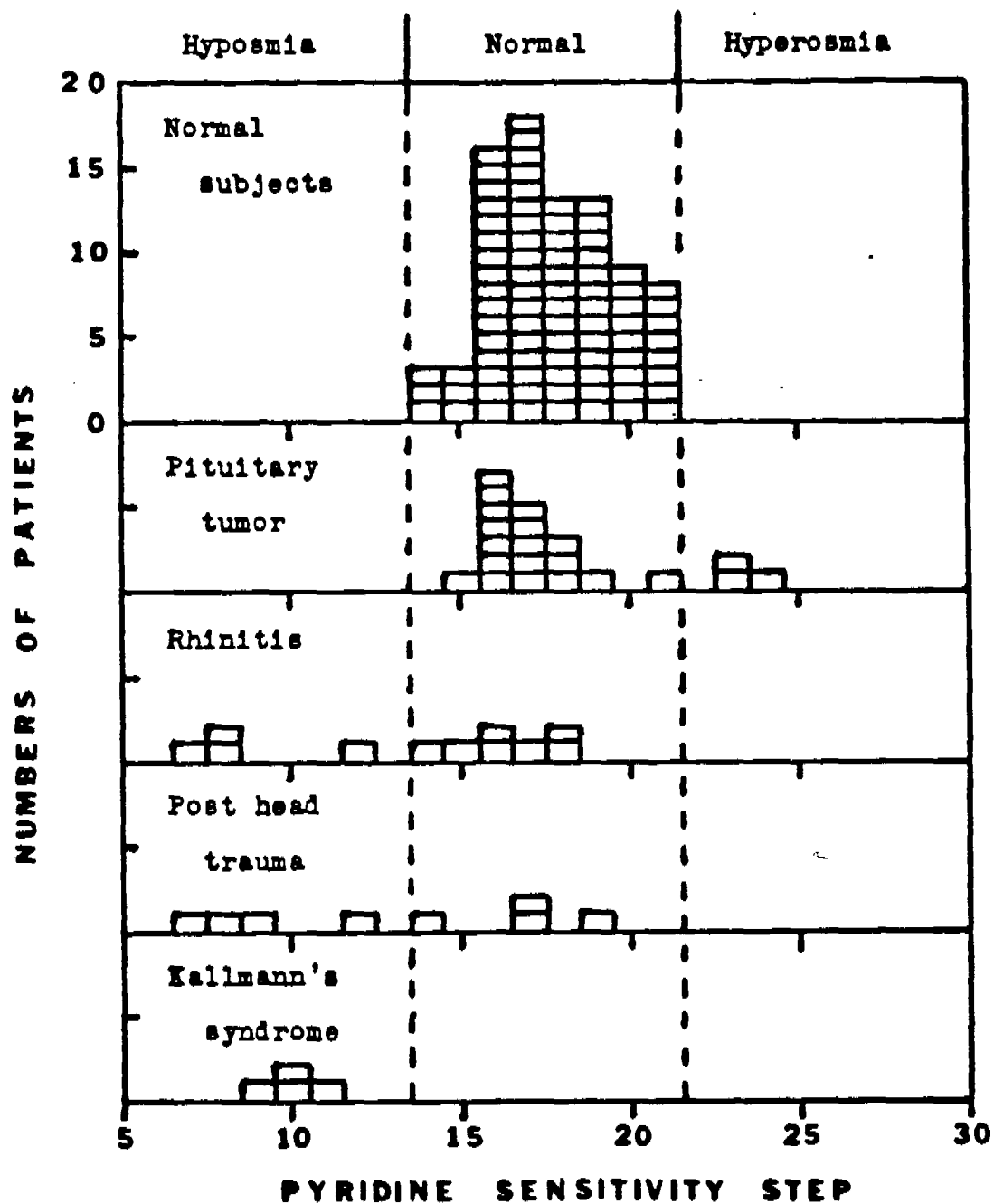
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Olfactory evaluation

Pyridin threshold is Step # _____

T s t d by: _____

CLINICAL OLFACTORY THRESHOLDS



CLINICAL INDICATIONS

Hyposmia type I (pyridine sensitivity step #9 or lower)

Mechanical blockage of airway by intranasal polyps, ethmoid sinusitis, allergic rhinitis, or carcinoma of paranasal sinuses or nasopharynx.
Damage to olfactory epithelium by acute or chronic infection, atrophic rhinitis, or certain industrial fumes and vapors.
Damage to olfactory nerves or bulbs by head trauma causing fracture, shearing, hemorrhage or concussion.
Abnormalities in the region of the floor of the anterior fossa, including meningioma, frontal lobe tumor, meningitis at base of frontal lobe, abscess of frontal or ethmoid bone, vascular tumor, or arteriosclerosis of the anterior cerebral artery.
Congenital defects such as deviated septum, absence of olfactory bulbs, familial dysautonomia, or hypogonadotrophic hypogonadism.
Miscellaneous problems, including nasal medication, surgical interference, radiation therapy to the head, idiopathic hyposmia with hyposmia; also hysteria and malingering.

Hyposmia type II (pyridine threshold steps #10 through #13)

Milder incidence of the above conditions.
Upper turbinate congestion due to allergy or head cold.
Acute viral hepatitis, poliomyelitis, advanced syphilis, diphtheria, leprosy.
Heavy smoking, chronic alcoholism, sniffing cocaine.
Diabetes mellitus, hypothyroidism, some forms of hypopituitarism, hyperactive adrenal cortex.
Some systemic medications and antibiotics.
Miscellaneous conditions, including vitamin A deficiency, pernicious anemia, uremia, zinc deficiency.

Hyperosmia (pyridine sensitivity step #22 or higher)

Glucocorticosteroid insufficiency (Addison's disease).
Some drugs, such as caffeine and strychnine.
Some cases of pituitary tumor.
Epilepsy, schizophrenia, specific allergy.

Literature odor thresholds for *n*-butyl alcohol^a

Water-dilution threshold		Air-dilution threshold		First reference
Original data	g l ⁻¹	Original data	g l ⁻¹	
		1 µg/l	1.00 × 10 ⁻⁶	Passy, 1892
		0.565 × 10 ⁻³ mol l ⁻¹	4.18 × 10 ⁻³	Backman, 1917
		0.000223 mg/l	2.23 × 10 ⁻³	Jung, 1936
		Act ₃₁ = 6 × 10 ⁻³	1.61 × 10 ⁻³	Gavaudan, 1948
		Act ₃₁ = 7.0 × 10 ⁻⁴	4.09 × 10 ⁻³	Mullins, 1955
0.005% (v/v)	4.03 × 10 ⁻³		1.45 × 10 ⁻³	Moncrieff, 1957
		15 ppm (v/v)	4.56 × 10 ⁻³	Scherberger, 1958
1 mg/l	1.00 × 10 ⁻³		3.60 × 10 ⁻³	Nazarenko, 1962
1.00 ppm (w/v)	1.00 × 10 ⁻³		3.60 × 10 ⁻³	Rosen, 1962
2.5 ppm (v/v)	2.01 × 10 ⁻³		7.24 × 10 ⁻³	Baker, 1963
		Act ₃₁ = 5 × 10 ⁻³	1.40 × 10 ⁻³	Gavaudan, 1966
		33 mg/m ³	3.30 × 10 ⁻³	May, 1966
0.50 ppm (v/v)	4.02 × 10 ⁻⁴		1.45 × 10 ⁻³	Fiath, 1967
		1.10 × 10 ¹³ mol/cc	1.34 × 10 ⁻³	Dravnieks, 1968
		1.2 mg/m ³	1.20 × 10 ⁻³	Khachatryan, 1969
		0.013 mg/l	1.30 × 10 ⁻³	Corbitt, 1971
		-log ₁₀ M/l = 7.91	9.12 × 10 ⁻³	Laffort, 1973
		0.30 ppm (v/v)	9.11 × 10 ⁻³	Hellman, 1974
		3.16 ppm (v/v)	9.60 × 10 ⁻³	Moskowitz, 1974
		62 ppm (v/v)	1.88 × 10 ⁻³	Moskowitz, 1974
2.0 mg/kg	2.00 × 10 ⁻³		7.20 × 10 ⁻³	de Grunt, 1975
3.6 × 10 ⁻⁴ M/l	2.67 × 10 ⁻³		9.61 × 10 ⁻³	Hertz, 1975
2.77 ppm (w/v)	2.77 × 10 ⁻³		9.97 × 10 ⁻³	Lillard, 1975
		0.0231 mmHg	9.23 × 10 ⁻³	Piggott, 1975
		0.390 ppm (v/v)	1.18 × 10 ⁻³	Dravnieks, 1976
		2.8 × 10 ⁻¹ ppm (v/v)	8.50 × 10 ⁻³	Williams, 1977
6.5 × 10 ⁻³ g/l	6.50 × 10 ⁻³		2.34 × 10 ⁻³	Amoore, 1978
		3.5 ppm (v/v)	1.06 × 10 ⁻³	Leing, 1978
		log ₁₀ ppb = 10.42	4.15 × 10 ⁻³	Punter, 1980



Geometric mean, air-dilution threshold = $2.54 \times 10^{-3} \text{ g l}^{-1}$ ($N = 29$)
 $= 2.54 \text{ mg m}^{-3}$
 $= 0.835 \text{ ppm (v/v)}$

European std units

Standard deviation = $x \pm 7.14$, Standard error = $x \pm 1.44$

^a MW = 74.1 g; D_{21} 0.806 g ml⁻¹; VP_{21} = 6.99 mmHg, S_{21} = 73.0 g l⁻¹; air-water partition coefficient at 25 °C = 3.6×10^{-4} (expt.), 3.61×10^{-4} (calc.).

US uses avg. threshold.

Russians use most sensitive member of the panel → lower v

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Explanation of column headings in Tables 2(a) and 2(b)

Column

1. TLV's listed by ACGIH, 1982.
2. Volatility = vapor press. (mm Hg at 25°C) x 1,316
3. Air odor threshold is geometric mean of all literature data (including converted water threshold data).
4. Standard error of mean odor threshold value.
5. Safe dilution factor (for saturated vapor) = volatility divided by TLV.
6. Odor safety factor = TLV divided by odor threshold.
7. Odor safety class: see Table on page 28 for interpretation.
8. Water TLV equivalent: the aqueous odorant concn. that is in equilibrium with air TLV concn.
9. Solubility = literature soly. (g/l) x 1,000
10. Water odor threshold: the aqueous odorant concn. that is in equilibrium with the air threshold concn.
- 11 & 12. Molecular weight and density are needed when measuring out odorants to prepare water or air dilutions (see Useful Formulae).
13. Water-air distribution ratio = reciprocal of the air-water partition coefficient (both concentrations in g/l).
14. The number(s) of literature reference values that were averaged to obtain the mean odor threshold in column 3.

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Table 2(a) Air-dilution odor threshold data on 214 industrial chemicals. The numerical data are mostly rounded off to two significant figures. Note that ppm on this half of Table 2 are in v/v units ($\mu\text{l l}^{-1}$) for the gaseous chemical in air dilution. See Methods for further explanation of each column. TLVs are reproduced from Ref. 1 (1982) with permission from ACGIH

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25°C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error ($\times/\pm$)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Acetaldehyde	100	g	0.050	1.7	10 000	2000	A
Acetic acid	10	20 000	0.48	1.5	2000	21	C
Acetic anhydride	5	6700	0.13	1.1	1300	39	B
Acetone	750	290 000	13	1.6	390	57	B
Acetonitrile	40	120 000	170	2.8	3000	0.23	D
Acetylene	140 000 ⁱ	g	620	2.8	7	230	B
Acrolein	0.1	360 000	0.16	1.5	3 600 000	0.61	D
Acrylic acid	10	5800	0.094	—	580	110	B
Acrylonitrile	2	140 000	17	2.4	72 000	0.12	E
Allyl alcohol	2	33 000	1.1	1.3	16 000	1.8	C
Allyl chloride	1	480 000	1.2	2.5	480 000	0.84	D
Ammonia	25	g	5.2	2.0	40 000	4.8	C
n-Amyl acetate	100	5200	0.054	2.1	52	1800	A
sec-Amyl acetate	125	9200	0.0020	—	74	61 000	A
Aniline	2	630	1.1	1.6	310	1.9	C
Arsine	0.05	g	0.50	—	20 000 000	0.10	E
Benzene	10	120 000	12	1.6	12 000	0.85	D
Benzyl chloride	1	1600	0.044	1.1	1600	23	C
Biphenyl	0.2	11	0.00083	—	56	240	B
Bromine	0.1	270 000	0.051	2.2	2 700 000	2.0	C
Bromoform	0.5	8000	1.3	2.3	16 000	0.39	D
1,3-Butadiene	1000	g	1.6	2.5	1000	640	A
Butane	800	g	2700	1.4	1300	0.29	D
2-Butoxyethanol	25	1300	0.10	—	52	250	B
n-Butyl acetate	150	16 000	0.39	2.5	110	390	B
n-Butyl acrylate	10	7100	0.035	5.3	720	290	B
n-Butyl alcohol	50	9200	0.83	1.4	180	60	B
sec-Butyl alcohol	100	23 000	2.6	2.0	230	38	B
tert-Butyl alcohol	100	55 000	47	2.6	550	2.1	C
n-Butylamine	5	93 000	1.8	2.5	19 000	2.7	C
n-Butyl lactate	5	590	7.0	—	120	0.71	D
n-butyl mercaptan	0.5	~49 000	0.00097	1.4	97 000	510	B
p-tert-Butyltoluene	10	850	5.0	—	85	2.0	C
Camphor	2	450	0.27	1.9	230	7.3	C
Carbon dioxide	5000	g	74 000	1.5	200	0.067	E
Carbon disulfide	10	470 000	0.11	1.9	47 000	92	B
Carbon monoxide	50	g	100 000 [†]	10	20 000	0.00050	E
Carbon tetrachloride	5	140 000	96	1.8	29 000	0.052	E
Chlorine	1	g	0.31	1.8	1 000 000	3.2	C
Chlorine dioxide	0.1	g	9.4	1.6	10 000 000	0.011	E
α -Chloroacetophenone	0.05	9.9	0.035	1.1	200	1.4	C
Chlorobenzene	75	15 000	0.68	1.6	200	110	B
Chlorobromomethane	200	190 000	400	—	940	0.50	D
Chloroform	10	250 000	85	1.7	25 000	0.12	E
Chloropicrin	0.1	34 000	0.78	1.4	340 000	0.13	E
β -Chloroprene	10	290 000	15	7.9	29 000	0.68	D
o-Chlorotoluene	50	4700	0.32	1.5	94	150	B
m-Cresol	5	180	0.00028	2.4	36	17 000	A
trans-Crotonaldehyde	2	~41 000	0.12	1.1	20 000	17	C
Cumene	50	5900	0.088	2.9	120	570	A

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Table 2(b) Water-dilution odor threshold data on the same 214 chemicals. Note that ppm on this half of Table 2 are in w/v units (mg l^{-1}) for the chemical in aqueous solution. The numerical values in Table 2 are almost invariably compiled, averaged, re-calculated or extrapolated from the literature, and are not new experimental determinations

Substance	8 Water TLV equivalent (ppm, w/v)	9 Solubility at 25°C (ppm; w/v)	10 Water odor threshold (ppm, w/v)	11 Molecular weight (g)	12 Density at 20-25°C (g ml^{-1})	13 Water-air distribution ratio (w/v)	14 Number of thresholds performed	
							air	water
Acetaldehyde	67	—	0.034	44	0.79 ₁₀	370	6	3
Acetic acid (A/4.7)	2000	—	97	60	1.05	82 000	14	4
Acetic anhydride	d	d	d	102	1.08	d	2	—
Acetone	1100	—	20	58	0.79	620	20	8
Acetonitrile	70	—	300	41	0.78	1000	3	—
Acetylene	(150)	1000	(0.67)	26	0	1.0	2	—
Acrolein	0.066	200 000	0.11	56	0.84	290	7	1
Acrylic acid (A/4.3)	—	—	—	72	1.05	—	1	—
Acrylonitrile	1.1	73 000	9.1	53	0.80	240	2	2
Allyl alcohol	26	—	14	58	0.85	5600	4	—
Allyl chloride	(0.0075)	3600 ₂₀	(0.0089)	76	0.94	2.4	2	—
Ammonia (B/9.2)	7.1	280 000	1.5	17	0	400	11	2
n-Amyl acetate	68	1800 ₂₀	0.037	130	0.88	130	5	4
sec-Amyl acetate	110	1700	0.0017	130	0.87	160	—	1
Aniline (B/4.6)	120	37 000	65	93	1.02	16 000	9	1
Arsine	(0.000035)	670	(0.00035)	78	0	0.22	1	—
Benzene	(0.15)	1800	(0.17)	78	0.88	4.6	19	4
Benzyl chloride	0.28	460 ₂₀	0.012	127	1.10	55	2	—
Biphenyl	0.12	6.7	0.00050	154	—	95	—	1
Bromine	0.012	33 000	0.0063	160	3.12	19	4	—
Bromoform	0.20	3100	0.51	253	2.89	38	4	1
1,3-Butadiene	(0.88)	850	(0.0014)	54	0	0.40	6	—
Butane	(0.051)	61	(0.17)	58	0	0.027	4	—
2-Butoxyethanol	—	—	—	118	0.90	—	1	—
n-Butyl acetate	65	6800	0.17	116	0.88	91	9	3
n-Butyl acrylate	2.2	1600 ₂₀	0.0078	128	0.90	43	2	1
n-Butyl alcohol	420	73 000	7.1	74	0.81	2800	20	9
sec-Butyl alcohol	730	200 000	19	74	0.81	2400	5	1
tert-Butyl alcohol	620	—	290	74	0.78	2000	4	1
n-Butylamine (B/10.6)	17	—	6.2	73	0.73	1100	3	2
n-Butyl lactate	370	42 000	520	146	0.98	12 000	1	—
n-Butyl mercaptan (A/10.8)	(0.0061)	600 ₂₀	(0.000012)	90	0.84	3.3	6	—
p-tert-Butyltoluene	(0.064)	~5.5	(0.032)	148	0.86	1.1	1	—
Camphor	7.5	1700 ₂₀	1.0	152	—	600	9	3
Carbon dioxide (A/6.4)	(7.5)	1400	(110)	44	0	0.83	2	—
Carbon disulfide	(0.036)	1700	(0.00039)	76	1.26	1.2	6	—
Carbon monoxide	(0.0013)	26	(2.7)	28	0	0.023	2	—
Carbon tetrachloride	(0.027)	770	(0.52)	154	1.59	0.85	10	1
Chlorine	(0.0065)	6300	(0.0020)	71	0	2.2	7	—
Chlorine dioxide (A)	0.0071	87 000 ₁₀	0.67	67	0	26	1	1
α-Chloroacetophenone	d	d	d	155	—	d	2	—
Chlorobenzene	5.5	1100	0.050	113	1.10	16	6	2
Chlorobromomethane	17	~16 000	34	129	1.93	16	1	—
Chloroform	(0.28)	7100	(2.4)	119	1.48	5.7	14	1
Chloropicrin	(0.0048)	1600	(0.037)	164	1.65	7.1	1	1
β-Chloroprene	(0.016)	480 ₂₀	(0.024)	88	0.96	0.45	2	1
o-Chlorotoluene	(1.1)	100 ₂₀	(0.0069)	127	1.08	4.1	1	1
m-Cresol (A/10.1)	640	23 000	0.037	108	1.03	29 000	3	3
trans-Crotonaldehyde	7.2	150 000 ₂₀	0.42	70	0.85	1200	1	1
Cumene	(0.45)	53	(0.00080)	120	0.86	1.8	6	1

Table 2(a)—Continued

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25°C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error (x/±)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Cyclohexane	300	130 000	25	2.8	430	12	C
Cyclohexanol	50	2000	0.15	2.1	39	340	B
Cyclohexanone	25	6000	0.88	2.2	240	28	B
Cyclohexene	300	99 000	0.18	—	330	1600	A
Cyclohexylamine	10	15 000	2.6	—	1500	3.8	C
Cyclopentadiene	75	~560 000	1.9	—	7500	40	B
Decaborane	0.05	~110	0.060	—	2300	0.83	D
Diacetone alcohol	50	1600	0.28	—	33	180	B
Diborane	0.1	9	2.5	—	10 000 000	0.040	E
<i>o</i> -Dichlorobenzene	50	1800	0.30	4.2	37	160	B
<i>p</i> -Dichlorobenzene	75	1200	0.18	4.1	17	420	B
<i>trans</i> -1,2-Dichloroethylene	200	420 000	17	16	2100	12	C
β,β' -Dichloroethyl ether	5	1500	0.049	—	290	100	B
Dicyclopentadiene	5	3600	0.0057	1.9	720	870	A
Diethanolamine	3	78	0.27	—	26	11	C
Diethylamine	10	310 000	0.13	2.9	31 000	77	B
Diethylaminoethanol	10	2900	0.011	—	290	910	A
Diethyl ketone	200	22 000	2.0	2.1	110	97	B
Diisobutyl ketone	25	3300	0.11	—	130	230	B
Diisopropylamine	5	110 000	1.8	3.9	21 000	2.7	C
<i>N</i> -Dimethylacetamide	10	2600	47	—	260	0.21	D
Dimethylamine	10	9	0.34	3.1	100 000	29	B
<i>N</i> -Dimethylaniline	5	1000	0.013	3.8	200	400	B
<i>N</i> -Dimethylformamide	10	3100	2.2	46	310	4.6	C
1,1-Dimethylhydrazine	0.5	210 000	1.7	5.5	410 000	0.30	D
1,4-Dioxane	25	52 000	24	2.4	1000	1.1	C
Epichlorohydrin	2	21 000	0.93	12	11 000	2.1	C
Ethane	140 000 ¹	9	120 000	5.9	7	1.2	C
Ethanolamine	3	780	2.6	—	260	1.2	C
2-Ethoxyethanol	5 ⁿ	7100	2.7	9.0	1400	1.8	C
2-Ethoxyethyl acetate	5 ⁿ	2700	0.056	—	530	89	B
Ethyl acetate	400	120 000	3.9	1.8	300	100	B
Ethyl acrylate	5	50 000	0.0012	4.1	10 000	4000	A
Ethyl alcohol	1000	75 000	84	1.8	75	12	C
Ethylamine	10	9	0.95	2.6	100 000	11	C
Ethyl <i>n</i> -amyl ketone	25	3600	6.0	—	140	4.2	C
Ethyl benzene	100	13 000	2.3	2.7	130	44	B
Ethyl bromide	200	610 000	3.1	—	3100	64	B
Ethyl chloride	1000	9	4.2	—	1000	240	B
Ethylene	140 000 ¹	9	290	2.6	7	490	B
Ethylenediamine	10	16 000	1.0	—	1600	10	C
Ethylene dichloride	10	110 000	88	2.1	11 000	0.11	E
Ethylene oxide	1 ⁿ	9	430	1.6	1 000 000	0.0023	E
Ethylenimine	0.5	260 000	1.5	1.3	520 000	0.32	D
Ethyl ether	400	700 000	8.9	3.3	1800	45	B
Ethyl formate	100	320 000	31	1.6	3200	3.3	C
Ethylidene norbornene	5	—	0.014	1.4	—	350	B
Ethyl mercaptan	0.5	710 000	0.00076	2.0	1 400 000	650	A
<i>N</i> -Ethylmorpholine	5	11 000	1.4	18	2100	3.5	C
Ethyl silicate	10	3000	17	4.9	300	0.57	D
Fluorine	1	9	0.14	—	1 000 000	7.3	C
Formaldehyde	1 ⁿ	9	0.83	2.3	1 000 000	1.2	C
Formic acid	5	57 000	49	1.9	11 000	0.10	E
Furfural	2	2100	0.078	1.7	1000	25	C
Furfuryl alcohol	10	810	8.0	—	81	1.2	C

Table 2(b)—Continued

Substance	8 Water TLV equivalent (ppm; w/v)	9 Solubility at 25°C (ppm; w/v)	10 Water odor threshold (ppm; w/v)	11 Molecular weight (g)	12 Density at 20-25°C (g ml ⁻¹)	13 Water-air distribution ratio (w/v)	14 Number of thresholds performed	
							air	water
Cyclohexane	(0.13)	55	(0.011)	84	0.78	0.12	6	—
Cyclohexanol	940	36 000	2.8	100	0.95	4600	3	2
Cyclohexanone	240	~ 54 000	8.3	98	0.95	2400	8	2
Cyclohexene	(0.65)	210	(0.00039)	82	0.81	0.64	1	—
Cyclohexylamine (B/10.6)	94	—	25	99	0.87	2300	—	1
Cyclopentadiene	(0.24)	~ 1800	(0.0060)	66	0.80	1.2	1	—
Decaborane				122	s		1	—
Diacetone alcohol		—	64	116	0.94		1	2
Diborane	d	d	d	28	g	d	1	—
o-Dichlorobenzene	3.9	140	0.024	147	1.30	13	3	2
p-Dichlorobenzene	4.7	79	0.011	147	s	10	2	3
trans-1,2-Dichloroethylene	(3.0)	6300	(0.26)	97	1.26	3.8	2	—
β,β'-Dichloroethyl ether	36	11 000	0.36	143	1.21	1200	—	1
Dicyclopentadiene				132	s		2	—
Diethanolamine (B/8.9)	240 000	—	22 000	105	1.10	19 000 000	1	—
Diethylamine (B/11.0)	36	—	0.47	73	0.71	1200	6	1
Diethylaminoethanol (B/8.8)		—		117	0.88		1	—
Diethyl ketone	450	48 000	4.7	86	0.81	640	3	—
Diisobutyl ketone	3.3	430	0.014	142	0.81	23	1	—
Diisopropylamine (B/11.0)	3.5		1.3	101	0.72	~ 170	2	1
N-Dimethylacetamide		—		87	0.94		1	—
Dimethylamine (B/10.7)	8.6	550 000	0.29	45	g	460	6	2
N-Dimethylaniline (B/5.2)	9.9	2000	0.025	121	0.96	400	3	—
N-Dimethylformamide		—	50	73	0.94		2	1
1,1-Dimethylhydrazine (B/7.2)		—		60	0.79		2	—
1,4-Dioxane	240	—	230	88	1.03	2700	7	1
Epichlorohydrin	6.4	65 000	3.0	92	1.18	840	2	—
Ethane (B/8)		60	(7.5)	30	g	0.051	2	—
Ethanolamine (B/9.5)	23 000	—	20 000	61	1.02	3 100 000	1	—
2-Ethoxyethanol		—	190	90	0.92		2	1
2-Ethoxyethyl acetate	450	200 000 ₂₀	5.0	132	0.97	16 000	1	—
Ethyl acetate	270	73 000	2.6	88	0.90	180	8	4
Ethyl acrylate	1.5	15 000	0.00038	100	0.92	74	2	1
Ethyl alcohol	9000	—	760	46	0.79	4800	13	5
Ethylamine (B/10.7)	45	— ₁₁	4.3	45	0.69 ₁₁	2400	3	3
Ethyl n-amy ketone	10	~ 1500	2.5	128	0.83	80	1	—
Ethyl benzene	(1.3)	160	(0.029)	106	0.87	2.9	2	3
Ethyl bromide	(2.9)	9000	(0.046)	109	1.43	3.3	1	—
Ethyl chloride	(4.7)	4700	(0.019)	64	g	1.8	1	—
Ethylene	(19)	130	(0.039)	28	g	0.12	4	1
Ethylenediamine (B/10.0)		—	16 000	60	0.90		1	1
Ethylene dichloride	0.80	8600	7.0	99	1.26	20	8	2
Ethylene oxide	0.33	270 000 ₂₀	140	44	g	180	2	—
Ethylenimine (B/8.0)	d	— _d	170 _d	43	0.83	d	2	1
Ethyl ether	34	56 000	0.75	74	0.71	28	7	—
Ethyl formate	35	100 000	11	74	0.92	120	1	1
Ethylidene norbornene				120			2	—
Ethyl mercaptan (A/10.5)	(0.0049)	7000	(0.0000075)	62	0.83	3.9	12	1
N-Ethylmorpholine (B/)		—		115	0.90		2	—
Ethyl silicate	d	d	d	208	0.93	d	2	—
Fluorine	d	d	d	38	g	d	1	—
Formaldehyde	0.73	550 000	0.60	30	g	590	9	4
Formic acid (A/3.7)	170	—	1700	46	1.22	18 000	4	5
Furfural	89	86 000	3.5	96	1.16	11 000	2	3
Furfuryl alcohol	d	— _d	d	98	1.13	d	1	—

Table 2(a)—Continued

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25 °C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error (x/-)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Halothane	50 ⁿ	390 000	33	—	7900	1.5	C
Heptane	400	60 000	150	1.7	150	2.7	C
Hexachlorocyclopentadiene	0.01	78	0.030	5.1	7800	0.34	D
Hexachloroethane	10	770	0.15	—	77	64	B
Hexane	50	200 000	130	2.0	4000	0.37	D
Hexylene glycol	25	100	50	—	4.0	0.50	D
Hydrazine	0.1	18 000	3.7	1.1	180 000	0.027	E
Hydrogen bromide	3	9	2.0	—	330 000	1.5	C
Hydrogen chloride	5	9	0.77	2.2	200 000	6.5	C
Hydrogen cyanide	10	970 000	0.58	1.9	97 000	17	C
Hydrogen fluoride	3	9	0.042	1.2	330 000	71	B
Hydrogen selenide	0.05	9	0.30	—	20 000 000	0.17	E
Hydrogen sulfide	10	9	0.0081	1.5	100 000	1200	A
Indene	10	2200	0.015	3.9	220	690	A
Iodoform	0.6	~ 49	0.0050	1.8	81	120	B
Isoamyl acetate	100	7100	0.025	1.6	71	3900	A
Isoamyl alcohol	100	4300	0.042	1.3	43	2300	A
Isobutyl acetate	150	26 000	0.64	1.8	170	230	B
Isobutyl alcohol	50	16 000	1.6	2.0	330	30	B
Isophorone	5	450	0.20	—	89	25	C
Isopropyl acetate	250	79 000	2.7	2.9	320	93	B
Isopropyl alcohol	400	57 000	22	1.8	140	18	C
Isopropylamine	5	740 000	1.2	2.8	150 000	4.1	C
Isopropyl ether	250	210 000	0.017	—	850	15 000	A
Maleic anhydride	0.25	~ 170	0.32	—	670	0.77	D
Mesityl oxide	15	13 000	0.45	26	850	33	B
2-Methoxyethanol	5 ⁿ	16 000	2.3	26	3200	2.1	C
Methyl acetate	200	270 000	4.6	3.5	1400	44	B
Methyl acrylate	10	110 000	0.0048	—	11 000	2100	A
Methyl acrylonitrile	1	88 000	7.0	—	88 000	0.14	E
Methyl alcohol	200	160 000	100	2.0	800	2.0	C
Methylamine	10	9	3.2	4.6	100 000	3.1	C
Methyl n-amyl ketone	50	2000	0.35	2.1	40	140	B
N-Methylaniline	0.5	640	1.7	—	1300	0.29	D
Methyl n-butyl ketone	5	5000	0.076	—	1000	66	B
Methyl chloroform	350	160 000	120	2.8	470	2.8	C
Methyl 2-cyanoacrylate	2	~ 530	2.2	—	260	0.91	D
Methylcyclohexane	400	61 000	630	—	150	0.63	D
cis-3-Methylcyclohexanol	50	710	500	—	14	0.10	E
Methylene chloride	100	550 000	250	1.2	5500	0.40	D
Methyl ethyl ketone	200	130 000	5.4	1.9	660	37	B
Methyl formate	100	760 000	800	2.9	7600	0.17	E
Methyl hydrazine	0.2	65 000	1.7	—	330 000	0.12	E
Methyl isoamyl ketone	50	4800	0.012	—	96	4200	A
Methyl isobutyl carbinol	25	7800	0.070	—	310	360	B
Methyl isobutyl ketone	50	9500	0.68	2.3	190	73	B
Methyl isocyanate	0.02	630 000	2.1	—	32 000 000	0.0094	E
Methyl isopropyl ketone	200	39 000	1.9	2.3	200	100	B
Methyl mercaptan	0.5	9	0.0016	2.0	2 000 000	300	B
Methyl methacrylate	100	52 000	0.083	1.9	620	1200	A
Methyl n-propyl ketone	200	21 000	11	2.2	110	18	C
α-Methyl styrene	50	3800	0.29	4.0	76	170	B
Morpholine	20	13 000	0.01	—	670	2000	A
Naphthalene	10	120	0.084	1.9	12	120	B
Nickel carbonyl	0.05	520 000	0.30	3.3	10 000 000	0.17	E

Table 2(b)-Continued

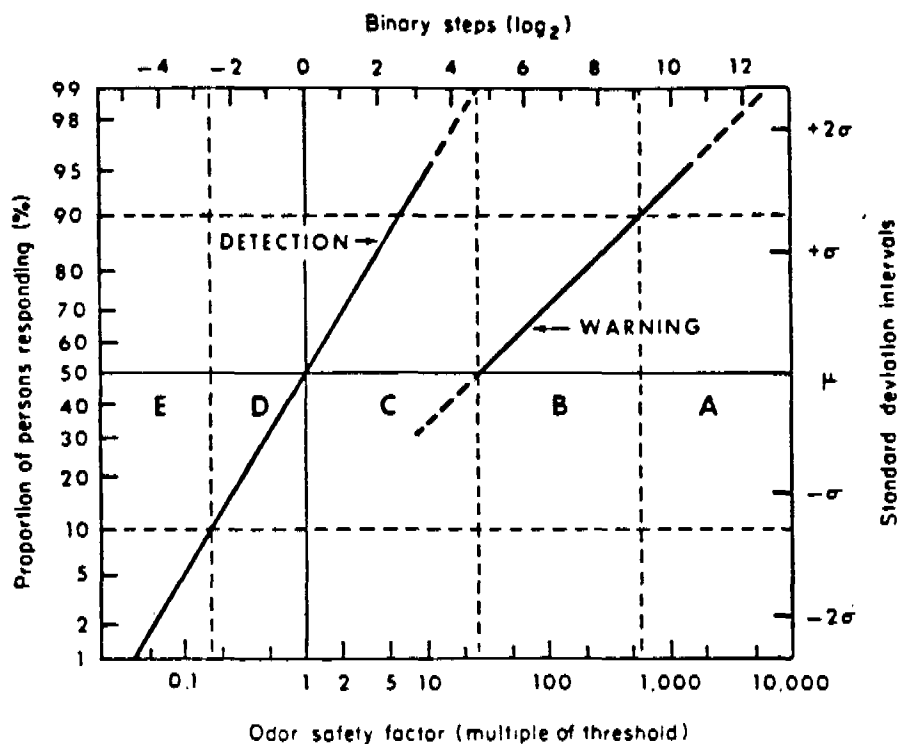
Substance	Water TLV equivalent (ppm, w/v)	Solubility at 25°C (ppm, w/v)	Water odor threshold (ppm, w/v)	Molecular weight (g)	Density at 20-25°C (g ml ⁻¹)	Water-air distribution ratio (w/v)	14 Number of thresholds performed	
							air	water
Halothane	(0.44)	3400	(0.29)	197	1.87	1.1	1	-
Heptane	(0.020)	2.9	(0.0073)	100	0.68	0.012	4	-
Hexachlorocyclopentadiene	0.0026	20	0.0077	273	1.70	23	1	1
Hexachloroethane	(0.65)	50	(0.010)	237	s	6.7	-	1
Hexane	(0.0024)	9.5	(0.0064)	86	0.66	0.014	2	-
Hexylene glycol	-	-	-	118	0.92	-	1	-
Hydrazine (B/8.5)	-	-	160	32	1.01	-	2	1
Hydrogen bromide (A)	d	1 200 000	d	81	g	d	1	-
Hydrogen chloride (A)	d	500 000	d	36	g	d	6	-
Hydrogen cyanide (A/9.2)	3.0	-	0.17	27	0.70	270	2	3
Hydrogen fluoride (A/3.2)	d	-	d	20	0.96	d	2	-
Hydrogen selenide (A/3.9)	(0.00035)	6800	(0.0021)	81	g	2.1	1	-
Hydrogen sulfide (A/7.0)	(0.036)	3500	(0.000029)	34	g	2.6	25	1
Indene	(0.18)	~40	(0.00026)	116	1.01	3.7	1	1
Iodoform	1.3	110	0.011	394	s	130	3	-
Isoamyl acetate	66	1400	0.017	130	0.87	120	8	3
Isoamyl alcohol	630	26 000	0.27	88	0.80	1700	5	3
Isobutyl acetate	34	5900	0.15	116	0.87	48	3	1
Isobutyl alcohol	310	89 000	10	74	0.80	2100	7	5
Isophorone	140	12 000	5.4	138	0.92	4800	1	-
Isopropyl acetate	97	30 000	1.0	102	0.87	92	4	-
Isopropyl alcohol	3000	-	160	60	0.78	3000	12	4
Isopropylamine (B/10.5)	20	-	4.9	59	0.69	~1700	2	1
Isopropyl ether	12	10 000	0.00080	102	0.73	11	1	-
Maleic anhydride	d	d	d	98	s	d	1	-
Mesityl oxide	35	29 000	1.0	98	0.85	570	2	-
2-Methoxyethanol	-	-	-	76	0.97	-	2	-
Methyl acetate	130	220 000	3.0	74	0.93	210	5	-
Methyl acrylate	4.5	49 000	0.0021	86	0.95	130	1	-
Methyl acrylonitrile	0.29	25 000	2.1	67	0.80	110	1	-
Methyl alcohol	1500	-	740	32	0.79	5600	13	4
Methylamine (B/10.6)	7.4	550 000	2.4	31	g	580	2	3
Methyl n-amyl ketone	40	4300	0.28	114	0.81	170	2	2
N-Methylaniline (B-4.8)	5.3	6700	18	107	0.99	2400	1	-
Methyl n-butyl ketone	17	16 000	0.25	100	0.81	800	1	-
Methyl chloroform	(2.8)	1300	(0.97)	133	1.34	1.4	3	-
Methyl 2-cyanoacrylate	-	-	-	111	1.11	-	1	-
Methylcyclohexane	(0.092)	14	(0.15)	98	0.77	0.057	1	-
cis-3-Methylcyclohexanol	660	9300	6600	114	0.91	2800	1	-
Methylene chloride	3.6	19 000	9.1	85	1.34	10	4	1
Methyl ethyl ketone	310	210 000	8.4	72	0.80	530	8	1
Methyl formate	25	170 000	150	60	0.97	100	3	-
Methyl hydrazine (B/7.9)	-	-	-	46	0.87	-	1	-
Methyl isoamyl ketone	56	5400	0.013	114	0.81	240	1	-
Methyl isobutyl carbinol	53	16 000	0.15	102	0.81	510	1	-
Methyl isobutyl ketone	94	18 000	1.3	100	0.80	460	5	-
Methyl isocyanate	d	d	d	57	0.96	d	1	-
Methyl isopropyl ketone	320	60 000	3.1	86	0.80	460	1	1
Methyl mercaptan (A/10.7)	(0.0075)	~14 000	(0.000024)	48	g	7.6	8	2
Methyl methacrylate	30	15 000	0.025	100	0.94	73	4	1
Methyl n-propyl ketone	270	54 000	15	86	0.81	380	2	1
α-Methyl styrene	7.4	560	0.043	118	0.91	31	3	1
Morpholine (B/8.7)	-	-	-	87	1.00	-	1	-
Naphthalene	2.5	30	0.021	128	s	47	6	4
Nickel carbonyl	(0.000012)	130	(0.000072)	171	1.32	0.035	3	-

Table 2(a) - Continued

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25°C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error ($\pm$)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Nitrobenzene	1	360	0.018	1.7	360	56	B
Nitroethane	100	27 000	2.1	—	270	46	B
Nitrogen dioxide	3	g	0.39	2.6	330 000	7.8	C
Nitromethane	100	47 000	3.5	—	470	29	B
1-Nitropropane	25	13 000	11	4.2	520	2.3	C
2-Nitropropane	10 ⁿ	22 000	70	2.2	2200	0.14	E
m-Nitrotoluene	2	~ 280	0.045	—	140	45	B
Nonane	200	6000	47	4.1	30	4.3	C
Octane	300	18 000	48	3.2	61	6.3	C
Osmium tetroxide	0.0002	12 000	0.0019	—	61 000 000	0.10	E
Oxygen difluoride	0.05	g	0.10	—	20 000 000	0.50	D
Ozone	0.1	g	0.045	1.9	10 000 000	2.2	C
Pentaborane	0.005	270 000	0.96	—	54 000 000	0.0052	E
Pentane	600	670 000	400	1.9	1100	1.5	C
Perchloroethylene	50	25 000	27	1.8	490	1.8	C
Phenol	5	460	0.040	1.5	92	130	B
Phenyl ether	1	29	0.0012	3.7	29	800	A
Phenyl mercaptan	0.5	2000	0.00094	4.4	4100	530	B
Phosgene	0.1	g	0.90	1.7	10 000 000	0.11	E
Phosphine	0.3	g	0.51	2.5	3 300 000	0.58	D
Phthalic anhydride	1	0.67	0.053	—	0.7	19	C
Propane	140 000	g	16 000	1.3	7	8.8	C
Propionic acid	10	5400	0.16	1.8	540	61	B
n-Propyl acetate	200	43 000	0.67	4.1	220	300	B
n-Propyl alcohol	200	26 000	2.6	1.7	130	78	B
Propylene	140 000	g	76	3.0	7	1800	A
Propylene dichloride	75	69 000	0.25	—	920	300	B
Propylene glycol 1-methyl ether	100	16 000	10	—	160	10	C
Propylene oxide	20	700 000	44	4.5	35 000	0.45	D
n-Propyl nitrate	25	30 000	50	—	1200	0.50	D
Pyridine	5	27 000	0.17	1.4	5300	30	B
Quinone	0.1	130	0.084	3.0	1300	1.2	C
Styrene	50	9600	0.32	2.0	190	160	B
Sulfur dioxide	2	g	1.1	1.3	500 000	1.7	C
1,1,2,2-Tetrachloroethane	5	8400	1.5	2.1	1700	3.4	C
Tetrahydrofuran	200	230 000	2.0	5.4	1100	99	B
Toluene	100	37 000	2.9	1.6	370	34	B
Toluene-2,4-diisocyanate	0.005 ⁿ	~ 21	0.17	2.9	4200	0.030	E
o-Toluidine	2	330	0.25	4.1	170	8.0	C
1,2,4-Trichlorobenzene	5	570	1.4	2.1	110	3.6	C
Trichloroethylene	50	99 000	28	1.7	2000	1.8	C
Trichlorofluoromethane	1000	g	5.0	—	1000	200	B
1,1,2-Trichloro-1,2,2-trifluoroethane	1000	430 000	45	—	430	22	C
Triethylamine	10 ⁿ	93 000	0.48	2.1	9300	21	C
Trimethylamine	10 ⁿ	g	0.00044	1.4	100 000	23 000	A
1,3,5-Trimethylbenzene	25	3600	0.55	1.9	150	45	B
Trimethyl phosphite	2	34 000	0.00010	—	17 000	20 000	A
n-Valeraldehyde	50	21 000	0.028	2.5	420	1800	A
Vinyl acetate	10	140 000	0.50	1.6	14 000	20	C
Vinyl chloride	5	g	3000	3.7	200 000	0.0017	E
Vinylidene chloride	5 ⁿ	790 000	190	3.7	160 000	0.027	E
Vinyl toluene	50	2400	10	—	48	5.0	C
m-Xylene	100	11 000	1.1	2.1	110	92	B
2,4-Xyldine	2	190	0.056	—	97	36	B

Table 2(b)-Continued

Substance	Water TLV equivalent (ppm, w/v)	Solubility at 25°C (ppm, w/v)	Water odor threshold (ppm, w/v)	Molecular weight (g)	Density at 20-25°C (g ml ⁻¹)	Water-air distribution ratio (w/v)	Number of thresholds performed	
							air	water
Nitrobenzene	6.0	2100	0.11	123	1.20	1200	13	2
Nitroethane (A/8.4)	100	27 000	2.2	75	1.05	330	-	1
Nitrogen dioxide (A)	d	d	d	46	g	d	6	-
Nitromethane (A/10.2)	260	110 000	9.1	61	1.13	1000	-	1
1-Nitropropane (A/-8)	29	15 000	12	89	1.00	310	2	1
2-Nitropropane (A/7.7)	7.6	16 000	53	89	0.98	210	1	1
m-Nitrotoluene	3.6	500 ₁₀	0.080	137	1.16	320	1	-
Nonane	(0.0056)	~0.17	(0.0013)	128	0.72	0.0054	2	-
Octane	(0.011)	0.66	(0.0017)	114	0.70	0.0077	2	-
Osmium tetroxide (A/12.0)	0.0012	69 000	0.012	254	s	580	1	-
Oxygen difluoride	(0.0000054)d	100 ₁₀ d	(0.000011)d	54	g	0.049d	1	-
Ozone	(0.00064)	6100	(0.00028)	48	g	3.2	6	-
Pentaborane	d	d	d	63	0.63	d	1	-
Pentane	(0.033)	38	(0.022)	72	0.62	0.019	3	-
Perchloroethylene	(0.31)	150	(0.17)	186	1.61	0.90	3	1
Phenol (A/10.0)	1000	85 000	7.9	94	s	52 000	16	6
Phenyl ether	150	4300	0.18	170	1.07	21 000	2	3
Phenyl mercaptan (A/6.5)	0.15	610	0.00028	110	1.08	66	2	2
Phosgene	d	d	d	99	g	d	6	-
Phosphine	(0.00011)	370 ₁₀	(0.00020)	34	g	0.27	6	-
Phthalic anhydride	d	d	d	148	s	d	1	-
Propane	(9.0)	62	(1.0)	44	g	0.036	2	-
Propionic acid (A/4.9)	1700	-	28	74	1.00	56 000	11	2
n-Propyl acetate	92	19 000 ₁₀	0.31	102	0.89	110	4	-
n-Propyl alcohol	1800	-	23	60	0.80	3600	12	5
Propylene	(50)	350	(0.028)	42	g	0.21	3	1
Propylene dichloride	(3.0)	2800	(0.010)	113	1.16	8.8	1	-
Propylene glycol 1-methyl ether				90	0.92		1	-
Propylene oxide	14	370 000	31	58	0.83	300	2	-
n-Propyl nitrate	7.4	8800 ₁₀	15	105	1.05	69	1	-
Pyridine (B/5.2)	28	-	0.95	79	0.98	1700	15	10
Quinone	11	14 000	9.3	108	s	25 000	2	1
Styrene	(1.7)	320	(0.011)	104	0.90	7.8	10	3
Sulfur dioxide (A/1.9)	0.19	88 000	0.11	64	g	37	13	-
1,1,2,2-Tetrachloroethane	1.7	2900	0.50	168	1.60	50	3	1
Tetrahydrofuran		-		72	0.89		3	-
Toluene	(1.4)	540	(0.042)	92	0.86	3.8	18	2
Toluene-2,4-diisocyanate	d	d	d	174	1.22	d	4	-
o-Toluidine (B/4.4)	91	15 000	11	107	1.00	10 000	3	1
1,2,4-Trichlorobenzene	(0.23)	~26	(0.064)	181	1.45	6.1	1	1
Trichloroethylene	(0.55)	1100	(0.31)	131	1.46	2.1	7	1
Trichlorofluoromethane				137	1.49		1	-
1,1,2-Trichloro-1,2,2-trifluoroethane				187	1.56		1	-
Triethylamine (B/10.9)	8.8	71 000	0.42	101	0.73	210	4	1
Trimethylamine (B/9.7)	4.5	410 000 ₁₀	0.00020	59	g	190	3	1
1,3,5-Trimethylbenzene	(0.67)	97	(0.015)	120	0.86	5.4	6	3
Trimethyl phosphite	d	d	d	124	1.05	d	1	-
n-Valeraldehyde	29	12 000	0.017	86	0.81	170	1	3
Vinyl acetate	1.8	25 000 ₁₀	0.088	86	0.93	50	4	1
Vinyl chloride	(0.0057)	1100	(3.4)	62	g	0.44	3	-
Vinylidene chloride	(0.041)	6400	(1.5)	97	1.22	2.0	2	-
Vinyl toluene	(2.1)	~100	(0.42)	118	0.90	8.7	1	-
m-Xylene	(1.6)	170	(0.017)	106	0.86	3.7	8	2
2,4-Xyldine (B/4.9)	66	6400	1.8	121	0.97	6600	1	-



A practical guide to the quantitative interpretation of odor safety factors. The coordinates are log/probit, so care is required in interpolating between marked intervals. The sloping lines indicate the percentages of the population expected to respond to various fractions or multiples of the mean detection threshold concentration (1.0 on the x axis). The detection line represents the performance of fully attentive persons under good laboratory conditions. The warning line shows what may be expected for distracted persons under factory or field conditions. The warning line is based on the results of Whisman *et al.*¹⁹ for the gas odorants ethyl mercaptan and thiophane.

Odor safety classification

Class	Odor safety factor	Interpretation
A	> 550	More than 90% of distracted persons perceive warning of TLV concentration in the air
B	26-550	50-90% of distracted persons perceive warning of TLV
C	1-26	Less than 50% of distracted persons perceive warning of TLV
D	0.18-1	10-50% of attentive persons can detect TLV concentration in the air
E	< 0.18	Less than 10% of attentive persons can detect the TLV

approx. 25x higher conc. needed to get someone's attention when they are distracted doing something else. (50% of population)²⁸ (~600x for 90% of population)
Detection vs. warning.

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CONFIDENTIAL

Irritant threshold concentrations of ten industrial chemicals.

Substance	1 Odor threshold (ppm; v/v)	2 Irritation thresholds		4 Ratio of irritation and odor thresholds	5 Irritation hazard factor
		Nose (ppm; v/v)	Eye (ppm; v/v)		
Acetaldehyde	0.066	2200	11 000	33 000	22
Acetic acid	0.16	160 ^a		1000	16
Acrolein	1.8	11	12	6.1	110
Allyl alcohol	1.4	30	59	21	15
Benzyl chloride	0.040	35	8.0	200	8.0
o-Chloroacetophenone	0.040	0.034	0.022	0.55	0.44
trans-Crotonaldehyde	0.11	14	19	130	7.0
Formic acid	130	1100 ^a		8.5	220
Propionic acid	0.24	370 ^a		1500	37
Pyridine	0.71	700 ^a		990	140

^a Detection threshold for a general anosmic.

Odorization of Industrial Gases

Gas	Danger level in air %	Typical odorization practice			
		Odorant	Threshold ppm	Concentration ppm	Safety factor
Natural (methane)	5	t-Butyl mercaptan	0.00025	3	600
Bottled (propane)	2	Ethyl mercaptan	0.00076	15	400
Inert (argon)	7	Ethyl mercaptan ^a	0.00076	6 ^a	550 ^a
Oxidant (oxygen)	2 ^b	Dimethyl sulfide	0.0067	6	18

^a Proposed

^b In addition to the normal 21% oxygen in air; i.e. a total level of 23% - *due to fish*

Properties of Fuel-Gas Odorants

Odorant	Threshold ^a ppm	Boils ^b °C	Freezes ^c °C	Molecular ^d weight	Relative reactivity ^e	TLV ^f ppm
Hydrogen sulfide	0.0081 (26)	-62	-83	34	5,000+	10
Methyl mercaptan	0.0016 (10)	6	-121	48	1,800	0.5
Ethyl mercaptan	0.00076 (13)	36	-148	62	230	0.5
n-Propyl mercaptan	0.0017 (5)	68	-113	76	98	-
n-Butyl mercaptan	0.00097 (6)	97	-116	90	91	0.5
t-Butyl mercaptan	0.00025 (5)	64	1	90	1	-
Dimethyl sulfide	0.0067 (10)	38	-98	62		20 ^g
Thiophane	0.00076 (9)	121	-97	88		-
Dimethyl disulfide	0.041 (7)	110	-85	94		-

^a In parentheses is the number of literature references that were averaged.

^b Helps to predict volatility and co-distillation.

^c To be considered for liquid or regenerated cryogenic gases.

^d For comparing vapor concentrations

^e Relative to tert-butyl mercaptan, arbitrarily set at 1.

^f Threshold Limit Value, to avoid adverse health effects (U.S. standards)

^g USSR standard; none quoted in U.S.

Proposed rating and assessment of individual olfactory threshold sensitivities, using the pyridine scale for illustrative purposes.

Pyridine scale step	Sensitivity rating	Sensitivity assessment	Approximate frequency (%) ^a
23 & above	➤ +5	Hyperosmia	2
22	+4	} High normal	14
21	+3		
20	+2	} Above average	68
19	+1		
18	A	Average	
17	-1	} Below average	
16	-2		
15	-3	} Low normal	14
14	-4		
13	-5	} Hypoamia	2
12	-6		
11	-7		
10	-8		
9 & below	◀ -9	Anosmia	~ 0.2
< 0	< -18	Complete anosmia	~ 0.02

^a Calculated for a normal distribution, assuming SD $\pm$ 2 binary steps.

Factors affecting the normal smell sensitivities of healthy people. Thresholds are for pyridine in water.

Class of persons ^a	Factor	Threshold (ppm)
Average 40 yr. man	1	4.0
Average woman	1	4.0
18 yr. person	0.5	2.0
62 yr. person	2	8.0
Moderate smoker	1	4.0
Smoking during test	4	16
Chewing during test	4	16
Head cold	4	16
Nasal allergy	4	16
Un-trained	1.4	5.6
Un-directed test	4	16
Mis-directed test	26	100
Odor <u>recognition</u> threshold	3	12

^a Understood to be average 40 yr. persons, unless indicated.

A classification of chemically induced hyposmias, according to the extent of the exposure and the duration of the resulting hyposmia.

Exposure	Hyposmia	Duration	Examples
ACUTE (sec/min/hr)	Temporary	minutes	H ₂ S HCN
	Recuperable	weeks	H ₂ Se ZnSO ₄
	Permanent	years	POCl ₃ SO ₂
CHRONIC (mo/yr)	Recuperable	weeks	Acetone
	Permanent	years	ZnCrO ₄ Cl ₂

Recuperable → Returns typically in approx. 6 weeks. (6-8 weeks)

Permanent → Basal cells killed - won't grow new olfactory cells.

Substances Reported to Cause Acute Olfactory Injury in Man, Resulting in Temporary, Recuperable, or Permanent Hyposmias,

The table concludes with one case of chronic, but recuperable, hyposmia.

Substance	Exposure		Olfactometric method	Incidence of hyposmia	
	Conc.	Time		Frequency (percent)	Assessment
A. Acute exposure, temporary hyposmia					
Formaldehyde		min	symptom		hyposmia
Hydrogen cyanide		sec	symptom		anosmia
Hydrogen selenide	0.3 ppm	min	symptom		hyposmia
Hydrogen sulfide	100 ppm	sec	symptom		anosmia
B. Acute exposure, recuperable hyposmia					
Hydrogen selenide	gas	2 sec [§]	symptom	1 case	anosmia
N-Methylformimino-methylester	sat. vap.	2 sec	symptom	1 case	anosmia
Sulfuric acid	5% soln.*	2 sec	symptom	1 case	anosmia
Zinc sulfate	1% soln.†	sec	symptom	25	anosmia
C. Acute exposure, permanent hyposmia					
Cesspool		h	symptom	1 case	anosmia
Decomp. cadaver		h	symptom	1 case	anosmia
Pepper	powder	2 sec	symptom	1 case	{ hyposmia cacosmia [#]
Cresol					
Phosphorus oxychloride		sec	symptom	1 case	anosmia
Sulfur dioxide	270 ppm‡	2 sec	symptom	1 case	anosmia
D. Chronic exposure, recuperable hyposmia					
Acetone	{	3 mo	recognition	1 case	{ hyposmia phantosmia*
Tetrahydrofuran					
Cyclohexanone					

*Patient fell into a disinfectant bath, the anosmia may have been an indirect consequence of the resultant chronic rhinitis.

†Nasal spray intended as a prophylactic against poliomyelitis.

‡Concentration seems underestimated. This was the head-space of a 6 percent solution of sulfuric acid, which is nearly saturated with sulfur dioxide.

§"Two-sec exposure" indicates a single sniff or inhalation.

||Confirmed in tests with mice (5). After 0.5-sec exposure to the saturated vapor, an anosmia of ~ 20 binary steps severity resulted, which persisted for 3 weeks.

#Terms for olfactory perceptual abnormalities (30). cacosmia, obnoxious smell sensation caused by normally pleasant or neutral odorants; phantosmia, persistent odor sensation, even when no odorant is inhaled.

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**Metallurgical Processes Considered Responsible, on Chronic Exposure,
for Permanent Hyposmia in Man**

Substance	Exposure time (years)	Olfactometric method	Incidence of hyposmia		
			Frequency (percent)	Rating (steps)	Assessment
Chromium	1.5	Eisberg	17	(-0.7)	below average
Chromium plating	4	recognition	cohort		low normal
Lead	8	Eisberg	33	(-0.8)†	below average
Lead (severe intox.)		Eisberg	cohort	-1.2	below average
Lead (severe intox.)		Eisberg	cohort	-1.3	below average
Magnet production*	10	recognition	10 cases		hyposmia
Mercury (chronic intox.)	29	Eisberg	55	-3.6	low normal
Nickel plating	4	recognition	cohort		low normal
Nickel refining (electrolytic)	> 5	recognition	33		anosmia
Silver plating	6	recognition	cohort		below average
Steel production	4	Eisberg	6	< -3.3	low normal
Zinc production	> 5	Eisberg	3	< -2.7	low normal

*Iron, Aluminum, nickel, cobalt, and chromium powders.

†Just one worker was affected, and he had a unilateral hyposmia.

*still within
normal = ± 2 st*

Metallic Compounds Considered Responsible, on Chronic Exposure, for Permanent Hyposmia in Man

Substance	Exposure		Olfactometric method	Incidence of Hyposmia		
	Conc. (mg/m ³)	Time (years)		Frequency (percent)	Rating (steps)	Assessment
Cadmium compounds			Eisberg	13		anosmia
Cadmium compounds*	1.3	7	Eisberg	66		hyposmia‡
Cadmium oxide		3	recognition	1 case		anosmia
Cadmium oxide } Nickel hydroxide }	9†	20	symptom	44		anosmia
Cadmium oxide } Nickel hydroxide }	0.5‡	15	Proetz	27	< -7.6	hyposmia
	0.01					
Chromate salts		18	T&T	27	< -18	anosmia
Zinc chromate	10	10	Roseburg	30	- - 7	hyposmia‡

*Oxide, sulfate, carbonate, nitrate, sulfide, selenide, stearate.

†Before dust control.

‡After installation of industrial hygiene equipment.

§The hyposmia was ameliorated by giving caffeine.

‡A follow-up study on 11 of the same workers 4 years later (after reducing the chrome-dust exposure in the factory) showed no recovery of olfactory performance (99).

Dusts Considered Responsible, on Chronic Exposure, for Permanent Hyposmia in Man

Substance	Exposure time (years)	Olfactometric method	Incidence of Hyposmia		
			Frequency (percent)	Rating (steps)	Assessment
Cement	6	Proetz	2		hyposmia
Chemicals		Proetz	8	< -6.5	hyposmia
Hardwoods		symptom	5		anosmia
Hardwoods		symptom			anosmia
Lime		Proetz	6		hyposmia†
Printing		Naus	24	-3.0	low normal
Silicosis (first stage)*		Eisberg	cohort	-1.2	below average

*First-, second-, and third-stage silicosis cohorts all showed about the same olfactory deficit.

†Damage to the olfactory epithelium, sensory cells, and bulbar fibers was observed in rats exposed 2 months in the dustiest locations in the factory (64).

Nonmetallic Inorganic Compounds Considered Responsible, on Chronic Exposure, for Permanent Hyposmia in Man

Substance	Exposure		Olfactometric method	Incidence of Hyposmia		
	Conc. (mg/m ³)	Time (years)		Frequency (percent)	Rating (steps)	Assessment
Carbon disulfide		15	Eisberg	22	-3.4	low normal
Carbon disulfide (average intox.)			Eisberg	cohort	-2.5	low normal
Carbon disulfide (intox.)	62‡	20	Eisberg‡	14		hyposmia
Carbon monoxide		13	recognition	1 case		anosmia
Carbon monoxide (intox.)*	> 100		Eisberg	6		anosmia
Chlorine		3	Proetz	70	< -6.5	hyposmia
Hydrazine			Eisberg	cohort	-0.8	below average
Nitrogen dioxide (NO _x)	3	5	Eisberg	cohort	-0.7	below average
Ammonia						
Nitrogen dioxide (NO _x)	30	8	Proetz	60	< -6.5	hyposmia
Sulfur dioxide (SO ₂)						
Sulfur dioxide	90	4	symptom	14		hyposmia
Sulfur dioxide	155	20	Eisberg	cohort	-3.4	low normal
Sulfur dioxide	80					
Ammonia†		32	T&T	cohort	-4.4	hyposmia
Sulfur dioxide (SO _x)		> 5	Eisberg	cohort	-1.2	below average
Nitrogen dioxide (NO _x)						
Fluorides (HF7)						

*Includes both acute and chronic intoxications.

†Workers exposed to ammonia alone showed no significant olfactory deficit.

‡Information given by Zank (11).

§The hyposmia could be partially or completely reversed, for 1 or 2 h, by injections of caffeine or eserine.

Organic Compounds Considered Responsible, on Chronic Exposure for Permanent Hyposmia in Man

Substance	Exposure		Olfactometric method	Incidence of hyposmia		
	Conc. (ppm)	Time (years)		Frequency (percent)	Rating (steps)	Assessment
Acetone		8	recognition	1 case		hyposmia
Acetophenone		6	Eisberg	12	(< -2.3)	low normal
Benzene		10	Eisberg	cohort	-0.8	below average
Benzine	400	5	Proetz	37	-6	hyposmia
Benzine						
Ethyl acetate	60	8	Eisberg	30	< -3.1	low normal
Butyl acetate						
Chloromethanes*			Eisberg	44	-2.7	low normal
Menthol			recognition	cohort		hyposmia
Menthol		45	symptom	1 case		hyposmia
Pentachlorophenol			symptom	1 case		anosmia‡
Trichloroethylene	380	10	Naus	cohort	-3.1†	low normal
Trichloroethylene (intermittent abuse)	sat. vap.	9	symptom	1 case		complete anosmia

*CH₃Cl, CH₂Cl₂, CHCl₃, CCl₄.

†Tested at beginning of shift, i.e., a permanent hyposmia. When tested at the end of the shift, an additional -2.1 steps of temporary hyposmia was demonstrated.

‡May have been due to upper respiratory tract infection, not occupational exposure.

Manufacturing Processes Considered Responsible, on Chronic Exposure, for Permanent Hyposmia in Man

Substance	Exposure time (years)	Olfactometric method	Incidence of Hyposmia		
			Frequency (percent)	Rating (steps)	Assessment
Acids (organic and inorganic)	7	Proetz	5	< -5.5	hyposmia
Asphalt (oxidized)	6	Eisberg	18	< -2.3	low normal
Cutting oils (machining)		Eisberg	cohort	-0.8	below average
Fragrances	4	recognition	50		below average
Paint (lead)		Naus	56	-2.9	low normal
Paprika	14	Eisberg	4		hyposmia
"Pavinol" (sewing)*		Eisberg	55	< -2.3	low normal
Spices	11	Naus	cohort	-1.0†	below average
Tobacco	12	Eisberg	1		hyposmia
Varnishes	10	recognition	78		low normal
Varnishes	5	Eisberg	1		hyposmia
Waste-water (refinery)	7	Eisberg	18	< -2.3	low normal

*A synthetic leather. The material contains a slightly volatile plasticizer, dibutyl phthalate, which may be responsible for the hyposmic effect.

†Tested at the beginning of the shift, i.e., a permanent hyposmia. When tested at the end of the shift, an additional -1.5 steps of temporary hyposmia was demonstrated.

Incidental Reports of Industrial Substances Suspected of an
Association with Hyposmia in Man, but with Insufficient Detail.

Substance	Type of hyposmia		
Metallurgical processes			
Aluminum fumes	Chronic		
Arsenic	Chronic		
Chromium fumes	Chronic		
Copper fumes	Chronic		
Manganese fumes	Chronic		
Tin fumes	Chronic		
Vanadium fumes	Chronic		
Zinc fumes	Chronic		
Metallic compounds			
Alum	Acute, recuperable		
Arsenic compounds	Chronic		
Bis-(diethyldithiocarbamate)-cadmium			
Chlorovinylarsine chlorides	Acute, permanent		
Chromic acid	Chronic, permanent		
Copper arsenite	Chronic, permanent		
Dichromates	Chronic		
Lye	Chronic		
Osmium tetroxide	Chronic, permanent		
Potassium sulfide			
Silver nitrate	Acute, recuperable		
Strontium sulfide			
Dusts			
Cotton	Chronic		
Cyanides	Chronic, permanent		
Flax	Chronic		
Flour	Chronic		
Potash	Chronic		
Nonmetallic inorganic compounds			
Ammonia	Chronic, permanent		
Bromine	Acute, temporary		
Flue gas (CO/SO ₂ ?)	Chronic, permanent		
Hydrazine	Chronic, permanent		
Hydrogen chloride	Chronic, permanent		
Hydrogen fluoride	Chronic, permanent		
Nitric acid	Chronic, permanent		
Nitrogen dioxide (NO ₂)	Chronic, permanent		
Phosgene	Acute, temporary		
Selenium dioxide	Chronic		
Sewer gas (H ₂ S?)	Chronic, permanent		
Sulfuric acid	Chronic, permanent		
		Organic compounds	
		Acetaldehyde	Chronic, permanent
		Acetic acid	Chronic, permanent
		Acetonitrile	
		Acid chlorides	Acute, temporary
		Benzaldehyde	Chronic, permanent
		Butylene glycol	Acute, permanent
		Carbon tetrachloride	Chronic, permanent
		Chloroform	
		Dimethyl sulfate	
		Ethyl ether	Acute, permanent
		Fluorine compounds	Acute, temporary
		Formaldehyde	Chronic, permanent
		Furfural	Chronic, permanent
		Halogen compounds	Chronic
		Iodoform	Chronic
		Isocyanates (TDI, etc.)	Chronic
		Nitro compounds	Chronic
		Phenylene diamine	Chronic
		Selenium compounds (volatile)	Acute, temporary
		Sulfur compounds	Chronic
		Tetrachloroethane	Chronic
		Trichloroethane	Chronic
		War gases (WW I)	Acute, permanent
		m-Xylene	
		Manufacturing processes	
		Blasting powder	Chronic, permanent
		Coal tar fumes	Chronic, permanent
		Perfumes (concentrated)	Chronic, permanent
		Rubber vulcanization	Chronic, permanent
		Tanning	Chronic, permanent

Industrial chemicals reported to reduce the sensitivity of the trigeminal nerve to irritants.

Substance	Exposure	Neuropathy	Reference
Carbon monoxide			Herberhold (1975)
Chloromethanes ^a			Pokina (1967)
Dichloroethylene			Koelsch (1959)
Smoke and soot ^b			Schwab (1965)
Trichloroethylene	1½ hr	2 mo	Feldman (1970)
Trichloroethylene	6 wk	> 1 yr	Mitchell (1969)
Trichloroethylene ^c	9 yr	> 1 yr	James (1963)
Trichloroethylene ^d			Barret (1982) ^e

^a CH₃Cl, CH₂Cl₂, CHCl₃, CCl₄

^b Locomotive drivers.

^c Intermittent abuse. Also caused anosmia.

^d Of 188 chronically exposed degreasers, 17% suffered neuropathy.

^e Includes literature review.

*can be entire face that loses sensitivity, not just inside nose, and
can be losing sensitivity to other irritations such as cold for instance.*

Average chronic exposure concentrations associated with hyposmia, compared with threshold limit values (TLV, 8 hr TWA) recommended by ACGIH (1984).

Substance	Table no.	Units	Concentration		Ratio Exposure / TLV
			Exposure	TLV	
Ammonia ^a	7	ppm	30	25	1.2
Benzine	8	ppm	400	300 ^b	1.3
Cadmium compounds	5	mg/m ³	1.3	0.05	26
Cadmium oxide	5	mg/m ³	9	0.05	180
Cadmium oxide	5	mg/m ³	0.5	0.05	10
Carbon disulfide	7	ppm	62	10	6
Carbon monoxide	7	ppm	> 100	50	> 2
Nitrogen dioxide (NO _x)	7	ppm	3	3	1
Sulfur dioxide	7	ppm	90	2	45
Sulfur dioxide	7	ppm	155	2	77
Sulfur dioxide	7	ppm	80	2	40
Trichloroethylene	8	ppm	380	50	7
Zinc chromate	5	mg/m ³	10	0.05 ^c	200

^a Not proven to cause hyposmia at this concentration. See footnote^b of Table 7.

^b TLV for gasoline.

^c Suspected carcinogenic potential for man.

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Odor pollution and odor annoyance near industrial plants in the Ruhr.

Estimated data, interpolated from Figures 3, 1 and 2 of Winneke and Kastka (1977).

Source	Distance from plant (meters)	Pollution Odor units ^a		Odor-induced disturbances		Degrees of annoyance by odors		
		50%	95%	Headache (%)	Nausea (%)	Sensory	Social	Somatic
Insulation plant (phenolics)	100	13	110	92	70	5.2	4.0	3.5
	400	5	16	58	45	3.4	2.0	1.1
	1600	-	-	26	4	0.0	0.8	0.0
Tar-oil plant (hydrocarbons & sulfur opds.)	10	15	110	65	44	4.2	2.8	1.8
	400	40	450	74	64	4.5	2.8	2.4
	1400	20	100	70	56	3.9	2.8	1.9

^a Odor concentrations that were not exceeded 50% or 95% of the time, respectively

= # of multiples of threshold, ie 13 is 13x threshold conc.

Predicted effects of ambient hydrogen sulfide level on frequency of odor detection, intensity of odor sensation, and incidence of annoyance by odor.

Hydrogen sulfide (ppb)	Persons able to detect odor ^a (%)	Perceived odor intensity ^b (ratio)	Odor units ^c 50%	Persons annoyed by odor ^d (%)
200	99 ^e	2.31	25	88
100	96 ^e	1.93	12	75
50	91	1.61	6.2	56
40	88	1.52	5.0	50
35	87	1.47	4.4	47
30	83	1.41	3.7	40
25	80	1.34	3.1	37
20	74	1.27	2.5	31
15	69	1.18	1.9	22
10	56	1.06	1.2	17
8	50	1.00	1.00	11
6	42	0.93	0.75	8
4	30	0.83	0.50	5
2	14	0.70	0.25	2
1	6	0.58	0.12	1
0.5	2	0.49	0.06	

^a Based on adopted mean detection threshold of 8.0 ppb and S.D. $\pm$ 2.0 binary steps.

^b For those who can detect the odor. Based on Lindvall's (1974) value for the intensity exponent, $n = 0.26$.

^c Hydrogen sulfide level divided by mean detection threshold (8.0 ppb).

^d Based on assumption that mean annoyance threshold is 5 x mean detection threshold, and S.D. $\pm$ 2.0 binary steps.

^e Theoretical for a normal distribution. These percentages may be reduced by the occurrence of selective smell-blindness.

cc → All T.C.

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DOW CHEMICAL U.S.A.

S/B LATEX TECHNOLOGY CENTER
August 21, 1984

MICHIGAN DIVISION
MIDLAND, MICHIGAN 48640

H. Ahlich Freeport
M. Barenburg Rheimmuenster
L. Battisti Livorno
J. Bornemann San Lorenzo
R. Brown Sarnia
J. Cortinas Bilbao
M. Dahley Midland (743)
C. Davis Altona

C. Fioranti Guaruja
J. Geaman Dalton
J. Martin Pittsburg
T. Mathewson Allyn's Point
M. Piche Varennes
C. Salway King's Lynn
G. Tegg Norrkoping
N. Tilmans Terneuzen

cc: C. Royalty . Midland (2040)
C. Baldwin . Midland (1803)

Reference: ODOR AS AN AID TO CHEMICAL SAFETY

I recently came across an article in the Journal of Applied Toxicology which I have attached in full. Additionally I have extracted the major raw materials that we handle in our S/B Latex Plants; note the impact of the probable change in the butadiene TLV.

The concept of an Odor Safety Class is, I felt, an excellent one as it highlights those chemicals which -

"YOU CANNOT SMELL BEFORE YOU ARE IN TROUBLE".

These chemicals are the ones which we need to put at the top of our industrial hygiene monitoring program. We need to pay special attention to abnormal jobs (i.e., line breaking) and put extra effort into plant design to minimize all exposures.

I intend to incorporate this idea into an update of our Industrial Hygiene Manual and future Plant Audit Books. If you have any data on raw materials that are not covered, please send it to me and we will distribute.

Dave

Dave Waite, Technical Manager
S/B Latex Technology Center
433 Building - Midland, Michigan

Enc. (20 pages)

dgr

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PER/TET & TOX T.C.



S/B LATEX RAW MATERIALS

ODOR SAFETY CLASSIFICATIONS

<u>RAW MATERIAL</u>	<u>Threshold Limit Value (ppm; v/v)</u>	<u>Air Odor Threshold (ppm; v/v)</u>	<u>Odor Safety Classification</u>
Acrylic Acid -----	10.0 -----	0.094 -----	B
Acrylonitrile -----	2.0 -----	17.000 -----	E
Ammonia -----	25.0 -----	5.200 -----	C
Bromoform -----	0.5 -----	1.300 -----	D
Butadiene (Current) -----	50.0 -----	1.600 -----	B
Butadiene (Proposed) -----	10.0 -----	1.600 -----	C
n-Butyl Acrylate -----	10.0 -----	0.035 -----	B
Carbon Tetrachloride -----	5.0 -----	96.000 -----	E
Formaldehyde -----	1.0 -----	0.830 -----	C
Styrene -----	50.0 -----	0.320 -----	B
Vinylidene Chloride -----	5.0 -----	190.000 -----	E

ODOR SAFETY CLASSIFICATIONS

<u>Class</u>	<u>Odor Safety Factor</u>	<u>Interpretation</u>
A -----	More than 550 -----	More than 90% of distracted persons perceive warning of TLV concentration in air.
B -----	26 to 550 -----	50 to 90% of distracted persons perceive warning of TLV.
C -----	1 to 26 -----	Less than 50% of distracted persons perceive warning of TLV.
D -----	0.18 to 1.00 -----	10 to 50% of attentive persons can detect TLV concentration in the air.
E -----	Less than 0.18 -----	Less than 10% of attentive persons can detect the TLV.

D. Waite
08-21-84
dgr

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Odor as an Aid to Chemical Safety: Odor Thresholds Compared with Threshold Limit Values and Volatilities for 214 Industrial Chemicals in Air and Water Dilution

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Key words: odor threshold; threshold limit value; volatility; solubility; distribution ratio; chemical safety.

The body of information in this paper is directed to specialists in industrial health and safety, and air and water pollution, who need quantitative data on the odor thresholds of potentially hazardous chemical vapors and gases. The literature, largely unorganized, has been reviewed for 214 compounds and condensed into tables based on consistent units. Data on the volatility, solubility, ionization and water-air distribution ratio at 25°C are included. From the currently recommended threshold limit value (TLV), a safe dilution factor and an odor safety factor are calculated for each compound. The equivalent data are presented for both air and water dilutions of the chemicals. Available data are summarized on the variability of odor sensitivities in the population, and the increased odor concentrations that are required to elicit responses from persons whose attention is distracted, or who are sleeping. This information is reduced to calibration charts that may be used to estimate the relative detectability, warning potential and rousing capacity of the odorous vapors. Each compound has been assigned a letter classification, from A to E, to indicate the margin of safety, if any, that may be afforded by the odor of the compound as a warning that its threshold limit value is being exceeded.

INTRODUCTION

The human sense of smell, although not as acute as that of some other mammals and certain insects, can be a valuable source of information about chemicals in the environment. The nose is exceedingly sensitive to certain repulsive-smelling compounds, produced in trace amounts by pathogenic or putrifying bacteria and molds, such as methyl mercaptan, trimethylamine, 1-pyrroline and isovaleric acid. Although these chemicals themselves are generally harmless to man in the concentrations occurring naturally in air, water or food, heightened odor sensitivities to them may have developed from the protection offered against dangerous or fatal infection or food poisoning.

With the advent of the industrial revolution, persons have been exposed to diverse chemicals, many of which are commonly found in workplace settings at concentrations much higher than occur naturally. Some of these pose an inherent risk to health at certain concentrations. In recognition of this potential hazard, the American Conference of Governmental Industrial Hygienists (ACGIH) publishes an annual listing of Threshold Limit Values (TLV).¹ (TLV[®] is a registered trademark of ACGIH, whom we thank for permission to use the TLV designation in this paper.) The TLV used in this paper is the time-weighted average value. Based on the best available industrial health data, it is defined as the time-weighted average concentration for a normal 8-h work-day and a 40-h work-week, to

which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

The actual concentrations of specific chemicals in the working environment can be sampled and analyzed by various chemical and instrumental means, to determine whether the TLV is being exceeded. The necessary equipment, however, is often expensive, cumbersome and slow, and requires professional skills to operate and interpret. Nevertheless, there is a little-considered alternative, the human nose, that could serve as a first-line warning system for hazardous concentrations of many chemical vapors. The nose is perfectly placed to sample the inspired air, monitors rapidly and continuously, and may even exceed the sensitivity of the best instruments. It is, however, at best only semi-quantitative, and it requires calibration to determine its sensitivity to those chemicals that are of importance in industrial practice. In this regard, it is necessary to evaluate the increased concentration of a compound that may be required to alert the average person to the presence of an odor, while engaged in another activity which requires attention. The typical variability of the population for odor sensitivity and responsiveness should also be taken into consideration.

METHODS

Literature search for basic data

A search was conducted for the olfactory and physicochemical characteristics of all volatile compounds and gases listed

† Author to whom correspondence should be addressed.

in the *Threshold Limit Values*¹ for 1982. The first objective was to find literature values for the odor-detection thresholds, measured by dilution in either air or water. Dilution of odorants in air can be achieved either dynamically, by adding a calibrated flow of odorant vapor to an air-stream, or statically, by dispersing a known amount of odorant in a vessel or chamber. In the water-dilution procedure, the odorant is prepared as a series of aqueous dilutions in closed, partially filled vessels from which the head-space vapors can be sniffed. Previous reviews include those of Laffort,² Patte *et al.*,³ van Gemert and Nettenbreijer,⁴ van Gemert,⁵ Fazzolari⁶ and the ACGIH *Documentation of Threshold Limit Values*.⁷

In practically every case, we consulted the original articles, so as to minimize errors of transcription, calculation or duplication. Nearly all of the odor thresholds and references are available in the recent comprehensive compilations by van Gemert.^{4,5} If an author gave only a recognition threshold, this was accepted, because recognition of an odor requires on average only about three times the detection threshold concentration.⁸

If, for any compound, an odor threshold could be located, then a further search was conducted for relevant physical data. The molecular weights, liquid densities and ionization constants (of acids and bases) for these common compounds can be found in laboratory handbooks. The vapor pressures at 25°C were usually interpolated by linear regression computations from the tables of Stull.⁹ Solubilities in water at 25°C were often interpolated graphically from data collected by Seidell and co-workers.^{10,11} More current information is given in Verschueren's handbook.¹² Certain missing data on vapor pressures, solubilities, ionization constants, and also occasionally data on the air-water partition coefficient, were found in Beilstein's *Handbuch*¹³ and its four supplements. A few solubilities were estimated by extrapolation of homologous series or by comparison with isomers.

The air-water partition coefficient describes the relative distribution of a chemical in this two-phase system. Quantitatively, it is the ratio of the concentrations of the chemical in air and water (both expressed as g l⁻¹) at equilibrium. For compounds of finite water solubility, the coefficient

Table 1. Literature odor thresholds for *n*-butyl alcohol^a

Water-dilution threshold		Air-dilution threshold		First reference
Original data	g l ⁻¹	Original data	g l ⁻¹	
		1 µg/l	1.00 × 10 ⁻⁶	Passy, 1892
		0.565 × 10 ⁻³ mol l ⁻¹	4.18 × 10 ⁻⁵	Backman, 1917
		0.000223 mg/l	2.23 × 10 ⁻⁵	Jung, 1936
		Act ₁₁ = 6 × 10 ⁻⁶	1.61 × 10 ⁻⁵	Gavaudan, 1948
		Act ₁₁ = 7.0 × 10 ⁻⁶	4.09 × 10 ⁻⁵	Mullins, 1955
0.005% (v/v)	4.03 × 10 ⁻³		1.45 × 10 ⁻⁵	Moncrieff, 1957
		15 ppm (v/v)	4.56 × 10 ⁻⁵	Scherberger, 1958
1 mg/l	1.00 × 10 ⁻³		3.60 × 10 ⁻⁵	Nazarenko, 1962
1.00 ppm (w/v)	1.00 × 10 ⁻³		3.60 × 10 ⁻⁵	Rosen, 1962
2.5 ppm (v/v)	2.01 × 10 ⁻³		7.24 × 10 ⁻⁵	Baker, 1963
		Act ₁₁ = 5 × 10 ⁻⁶	1.40 × 10 ⁻⁵	Gavaudan, 1966
		33 mg/m ³	3.30 × 10 ⁻⁵	Mav, 1966
0.50 ppm (v/v)	4.02 × 10 ⁻⁴		1.45 × 10 ⁻⁵	Flath, 1967
		1.10 × 10 ⁻³ mol/cc	1.34 × 10 ⁻⁵	Dravnieks, 1968
		1.2 mg/m ³	1.20 × 10 ⁻⁵	Khachatryan, 1969
		0.013 mg/l	1.30 × 10 ⁻⁵	Corbitt, 1971
		-log ₁₀ M/l = 7.91	9.12 × 10 ⁻⁵	Laffort, 1973
		0.30 ppm (v/v)	9.11 × 10 ⁻⁵	Hellman, 1974
		3.16 ppm (v/v)	9.60 × 10 ⁻⁵	Moskowitz, 1974
		62 ppm (v/v)	1.88 × 10 ⁻⁴	Moskowitz, 1974
2.0 mg/kg	2.00 × 10 ⁻³		7.20 × 10 ⁻⁵	de Grunt, 1975
3.6 × 10 ⁻⁴ M/l	2.67 × 10 ⁻³		9.61 × 10 ⁻⁵	Hertz, 1975
2.77 ppm (w/v)	2.77 × 10 ⁻³		9.97 × 10 ⁻⁵	Lillard, 1975
		0.0231 mmHg	9.23 × 10 ⁻⁵	Piggott, 1975
		0.390 ppm (v/v)	1.18 × 10 ⁻⁴	Dravnieks, 1976
		2.8 × 10 ⁻¹ ppm (v/v)	8.50 × 10 ⁻⁵	Williams, 1977
			2.34 × 10 ⁻⁴	Amoore, 1978
6.5 × 10 ⁻³ g/l	6.50 × 10 ⁻³	3.5 ppm (v/v)	1.06 × 10 ⁻⁴	Laing, 1978
		log ₁₀ ppb = 10.42	4.15 × 10 ⁻⁴	Punter, 1980

Geometric mean, air-dilution threshold = 2.54×10^{-5} g l⁻¹ (N = 29)

= 2.54 mg m⁻³

= 0.835 ppm (v/v)

Standard deviation = $x \pm 7.14$; Standard error = $x \pm 1.44$

^a MW = 74.1 g; D₄ = 0.806 g ml⁻¹; VP₂₅ = 6.99 mmHg; S₂₅ = 73.0 g l⁻¹; air-water partition coefficient at 25°C = 3.6×10^{-3} (expt.), 3.61×10^{-3} (calc.).

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Table 2(a) Air-dilution odor threshold data on 214 industrial chemicals. The numerical data are mostly rounded off to two significant figures. Note that ppm on this half of Table 2 are in v/v units ($\mu\text{l l}^{-1}$) for the gaseous chemical in air dilution. See Methods for further explanation of each column. TLVs are reproduced from Ref. 1 (1982) with permission from ACGIH

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25°C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error ($\pm$)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Acetaldehyde	100	g	0.050	1.7	10 000	2000	A
Acetic acid	10	20 000	0.48	1.5	2000	21	C
Acetic anhydride	5	6700	0.13	1.1	1300	39	B
Acetone	750	290 000	13	1.6	390	57	B
Acetonitrile	40	120 000	170	2.8	3000	0.23	D
Acetylene	140 000 ¹	g	620	2.8	7	230	B
Acrolein	0.1	360 000	0.16	1.5	3 600 000	0.61	D
Acrylic acid	10	5800	0.094	—	580	110	B
Acrylonitrile	2	140 000	17	2.4	72 000	0.12	E
Allyl alcohol	2	33 000	1.1	1.3	16 000	1.8	C
Allyl chloride	1	480 000	1.2	2.5	480 000	0.84	D
Ammonia	25	g	5.2	2.0	40 000	4.8	C
n-Amyl acetate	100	5200	0.054	2.1	52	1800	A
sec-Amyl acetate	125	9200	0.0020	—	74	61 000	A
Aniline	2	630	1.1	1.6	310	1.9	C
Argine	0.05	g	0.50	—	20 000 000	0.10	E
Benzene	10	120 000	12	1.6	12 000	0.85	D
Benzyl chloride	1	1600	0.044	1.1	1600	23	C
Biphenyl	0.2	11	0.00083	—	56	240	B
Bromine	0.1	270 000	0.051	2.2	2 700 000	2.0	C
Bromoform	0.5	8000	1.3	2.3	16 000	0.39	D
1,3-Butadiene	1000 (10)	g	1.6	2.5	1000	640 (6.3)	A (C)
Butane	800	g	2700	1.4	1300	0.29	D
2-Butoxyethanol	25	1300	0.10	—	52	250	B
n-Butyl acetate	150	16 000	0.39	2.5	110	390	B
n-Butyl acrylate	10	7100	0.035	5.3	720	290	B
n-Butyl alcohol	50	9200	0.83	1.4	180	60	B
sec-Butyl alcohol	100	23 000	2.6	2.0	230	38	B
tert-Butyl alcohol	100	55 000	47	2.6	550	2.1	C
n-Butylamine	5	93 000	1.8	2.5	19 000	2.7	C
n-Butyl lactate	5	590	7.0	—	120	0.71	D
n-Butyl mercaptan	0.5	~49 000	0.00097	1.4	97 000	510	B
p-tert-Butyltoluene	10	850	5.0	—	85	2.0	C
Camphor	2	450	0.27	1.9	230	7.3	C
Carbon dioxide	5000	g	74 000	1.5	200	0.067	E
Carbon disulfide	10	470 000	0.11	1.9	47 000	92	B
Carbon monoxide	50	g	100 000	10	20 000	0.00050	E
Carbon tetrachloride	5	140 000	96	1.8	29 000	0.052	E
Chlorine	1	g	0.31	1.8	1 000 000	3.2	C
Chlorine dioxide	0.1	g	9.4	1.6	10 000 000	0.011	E
o-Chloroacetophenone	0.05	9.9	0.035	1.1	200	1.4	C
Chlorobenzene	75	15 000	0.68	1.6	200	110	B
Chlorobromomethane	200	190 000	400	—	940	0.50	D
Chloroform	10	250 000	85	1.7	25 000	0.12	E
Chloropicrin	0.1	34 000	0.78	1.4	340 000	0.13	E
β-Chloroprene	10	290 000	15	7.9	29 000	0.68	D
o-Chlorotoluene	50	4700	0.32	1.5	94	150	B
m-Cresol	5	180	0.00028	2.4	36	17 000	A
trans-Crotonaldehyde	2	~41 000	0.12	1.1	20 000	17	C
Cumene	50	5900	0.028	2.9	120	570	A

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Table 2(b) Water-dilution odor threshold data on the same 214 chemicals. Note that ppm on this half of Table 2 are in w/v units (mg l^{-1}) for the chemical in aqueous solution. The numerical values in Table 2 are almost invariably compiled, averaged, re-calculated or extrapolated from the literature, and are *not* new experimental determinations

Substance	8 Water TLV equivalent (ppm; w/v)	9 Solubility at 25°C (ppm; w/v)	10 Water odor threshold (ppm; w/v)	11 Molecular weight (g)	12 Density at 20-25°C (g ml^{-1})	13 Water-air distribution ratio (w/v)	14 Number of thresholds performed	
							air	water
Acetaldehyde	67	—	0.034	44	0.79 ₁	370	6	3
Acetic acid (A/4.7)	2000	—	97	60	1.05	82 000	14	4
Acetic anhydride	d	d	d	102	1.08	d	2	—
Acetone	1100	—	20	58	0.79	620	20	8
Acetonitrile	70	—	300	41	0.78	1000	3	—
Acetylene	(150)	1000	(0.67)	26	g	1.0	2	—
Acrolein	0.066	200 000	0.11	56	0.84	290	7	1
Acrylic acid (A/4.3)	—	—	—	72	1.05	—	1	—
Acrylonitrile	1.1	73 000	9.1	53	0.80	240	2	2
Allyl alcohol	26	—	14	58	0.85	5600	4	—
Allyl chloride	(0.0075)	3600 ₁	(0.0089)	76	0.94	2.4	2	—
Ammonia (B/9.2)	7.1	280 000	1.5	17	g	400	11	2
n-Amyl acetate	68	1800 ₁	0.037	130	0.88	130	5	4
sec-Amyl acetate	110	1700	0.0017	130	0.87	160	—	1
Aniline (B/4.6)	120	37 000	65	93	1.02	16 000	9	1
Argine	(0.000035)	670	(0.00035)	78	g	0.22	1	—
Benzene	(0.15)	1800	(0.17)	78	0.88	4.6	19	4
Benzyl chloride	0.28	460 ₁	0.012	127	1.10	55	2	—
Biphenyl	0.12	6.7	0.00050	154	s	95	—	1
Bromine	0.012	33 000	0.0063	160	3.12	19	4	—
Bromoform	0.20	3100	0.51	253	2.89	38	4	1
1,3-Butadiene	(0.88)	850	(0.0014)	54	g	0.40	6	—
Butane	(0.051)	61	(0.17)	58	g	0.027	4	—
2-Butoxyethanol	—	—	—	118	0.90	—	1	—
n-Butyl acetate	65	6600	0.17	116	0.88	91	9	3
n-Butyl acrylate	2.2	1600 ₁	0.0078	128	0.90	43	2	1
n-Butyl alcohol	420	73 000	7.1	74	0.81	2800	20	9
sec-Butyl alcohol	730	200 000	19	74	0.81	2400	5	1
tert-Butyl alcohol	620	—	290	74	0.78	2000	4	1
n-Butylamine (B/10.6)	17	—	8.2	73	0.73	1100	3	2
n-Butyl lactate	370	42 000	520	146	0.98	12 000	1	—
n-Butyl mercaptan (A/10.8)	(0.0061)	600 ₁	(0.00012)	90	0.84	3.3	6	—
p-tert-Butyltoluene	(0.064)	~5.5	(0.032)	148	0.86	1.1	1	—
Camphor	7.5	1700 ₁	1.0	152	s	600	9	3
Carbon dioxide (A/6.4)	(7.5)	1400	(110)	44	g	0.83	2	—
Carbon disulfide	(0.036)	1700	(0.00039)	76	1.26	1.2	6	—
Carbon monoxide	(0.0013)	26	(2.7)	28	g	0.023	2	—
Carbon tetrachloride	(0.027)	770	(0.52)	154	1.59	0.85	10	1
Chlorine	(0.0065)	6300	(0.0020)	71	g	2.2	7	—
Chlorine dioxide (A)	0.0071	87 000 ₁	0.67	67	g	26	1	1
o-Chloroacetophenone	d	d	d	155	s	d	2	—
Chlorobenzene	5.5	1100	0.050	113	1.10	16	6	2
Chlorobromomethane	17	~16 000	34	129	1.93	16	1	—
Chloroform	(0.28)	7100	(2.4)	119	1.48	5.7	14	1
Chloropicrin	(0.0048)	1600	(0.037)	164	1.65	7.1	1	1
β-Chloroprene	(0.016)	480 ₁	(0.024)	88	0.96	0.45	2	1
o-Chlorotoluene	(1.1)	100 ₁	(0.0069)	127	1.08	4.1	1	1
m-Cresol (A/10.1)	640	23 000	0.037	108	1.03	29 000	3	3
trans-Crotonaldehyde	7.2	150 000 ₁	0.42	70	0.85	1200	1	1
Cumene	(0.45)	53	(0.00280)	120	0.86	1.8	6	1

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Table 21a1-Continued

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25°C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error (μ /s)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Cyclohexane	300	120 000	25	2.8	430	12	C
Cyclohexanol	50	2000	0.15	2.1	39	340	B
Cyclohexanone	25	6000	0.88	2.2	240	28	B
Cyclohexene	300	99 000	0.18	—	330	1600	A
Cyclohexylamine	10	15 000	2.8	—	1500	3.8	C
Cyclopentadiene	75	~560 000	1.9	—	7500	40	B
Decaborane	0.05	~110	0.060	—	2300	0.83	D
Diacetone alcohol	50	1600	0.28	—	33	180	B
Diborane	0.1	9	2.5	—	10 000 000	0.040	E
o-Dichlorobenzene	50	1800	0.30	4.2	37	160	B
p-Dichlorobenzene	75	1200	0.18	4.1	17	420	B
trans-1,2-Dichloroethylene	200	420 000	17	16	2100	12	C
p,p'-Dichloroethyl ether	5	1500	0.049	—	290	100	B
Dicyclopentadiene	5	3600	0.0057	1.9	720	870	A
Diethanolamine	3	78	0.27	—	26	11	C
Diethylamine	10	310 000	0.13	2.9	31 000	77	B
Diethylaminethanol	10	2900	0.011	—	290	910	A
Diethyl ketone	200	22 000	2.0	2.1	110	97	B
Diisobutyl ketone	25	3300	0.11	—	130	230	B
Diisopropylamine	5	110 000	1.8	3.9	21 000	2.7	C
N-Dimethylacetamide	10	2600	47	—	260	0.21	D
Dimethylamine	10	9	0.34	3.1	100 000	29	B
N-Dimethylaniline	5	1000	0.013	3.8	200	400	B
N-Dimethylformamide	10	3100	2.2	46	310	4.6	C
1,1-Dimethylhydrazine	0.5	210 000	1.7	5.5	410 000	0.30	D
1,4-Dioxane	25	52 000	24	2.4	1000	1.1	C
Epichlorohydrin	2	21 000	0.93	12	11 000	2.1	C
Ethane	140 000 ¹	9	120 000	5.9	7	1.2	C
Ethanolamine	3	780	2.6	—	260	1.2	C
2-Ethoxyethanol	5 ⁿ	7100	2.7	9.0	1400	1.8	C
2-Ethoxyethyl acetate	5 ⁿ	2700	0.056	—	530	89	B
Ethyl acetate	400	120 000	3.9	1.8	300	100	B
Ethyl acrylate	5	50 000	0.0012	4.1	10 000	4000	A
Ethyl alcohol	1000	75 000	84	1.8	75	12	C
Ethylamine	10	9	0.95	2.6	100 000	11	C
Ethyl n-amyl ketone	25	3600	6.0	—	140	4.2	C
Ethyl benzene	100	13 000	2.3	2.7	130	44	B
Ethyl bromide	200	610 000	3.1	—	3100	64	B
Ethyl chloride	1000	9	4.2	—	1000	240	B
Ethylene	140 000 ¹	9	290	2.6	7	490	B
Ethylenediamine	10	16 000	1.0	—	1600	10	C
Ethylene dichloride	10	110 000	88	2.1	11 000	0.11	E
Ethylene oxide	1 ⁿ	9	430	1.6	1 000 000	0.0023	E
Ethylenimine	0.5	260 000	1.5	1.3	520 000	0.32	D
Ethyl ether	400	700 000	8.9	3.3	1800	45	B
Ethyl formate	100	320 000	31	1.6	3200	3.3	C
Ethylidene norbornene	5	—	0.014	1.4	—	350	B
Ethyl mercaptan	0.5	710 000	0.00076	2.0	1 400 000	650	A
N-Ethylmorpholine	5	11 000	1.4	18	2100	3.5	C
Ethyl silicate	10	3000	17	4.9	300	0.57	D
Fluorine	1	9	0.14	—	1 000 000	7.3	C
Formaldehyde	1 ⁿ	9	0.83	2.3	1 000 000	1.2	C
Formic acid	5	57 000	49	1.9	11 000	0.10	E
Furfural	2	2100	0.078	1.7	1000	25	C
Furfuryl alcohol	10	810	8.0	—	81	1.2	C

Table 2(b)-Continued

Substance	Water TLV equivalent (ppm; w/v)	Solubility at 25°C (ppm; w/v)	Water odor threshold (ppm; w/v)	Molecular weight (g)	Density at 20-25°C (g ml ⁻¹)	Water-air distribution ratio (w/v)	Number of thresholds performed	
							air	water
Cyclohexane	(0.13)	55	(0.011)	84	0.78	0.12	6	-
Cyclohexanol	940	38 000	2.8	100	0.95	4600	3	2
Cyclohexanone	240	~54 000	8.3	98	0.95	2400	8	2
Cyclohexene	(0.65)	210	(0.00039)	82	0.81	0.64	1	-
Cyclohexylamine (B/10.6)	94	-	25	99	0.87	2300	-	1
Cyclopentadiene	(0.24)	~1800	(0.0060)	66	0.80	1.2	1	-
Decaborane	-	-	-	122	-	-	1	-
Diacetone alcohol	-	-	64	116	0.94	-	1	2
Diborane	d	d	d	28	-	d	1	-
O-Dichlorobenzene	3.9	140	0.024	147	1.30	13	3	2
p-Dichlorobenzene	4.7	79	0.011	147	-	10	2	3
trans-1,2-Dichloroethylene	(3.0)	6300	(0.26)	97	1.26	3.8	2	-
β,β'-Dichloroethyl ether	36	11 000	0.36	143	1.21	1200	-	1
Dicyclopentadiene	-	-	-	132	-	-	2	-
Diethanolamine (B/8.9)	240 000	-	22 000	105	1.10	19 000 000	1	-
Diethylamine (B/11.0)	36	-	0.47	73	0.71	1200	6	1
Diethylaminoethanol (B/8.8)	-	-	-	117	0.88	-	1	-
Diethyl ketone	450	48 000	4.7	86	0.81	640	3	-
Diisobutyl ketone	3.3	430	0.014	142	0.81	23	1	-
Diisopropylamine (B/11.0)	3.5	-	1.3	101	0.72	~170	2	1
N-Dimethylacetamide	-	-	-	87	0.94	-	1	-
Dimethylamine (B/10.7)	8.6	550 000	0.29	45	-	460	6	2
N-Dimethylaniline (B/5.2)	9.9	2000	0.025	121	0.96	400	3	-
N-Dimethylformamide	-	-	50	73	0.94	-	2	1
1,1-Dimethylhydrazine (B/7.2)	-	-	-	60	0.79	-	2	-
1,4-Dioxane	240	-	230	88	1.03	2700	7	1
Epichlorohydrin	8.4	65 000	3.0	92	1.18	840	2	-
Ethane	(8.8)	60	(7.5)	30	-	0.051	2	-
Ethanolamine (B/9.5)	23 000	-	20 000	61	1.02	3 100 000	1	-
2-Ethoxyethanol	-	-	190	90	0.92	-	2	1
2-Ethoxyethyl acetate	450	200 000,,	5.0	132	0.97	16 000	1	-
Ethyl acetate	270	73 000	2.6	88	0.90	180	8	4
Ethyl acrylate	1.5	15 000	0.00038	100	0.92	74	2	1
Ethyl alcohol	9000	-	760	46	0.79	4800	13	5
Ethylamine (B/10.7)	45	-,,	4.3	45	0.69,,	2400	3	3
Ethyl n-amyl ketone	10	~1500	2.5	128	0.83	80	1	-
Ethyl benzene	(1.3)	160	(0.029)	106	0.87	2.9	2	3
Ethyl bromide	(2.9)	9000	(0.046)	109	1.43	3.3	1	-
Ethyl chloride	(4.7)	4700	(0.019)	64	-	1.8	1	-
Ethylene	(19)	130	(0.039)	28	-	0.12	4	1
Ethylenediamine (B/10.0)	-	-	16 000	60	0.90	-	1	1
Ethylene dichloride	0.80	8600	7.0	99	1.26	20	8	2
Ethylene oxide	0.33	270 000,,	140	44	-	180	2	-
Ethyl enamine (B/8.0)	d	-d	170d	43	0.83	d	2	1
Ethyl ether	34	56 000	0.75	74	0.71	28	7	-
Ethyl formate	35	100 000	11	74	0.92	120	1	1
Ethylidene norbornene	-	-	-	120	-	-	2	-
Ethyl mercaptan (A/10.5)	(0.0049)	7000	(0.0000075)	62	0.83	3.9	12	1
N-Ethylmorpholine (B/)	-	-	-	115	0.90	-	2	-
Ethyl silicate	d	d	d	208	0.93	d	2	-
Fluorine	d	d	d	38	-	d	1	-
Formaldehyde	0.73	550 000	0.60	30	-	590	9	4
Formic acid (A/3.7)	170	-	1700	46	1.22	18 000	4	5
Furfural	89	86 000	3.5	96	1.16	11 000	2	3
Furfuryl alcohol	d	-d	d	98	1.13	d	1	-

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Table 2(a)—Continued

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25°C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error (v/v)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Halothane	50 ⁿ	390 000	33	—	7900	1.8	C
Heptane	400	60 000	150	1.7	150	2.7	C
Hexachlorocyclopentadiene	0.01	78	0.030	8.1	7800	0.34	D
Hexachloroethane	10	770	0.15	—	77	64	B
Hexane	50	200 000	130	2.0	4000	0.37	D
Hexylene glycol	25	100	50	—	4.0	0.50	D
Hydrazine	0.1	18 000	3.7	1.1	180 000	0.027	E
Hydrogen bromide	3	9	2.0	—	330 000	1.5	C
Hydrogen chloride	5	9	0.77	2.2	200 000	6.5	C
Hydrogen cyanide	10	970 000	0.58	1.9	97 000	17	C
Hydrogen fluoride	3	9	0.042	1.2	330 000	71	B
Hydrogen selenide	0.05	9	0.30	—	20 000 000	0.17	E
Hydrogen sulfide	10	9	0.0081	1.5	100 000	1200	A
Indene	10	2200	0.015	3.9	220	690	A
Iodoform	0.6	~49	0.0050	1.8	81	120	B
Isamyl acetate	100	7100	0.025	1.6	71	3900	A
Isamyl alcohol	100	4300	0.042	1.3	43	2300	A
Isobutyl acetate	150	26 000	0.64	1.8	170	230	B
Isobutyl alcohol	50	16 000	1.6	2.0	330	30	B
Isophorone	5	450	0.20	—	89	25	C
Isopropyl acetate	250	79 000	2.7	2.9	320	93	B
Isopropyl alcohol	400	57 000	22	1.8	140	18	C
Isopropylamine	5	740 000	1.2	2.8	150 000	4.1	C
Isopropyl ether	250	210 000	0.017	—	850	15 000	A
Maleic anhydride	0.25	~170	0.32	—	670	0.77	D
Mesityl oxide	15	13 000	0.45	26	850	33	B
2-Methoxyethanol	5 ⁿ	16 000	2.3	26	3200	2.1	C
Methyl acetate	200	270 000	4.6	3.5	1400	44	B
Methyl acrylate	10	110 000	0.0048	—	11 000	2100	A
Methyl acrylonitrile	1	88 000	7.0	—	88 000	0.14	E
Methyl alcohol	200	160 000	100	2.0	800	2.0	C
Methylamine	10	9	3.2	4.6	100 000	3.1	C
Methyl n-amyl ketone	50	2000	0.35	2.1	40	140	B
N-Methylaniline	0.5	640	1.7	—	1300	0.29	D
Methyl n-butyl ketone	5	5000	0.076	—	1000	66	B
Methyl chloroform	350	160 000	120	2.8	470	2.8	C
Methyl 2-cyanoacrylate	2	~530	2.2	—	260	0.91	D
Methylcyclohexane	400	61 000	630	—	150	0.63	D
cis-3-Methylcyclohexanol	50	710	500	—	14	0.10	E
Methylene chloride	100	550 000	250	1.2	5500	0.40	D
Methyl ethyl ketone	200	130 000	5.4	1.9	660	37	B
Methyl formate	100	760 000	600	2.9	7600	0.17	E
Methyl hydrazine	0.2	65 000	1.7	—	330 000	0.12	E
Methyl isamyl ketone	50	4800	0.012	—	96	4200	A
Methyl isobutyl carbinol	25	7800	0.070	—	310	360	B
Methyl isobutyl ketone	50	9500	0.68	2.3	190	73	B
Methyl isocyanate	0.02	830 000	2.1	—	32 000 000	0.0094	E
Methyl isopropyl ketone	200	39 000	1.9	2.3	200	100	B
Methyl mercaptan	0.5	9	0.0016	2.0	2 000 000	300	B
Methyl methacrylate	100	52 000	0.083	1.9	520	1200	A
Methyl n-propyl ketone	200	21 000	11	2.2	110	18	C
o-Methyl styrene	50	3800	0.29	4.0	76	170	B
Morpholine	20	13 000	0.01	—	670	2000	A
Naphthalene	10	120	0.084	1.9	12	120	B
Nickel carbonyl	0.05	570 000	0.30	3.3	10 000 000	0.17	E

Table 2(b)-Continued

Substance	8 Water TLV equivalent (ppm; w/v)	9 Solubility at 25°C (ppm; w/v)	10 Water odor threshold (ppm; w/v)	11 Molecular weight (g)	12 Density at 20-25°C (g ml ⁻¹)	13 Water-air distribution ratio (w/v)	14 Number of thresholds performed	
							air	water
Hexothane	(0.44)	3400	(0.29)	197	1.87	1.1	1	-
Heptane	(0.020)	2.9	(0.0073)	100	0.68	0.012	4	-
Hexachlorocyclopentadiene	0.0026	20	0.0077	273	1.70	23	1	1
Hexachloroethane	(0.65)	50	(0.010)	237	1	6.7	-	1
Hexane	(0.0024)	9.5	(0.0064)	86	0.66	0.014	2	-
Hexylene glycol	-	-	-	118	0.92	-	1	-
Hydrazine (8/8.5)	-	-	160	32	1.01	-	2	1
Hydrogen bromide (A)	d	1 200 000	d	81	9	d	1	-
Hydrogen chloride (A)	d	500 000	d	36	9	d	6	-
Hydrogen cyanide (A/9.2)	3.0	-	0.17	27	0.70	270	2	3
Hydrogen fluoride (A/3.2)	d	-	d	20	0.96	d	2	-
Hydrogen selenide (A/3.9)	(0.00035)	6800	(0.0021)	81	9	2.1	1	-
Hydrogen sulfide (A/7.0)	(0.036)	3500	(0.000029)	34	9	2.6	25	1
Indene	(0.18)	~40	(0.00025)	116	1.01	3.7	1	1
Iodoform	1.3	110	0.011	394	1	130	3	-
Isamyl acetate	66	1400	0.017	130	0.87	120	8	3
Isamyl alcohol	630	26 000	0.27	88	0.80	1700	5	3
Isobutyl acetate	34	5900	0.15	116	0.87	48	3	1
Isobutyl alcohol	310	89 000	10	74	0.80	2100	7	5
Isophorone	140	12 000	5.4	138	0.92	4800	1	-
Isopropyl acetate	97	30 000	1.0	102	0.87	92	4	-
Isopropyl alcohol	3000	-	160	60	0.78	3000	12	4
Isopropylamine (8/10.5)	20	-	4.9	59	0.69	~1700	2	1
Isopropyl ether	12	10 000	0.00080	102	0.73	11	1	-
Maleic anhydride	d	d	d	98	1	d	1	-
Mesityl oxide	35	29 000	1.0	98	0.85	570	2	-
2-Methoxyethanol	-	-	-	76	0.97	-	2	-
Methyl acetate	130	220 000	3.0	74	0.93	210	5	-
Methyl acrylate	4.5	49 000	0.0021	86	0.95	130	1	-
Methyl acrylonitrile	0.29	25 000	2.1	87	0.80	110	1	-
Methyl alcohol	1500	-	740	32	0.79	5600	13	4
Methylamine (8/10.6)	7.4	550 000	2.4	31	9	580	2	3
Methyl n-amyl ketone	40	4300	0.28	114	0.81	170	2	2
N-Methylaniline (8/4.8)	5.3	6700	18	107	0.99	2400	1	-
Methyl n-butyl ketone	17	16 000	0.25	100	0.81	800	1	-
Methyl chloroform	(2.8)	1300	(0.97)	133	1.34	1.4	3	-
Methyl 2-cyanoacrylate	-	-	-	111	1.11	-	1	-
Methylcyclohexane	(0.092)	14	(0.15)	98	0.77	0.057	1	-
cis-3-Methylcyclohexanol	660	9300	6600	114	0.91	2800	1	-
Methylene chloride	3.6	19 000	9.1	85	1.34	10	4	1
Methyl ethyl ketone	310	210 000	8.4	72	0.80	530	8	1
Methyl formate	25	170 000	150	60	0.97	100	3	-
Methyl hydrazine (8/7.9)	-	-	-	46	0.87	-	1	-
Methyl isamyl ketone	56	5400	0.013	114	0.81	240	1	-
Methyl isobutyl carbinol	53	16 000	0.15	102	0.81	510	1	-
Methyl isobutyl ketone	94	18 000	1.3	100	0.80	460	5	-
Methyl isocyanate	d	d	d	57	0.96	d	1	-
Methyl isopropyl ketone	320	60 000	3.1	86	0.80	460	1	1
Methyl mercaptan (A/10.7)	(0.0075)	~14 000	(0.000024)	48	9	7.6	8	2
Methyl methacrylate	30	15 000	0.025	100	0.94	73	4	1
Methyl n-propyl ketone	270	54 000	15	86	0.81	380	2	1
o-Methyl styrene	7.4	560	0.043	118	0.91	31	3	1
Morpholine (8/8.7)	-	-	-	87	1.00	-	1	-
Naphthalene	2.5	30	0.021	128	1	47	6	4
Nickel carbonyl	(0.000012)	130	(0.000072)	171	1.32	0.035	3	-

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Table 2(a) - Continued

Substance	1 Threshold limit value (ppm; v/v)	2 Volatility at 25°C (ppm; v/v)	3 Air odor threshold (ppm; v/v)	4 Standard error (x/±)	5 Safe dilution factor	6 Odor safety factor	7 Odor safety class
Nitrobenzene	1	360	0.018	1.7	360	56	B
Nitroethane	100	27 000	2.1	—	270	48	B
Nitrogen dioxide	3	g	0.39	2.6	330 000	7.8	C
Nitromethane	100	47 000	3.5	—	470	29	B
1-Nitropropane	25	13 000	11	4.2	520	2.3	C
2-Nitropropane	10 ⁿ	22 000	70	2.2	2200	0.14	E
m-Nitrotoluene	2	~280	0.045	—	140	45	B
Nonane	200	6000	47	4.1	30	4.3	C
Octane	300	18 000	48	3.2	61	6.3	C
Osmium tetroxide	0.0002	12 000	0.0019	—	61 000 000	0.10	E
Oxygen difluoride	0.05	g	0.10	—	20 000 000	0.50	D
Ozone	0.1	g	0.045	1.9	10 000 000	2.2	C
Pentaborane	0.005	270 000	0.96	—	54 000 000	0.0052	E
Pentane	600	670 000	400	1.9	1100	1.5	C
Perchloroethylene	50	25 000	27	1.8	490	1.8	C
Phenol	5	460	0.040	1.5	92	130	B
Phenyl ether	1	29	0.0012	3.7	29	800	A
Phenyl mercaptan	0.5	2000	0.00094	4.4	4100	530	B
Phosgene	0.1	g	0.90	1.7	10 000 000	0.11	E
Phosphine	0.3	g	0.51	2.5	3 300 000	0.58	D
Phthalic anhydride	1	0.67	0.053	—	0.7	19	C
Propane	140 000 ¹	g	16 000	1.3	7	8.8	C
Propionic acid	10	5400	0.16	1.8	540	61	B
n-Propyl acetate	200	43 000	0.67	4.1	220	300	B
n-Propyl alcohol	200	26 000	2.6	1.7	130	78	B
Propylene	140 000 ¹	g	76	3.0	7	1800	A
Propylene dichloride	75	69 000	0.25	—	920	300	B
Propylene glycol dimethyl ether	100	16 000	10	—	160	10	C
Propylene oxide	20	700 000	44	4.5	35 000	0.45	D
n-Propyl nitrate	25	30 000	50	—	1200	0.50	D
Pyridine	5	27 000	0.17	1.4	5300	30	B
Quinone	0.1	130	0.084	3.0	1300	1.2	C
Styrene	50	9600	0.32	2.0	190	160	B
Sulfur dioxide	2	g	1.1	1.3	500 000	1.7	C
1,1,2,2-Tetrachloroethane	5	8400	1.5	2.1	1700	2.4	C
Tetrahydrofuran	200	230 000	2.0	5.4	1100	99	B
Toluene	100	37 000	2.9	1.8	370	34	B
Toluene-2,4-diisocyanate	0.005 ⁿ	~21	0.17	2.9	4200	0.030	E
o-Toluidine	2	330	0.25	4.1	170	8.0	C
1,2,4-Trichlorobenzene	5	570	1.4	2.1	110	3.6	C
Trichloroethylene	50	99 000	28	1.7	2000	1.8	C
Trichlorofluoromethane	1000	g	5.0	—	1000	200	B
1,1,2-Trichloro-1,2,2-trifluoroethane	1000	430 000	45	—	430	22	C
Triethylamine	10 ⁿ	93 000	0.48	2.1	9300	21	C
Trimethylamine	10 ⁿ	g	0.00044	1.4	100 000	23 000	A
1,3,5-Trimethylbenzene	25	3600	0.55	1.9	150	45	B
Trimethyl phosphite	2	34 000	0.00010	—	17 000	20 000	A
n-Valeraldehyde	50	21 000	0.028	2.5	420	1800	A
Vinyl acetate	10	140 000	0.50	1.6	14 000	20	C
Vinyl chloride	5	g	3000	3.7	200 000	0.0017	E
Vinylidene chloride	5 ⁿ	790 000	190	3.7	160 000	0.027	E
Vinyl toluene	50	2400	10	—	48	5.0	C
m-Xylene	100	11 000	1.1	2.1	110	92	B
2,4-Xyldine	2	190	0.058	—	97	36	B

Table 2(b)-Continued

Substance	Water TLV equivalent (ppm; w/v)	Solubility at 25°C (ppm; w/v)	Water odor threshold (ppm; w/v)	Molecular weight (g)	Density at 20-25°C (g ml ⁻¹)	Water-air distribution ratio (w/v)	Number of thresholds performed	
							air	water
Nitrobenzene	60	2100	0.11	123	1.20	1200	13	2
Nitroethane (A/8.4)	100	27 000	2.2	75	1.05	330	-	1
Nitrogen dioxide (A)	d	d	d	46	g	d	6	-
Nitromethane (A/10.2)	250	110 000	9.1	61	1.13	1000	-	1
1-Nitropropane (A/-8)	29	15 000	12	89	1.00	310	2	1
2-Nitropropane (A/7.7)	7.6	16 000	53	89	0.98	210	1	1
m-Nitrotoluene	3.6	500 ₁₀	0.080	137	1.16	320	1	-
Nonane	(0.0056)	~0.17	(0.0013)	128	0.72	0.0054	2	-
Octane	(0.011)	0.66	(0.0017)	114	0.70	0.0077	2	-
Osmium tetroxide (A/12.0)	0.0012	69 000	0.012	254	g	880	1	-
Oxygen difluoride	(0.0000054)d	100 ₁₀ d	(0.000011)d	54	g	0.049d	1	-
Ozone	(0.00064)	6100	(0.00028)	48	g	3.2	6	-
Pentaborane	d	d	d	63	0.63	d	1	-
Pentane	(0.033)	38	(0.022)	72	0.62	0.019	3	-
Perchloroethylene	(0.31)	150	(0.17)	166	1.61	0.90	3	1
Phenol (A/10.0)	1000	85 000	7.9	94	g	52 000	16	6
Phenyl ether	150	4300	0.18	170	1.07	21 000	2	3
Phenyl mercaptan (A/6.5)	0.15	610	0.00028	110	1.08	66	2	2
Phosgene	d	d	d	99	g	d	6	-
Phosphine	(0.00011)	370 ₁₁	(0.00020)	34	g	0.27	6	-
Phthalic anhydride	d	d	d	148	g	d	1	-
Propane	(9.0)	62	(1.0)	44	g	0.036	2	-
Propionic acid (A/4.9)	1700	-	28	74	1.00	56 000	11	2
n-Propyl acetate	92	19 000 ₁₀	0.31	102	0.89	110	4	-
n-Propyl alcohol	1800	-	23	60	0.80	3600	12	5
Propylene	(50)	350	(0.028)	42	g	0.21	3	1
Propylene dichloride	(3.0)	2800	(0.010)	113	1.16	8.8	1	-
Propylene glycol 1-methyl ether				90	0.92		1	-
Propylene oxide	14	370 000	31	58	0.83	300	2	-
n-Propyl nitrate	7.4	8800 ₁₀	15	105	1.05	69	1	-
Pyridine (B/5.2)	28	-	0.95	79	0.98	1700	15	10
Quinone	11	14 000	9.3	108	g	25 000	2	1
Styrene	(1.7)	320	(0.011)	104	0.90	7.8	10	3
Sulfur dioxide (A/1.9)	0.19	88 000	0.11	64	g	37	13	-
1,1,2,2-Tetrachloroethane	1.7	2900	0.50	168	1.60	50	3	1
Tetrahydrofuran		-		72	0.89		3	-
Toluene	(1.4)	540	(0.042)	92	0.86	3.8	18	2
Toluene-2,4-diisocyanate	d	d	d	174	1.22	d	4	-
o-Toluidine (B/4.4)	91	15 000	11	107	1.00	10 000	3	1
1,2,4-Trichlorobenzene	(0.23)	~26	(0.064)	181	1.45	6.1	1	1
Trichloroethylene	(0.55)	1100	(0.31)	131	1.46	2.1	7	1
Trichlorofluoromethane				137	1.49		1	-
1,1,2-Trichloro-1,2,2-trifluoroethane				187	1.56		1	-
Triethylamine (B/10.9)	8.8	71 000	0.42	101	0.73	210	4	1
Trimethylamine (B/9.7)	4.5	410 000 ₁₀	0.00020	59	g	190	3	1
1,3,5-Trimethylbenzene	(0.67)	97	(0.015)	120	0.86	5.4	6	3
Trimethyl phosphite	d	d	d	124	1.05	d	1	-
n-Valeraldehyde	29	12 000	0.017	86	0.81	170	1	3
Vinyl acetate	1.8	25 000 ₁₀	0.088	86	0.93	50	4	1
Vinyl chloride	(0.0057)	1100	(3.4)	62	g	0.44	3	-
Vinylidene chloride	(0.041)	6400	(1.5)	97	1.22	2.0	2	-
Vinyl toluene	(2.1)	~100	(0.42)	118	0.90	8.7	1	-
m-Xylene	(1.6)	170	(0.017)	106	0.86	3.7	8	2
2,4-Xylidine (B/4.9)	66	6400	1.8	121	0.97	6600	1	-

at 25 °C can be calculated¹⁴ from the vapor pressure and the solubility at 25 °C. The coefficients for some of the compounds that are infinitely soluble in water at 25 °C were calculated from tabulated activity data¹⁵ or measured experimentally.¹⁴

The results for *n*-butyl alcohol, which has provided the most plentiful odor-threshold data, are given in Table 1 as a demonstration of data reduction. The original threshold data, in a variety of concentration units, were converted² into common units of g l⁻¹. Any water dilution thresholds were further converted to the equivalent air dilution threshold, through multiplication by the air-water partition coefficient.¹⁴ The relationship between odor-intensity sensation and odorant concentration is exponential.¹⁶ Therefore, in order to preserve the normal distributions of olfactory-threshold measurements, all chemical concentrations of odorants were calculated on a logarithmic scale. Hence the geometric mean of all 29 odor thresholds, expressed in air dilution, was computed (by converting to the logarithms, finding their arithmetic mean, and taking its antilogarithm).² The mean air dilution threshold, in g l⁻¹, was finally converted to mg m⁻³, and to ppm by volume.

Explanation of Table 2 (odor thresholds)

Column 1. Threshold limit values (TLV) adopted by ACGIH, 1982.¹ The superscript *n* indicates that the TLV used is the value proposed in the 1982 Notice of Intended Changes. The superscript *l* indicates an inert gas (simple asphyxiant) for which no TLV is assigned by ACGIH, merely a requirement that the oxygen content of the air not be reduced below 18%. This would be expected to occur if the asphyxiant reaches 14%, or 140 000 ppm, which is in effect the TLV for inert gases.

Column 2. The volatility in ppm (v/v) is given by the literature vapor pressure (in mmHg at 25 °C) multiplied by 1316 (1 000 000 ppm per 760 mmHg). ~ Indicates approximate value obtained by extrapolating the linear regression from vapor pressures recorded at substantially higher temperatures. g, gaseous at 25 °C.

Column 3. Air-dilution odor thresholds are geometric averages of all available literature data, omitting extreme points and duplicate quotations. Odor thresholds originally measured in water dilution were converted to the equivalent air dilution, as illustrated in Table 1 for *n*-butyl alcohol.

Column 4. When two or more acceptable literature thresholds were located, the standard error of their mean was calculated. The standard error is the standard deviation divided by the square root of the number of literature thresholds. This factor is applicable to the data in columns 3, 6 and 10. The smaller the standard error, the greater the confidence that may be placed in the accuracy of the mean threshold value. (It should be borne in mind, however, that a small standard error, based on only two thresholds, could itself be the result of a fairly probable coincidence.)

Column 5. Safe dilution factor, for the saturated vapor at 25 °C, is the volatility divided by the threshold limit value (column 2 divided by column 1). For substances that are less than infinitely soluble in water, the same safe dilution factor applies to the saturated solution at 25 °C (column 9).

Column 6. Odor safety factor is the threshold limit value divided by the odor threshold (column 1 divided by column 3). This factor may be interpreted quantitatively by reference to Fig. 2, in terms of what percentage of attentive persons can detect the TLV concentration, and what percentage of distracted persons will perceive a warning of the TLV concentration.

Column 7. The scale of odor safety classes is explained in Table 3. Class A substances provide the strongest odorous warning of their presence at threshold limit value concentrations, whereas class E substances are practically odorless at the TLV concentration.

Table 3. Odor safety classification

Class	Odor safety factor	Interpretation
A	> 550	More than 90% of distracted persons perceive warning of TLV concentration in the air
B	26-550	50-90% of distracted persons perceive warning of TLV
C	1-26	Less than 50% of distracted persons perceive warning of TLV
D	0.18-1	10-50% of attentive persons can detect TLV concentration in the air
E	< 0.18	Less than 10% of attentive persons can detect the TLV

Column 8. Water TLV equivalent is the concentration of the substance in water, which will generate the air TLV concentration in the headspace of a stoppered flask or other closed system. It is calculated from column 1 by multiplying by the distribution ratio in column 13, then dividing by 24 400 (volume in ml of one gram molecule of vapor at 25 °C) and multiplying by the molecular weight. Solutions with values in parentheses lack enough persistence for reference purposes, due to an unfavorably low water-air distribution ratio (< 10) in column 13; d, decomposes in water.

Column 9. Solubility in ppm (w/v) is the literature solubility (expressed as g l⁻¹ of saturated solution at 25 °C) multiplied by 1000. ~ Indicates uncertain or extrapolated values. Temperatures other than 25 °C are indicated by subscripts.

Columns 10. Water-dilution odor threshold is the concentration of the substance in water which will generate the air odor threshold concentration in the headspace of a stoppered flask. It is calculated from column 3 by multiplying by the distribution ratio in column 13, then dividing by 24 400 and multiplying by the molecular weight. Values in parentheses have the same meaning as in column 8.

Column 11. The molecular weight (MW, rounded off to the nearest whole number expressed in grams) can be used to convert the air concentrations in ppm (v/v) (columns 1, 2 and 3) into mg m⁻³. Multiply by MW and divide by 24.4 (volume in liters of one gram molecule of vapor at 25 °C).

Column 12. The density (D , at 20–25 °C) is needed when measuring out liquid odorants by volume to prepare water or air dilutions:

$$1 \text{ ppm (w/v)} = 1 \text{ mg (or } (1/D) \mu\text{l) per liter of water}$$

$$1 \text{ ppm (v/v)} = \frac{\text{MW}}{24.4} \text{ mg (or } \frac{\text{MW}}{24.4 \times D} \mu\text{l) per cubic meter of air}$$

g. gaseous at 20 °C; s. solid at 20 °C.

Column 13. The water-air distribution ratio is the reciprocal of the air-water partition coefficient. Where experimental values are unavailable in the literature, which is usually the case, the ratio has been calculated from data in columns 9, 2 and 11, or from other approaches mentioned earlier. An estimate of the water-air distribution ratio is given by dividing the solubility (column 9) by the volatility (column 2), then multiplying by 24 400 and dividing by the molecular weight (column 11).

Column 14. The numbers indicate how many original literature odor thresholds were included in calculating the average threshold in column 3 and the standard error in column 4. On the left is the number of air-dilution thresholds, and on the right the number measured in water dilution.

Ionizable odorants (weak acids and bases) are indicated in Table 2(b) by appending to the compound name the symbol A for acid and B for base, followed by the acid dissociation constant pK_a . Data given for such compounds in columns 8, 9, 10 and 13 are accurate only for solutions in which the odorant is practically un-ionized and hence potentially volatile. That is, the pH of the solution should be less than two pH units lower than the pK_a for an acid, or should be more than two pH units higher than the pK_a for a base. The odorant volatilities at pH values outside of these limits can be estimated by calculating the concentration of the un-ionized species using the Henderson-Hasselbalch equation.¹⁶ For demonstration purposes, it will suffice to make solutions of the acids in 0.01 N H_2SO_4 and the bases in 0.01 N NaOH.

The data in Table 2 are incomplete for some physical properties of 25 compounds, because no literature values could be located, and no justifiable estimates could be made. The missing data are mostly water solubilities or water-air distribution ratios, which in turn preclude estimates of TLV equivalents in water and water-dilution odor thresholds. If the reader is aware of values for the missing data, or knows of more accurate measurements or estimates of the recorded data, the authors would be grateful for the information. Odor threshold data on TLV-listed compounds not included in Table 2 would also be welcome.

Variance of human responsiveness to odors

When the individual olfactory detection thresholds for a given compound are determined on a sample of the human population, the data typically generate a (log)normal or Gaussian distribution.¹⁷ For this result, it is necessary to use a logarithmic scale for the odorant concentration, such as a binary or decadic dilution series. The quantitative interpretation of a Gaussian curve is facilitated by re-

plotting the data on probability graph paper. The resulting probit approximates a straight line if the distribution of sensitivities in the population is in fact normal. Literature data on the percentages of persons responding to odorant when they were attentive,¹⁸ distracted,¹⁹ or asleep²⁰ were replotted as probits in Figs 1, 2 and 3.

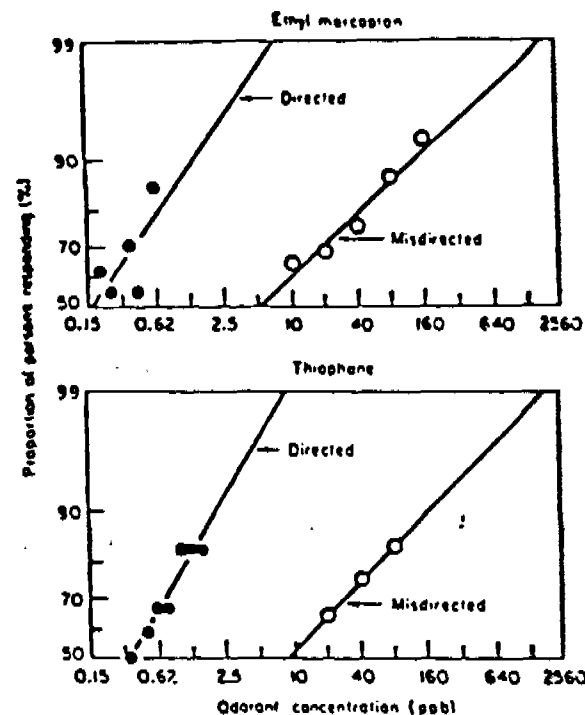


Figure 1. Tests of responsiveness of persons to fuel gas odorant. The data were taken from the report by Whisman *et al.*¹⁹ Figs 13, and Table 23, then re-plotted on log/probit coordinates. The misdirected tests, the attention of the subjects was deliberately channeled to other matters. Note that the concentration units in this Figure are ppb (v/v).

Some chemicals, but not all, besides having a true odor also cause immediate irritation in the nose, eyes or thro. The sensation of stinging, prickling or burning, conveyed the trigeminal or 5th cranial nerve, is quite distinct from the smell sensation carried by the olfactory or 1st cranial nerve.²¹ Irritation usually requires a higher chemical concentration than odor, and trained normal subjects can readily report the distinct irritation threshold.²² Another approach is to use subjects who have suffered a chronic loss of their olfactory nerve function, but still retain an active trigeminal nerve sensitivity.²³

Explanation of Table 4 (irritant thresholds)

Column 1. In this Table, each odor threshold was derived from the same source which reported the irritant threshold; hence the odor threshold in Table 4 may differ from that given for the same compound in Table 2; column 3, which may be an average of several literature values.

Columns 2 and 3. Irritation thresholds are the lowest concentrations that cause immediate stinging or burning sensations in the nose, or stinging or lacrimation of the e

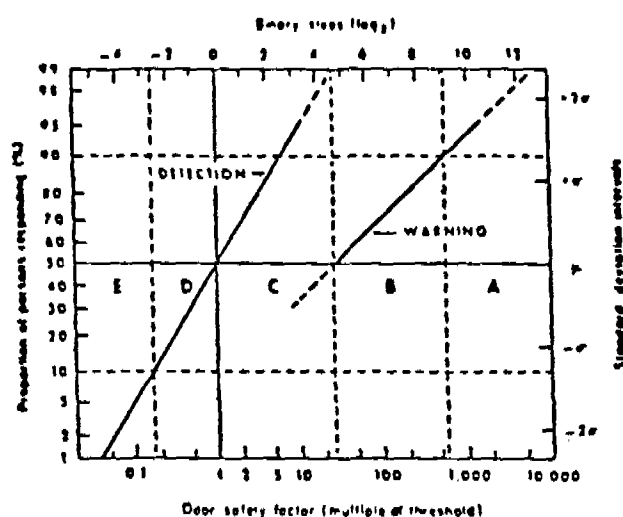


Figure 2. A practical guide to the quantitative interpretation of odor safety factors. The coordinates are log/probit, so care is required in interpolating between marked intervals. The sloping lines indicate the percentages of the population expected to respond to various fractions or multiples of the mean detection threshold concentration (1.0 on the x axis). The detection line represents the performance of fully attentive persons under good laboratory conditions. The warning line shows what may be expected for distracted persons under factory or field conditions. The warning line is based on the results of Whisman *et al.*¹⁰ for the gas odorants ethyl mercaptan and thiophane.

In four compounds, designated by superscript a, they are the lowest concentrations that could be distinguished from pure air by a general anosmic, i.e. by a person who has no olfactory nerve sensation, but whose trigeminal nerve sensitivity is intact.

Column 4. The lower of the nose and eye thresholds (if both are available) was used for calculating this ratio of irritation and odor thresholds.

Column 5. The Irritation hazard factor is obtained by dividing the nose or eye irritation threshold (whichever is lower, columns 2 or 3) by the threshold limit value from

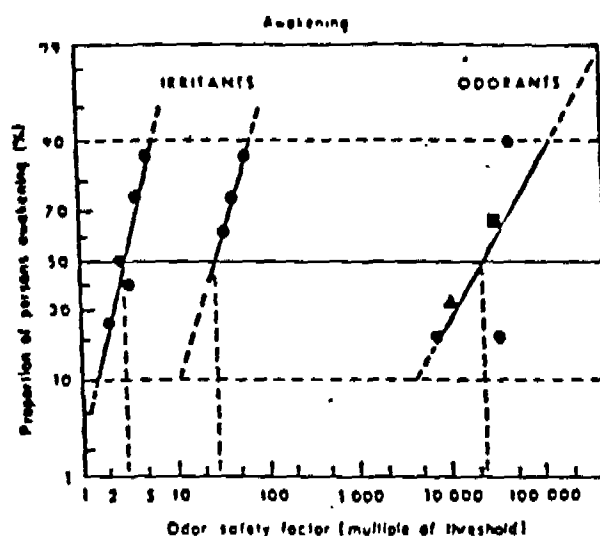


Figure 3. An illustration of the efficacy of certain vapors in awakening sleeping persons. The data were taken from the work of Fieldner *et al.*,¹⁰ Tables 8, 12 and 14, then plotted on log/probit coordinates. The irritants were allyl alcohol on the left, and crotonaldehyde on the right. The odorants were ethyl mercaptan (○), phenyl ether (△) and isoamyl acetate (□). The concentrations in this figure are stated as multiples of the odor thresholds reported by Fieldner *et al.*¹⁰

Table 2(a), column 1. This datum indicates by what multiple the TLV is exceeded, if eye or nose irritation can be detected.

Column 6. References in italics indicate that thresholds were obtained using water dilutions.

RESULTS AND DISCUSSION

Literature search for odor thresholds

The ACGIH compilation includes approximately 350 appreciably volatile compounds for which time-weighted average threshold limit values have been adopted or pro-

Table 4. Irritant threshold concentrations of ten industrial chemicals. See Methods for further explanation of each column

Substance	1 Odor threshold (ppm; v/v)	2 Irritation thresholds		4 Ratio of irritation and odor thresholds	5 Irritation hazard factor	6 Reference
		Nose (ppm; v/v)	Eye (ppm; v/v)			
Acetaldehyde	0.066	2200	11000	33000	22	22
Acetic acid	0.16	160 ^a		1000	16	23
Acrolein	1.8	11	12	6.1	110	22
Allyl alcohol	1.4	30	59	21	15	22
Benzyl chloride	0.040	35	8.0	200	8.0	22
o-Chloroacetophenone	0.040	0.034	0.022	0.55	0.44	22
trans-Crotonaldehyde	0.11	14	19	130	7.0	22
Formic acid	130	1100 ^a		8.5	220	23
Propionic acid	0.24	370 ^a		1500	37	23
Pyridine	0.71	700 ^a		990	140	27

^a Detection threshold for a general anosmic.

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posed.¹ Among these, there are 214 compounds for which we were able to locate at least one literature value for the olfactory detection or recognition threshold, measured in air or water dilution. The data are widely scattered in the literature, and there is little conformity in the choice of units for expressing the results. For example, the 29 reported thresholds for *n*-butyl alcohol (Table 1) were gathered from the works of 26 principal authors, who used 18 different systems of concentration units in publishing their data, in 24 journals. Furthermore, no two of these 29 thresholds were measured by precisely the same experimental method.

The lack of standardization, taken in conjunction with the inconsistent purity of the chemical samples and the variability of human sensitivity, is responsible for the rather wide range of threshold concentrations usually found in the literature for a given compound. As indicated at the foot of Table 1, the mean threshold for *n*-butyl alcohol is 0.835 ppm. (In this compilation, the data were collected and calculated to three significant figures, then rounded off to two significant figures for the Tables.) The threshold concentrations having been calculated as logarithms, statistical deviations and errors from the geometric mean should be stated in the form of factors (rather than the differences used with ordinary arithmetic means). The standard deviation of the logarithms of the observed thresholds was $\pm 0.854 \log_{10}$ units, for which the antilog yields a factor of $x \pm 7.14$. Taking into account all 29 literature values (i.e. dividing by $\sqrt{29}$), this reduces to a standard error of $\pm 0.159 \log_{10}$ units, corresponding to a factor of $x \pm 1.44$. This indicates that there is approximately a 68% probability ($\pm 1\sigma$ or SD) that the true threshold for *n*-butyl alcohol lies between $(0.835/1.44) = 0.58$ ppm and $(0.835 \times 1.44) = 1.20$ ppm. There is a 96% probability ($\pm 2\sigma$) that it lies between $(0.58/1.44) = 0.40$ ppm and $(1.20 \times 1.44) = 1.73$ ppm. Olfactory thresholds could, if necessary, be obtained with greater consistency and smaller standard errors, by determining conversion factors between different experimental methods,^{2,3,14} or by redetermining the thresholds by using a standardized procedure with careful minimization of known sources of error.

In the literature, we found for these 214 compounds a total of 1054 acceptable thresholds. Some thresholds had to be rejected on the grounds that they had been measured without consideration of substantial ionization, unfavorable partition coefficients, likely impurities or the inapplicability of Raoult's law. A few remaining extreme points were discarded because they diverged more than 100-fold from the nearest of two or more other thresholds for the same compound.²⁴ For 152 of the compounds, we found two or more acceptable thresholds. We calculated the mean threshold and its standard deviation for each compound. The average of the individual standard deviations for all these 152 multiple threshold compounds was a factor of $x \pm 7.0$. The remaining 62 compounds each yielded only one usable threshold, so no standard error could be calculated, which accounts for the dashes in column 4 of Table 2(a). The uncertainty in a given olfactory threshold measurement should be independent of whether the compound has been reported several times in the literature, or only once. As a rough guide, we may assume the same average standard error factor of $x \pm 7.0$ for these single-threshold compounds.

Safe dilution factors for saturated vapors

The procedure of expressing threshold limit values, volatilities and odor thresholds all in the same units (ppm; v/v) brings to light certain relationships that are not apparent when miscellaneous units are used. Nearly all of the compounds in Table 2(a) have volatilities at 25°C which exceed, sometimes by an enormous factor, their threshold limit values. Accordingly, a sniff, from the headspace of a bottle or drum, or from a confined space containing a spill, of almost any of these substances, inevitably exceeds the TLV. The safe dilution factor in column 5 indicates the minimum number of volumes of uncontaminated air that would be required to dilute, to the safe level, one volume of air that has been saturated by exposure to the named compound (assuming perfect mixing). Plant location, layout, ventilation, chimneys and emergency procedures should be designed with the realization of the safe dilution factor in mind, at least for compounds for which dilution ventilation is an allowable method of control. Any increase in temperature of the chemical above 25°C increases the required safe dilution factor, in proportion to the vapor pressure.

A majority of these compounds are not completely miscible with water. Nevertheless, a saturated solution of any volatile compound is theoretically capable of saturating the headspace to the same concentration as the pure compound could achieve. Whether or not it will do so in a finite time depends upon the water-air distribution ratio, the relative volumes of air and water, and the degree of agitation. To err on the safe side, it would be prudent to use the same safe dilution factor in calculating the number of volumes of clean water which would be needed to dilute one volume of a saturated aqueous solution of the compound before discharge to a sewer, lagoon or river, where this is permitted.

Odor safety factors as chemical safeguards

When the threshold limit value is substantially higher than the odor threshold, the intrinsic odor of the compound usually, but not invariably, provides an indication of its presence, at a concentration level low enough that no harm is likely to the human observer. Conversely, if the odor threshold is much higher than the TLV, then anybody detecting the odor of the compound has a warning that a safe vapor concentration has already been exceeded. The exposed worker would be well advised to request a professional evaluation and perhaps instrumental assessment of the situation. It should be determined whether the applicable TLV criterion (time-weighted average, short-term exposure limit or ceiling value)¹ is likely to be exceeded in the particular working regime, and if so, what the health significance may be.

The potential warning power of a given chemical is conveniently expressed by the odor safety factor (column 6 of Table 2(a)), which is simply the TLV divided by the odor threshold. Any chemical with an odor safety factor less than 1.0 carries the risk that hazardous concentrations will not be detected by odor. Conversely, an odor safety factor greater than 1.0 bears the promise that a hazardous concentration could be perceived by sniff. Nevertheless, the question of whether or not a hazardous concentra-

tion will actually be smelt, is quite complex, and depends upon a variety of circumstances. (A very few people, roughly 1 in 500, have no true sense of smell at all;¹² the existence of anosmic persons, while of some practical importance, is omitted from our discussion.)

The average odor threshold has not been sufficiently rigorously evaluated for all these compounds, many of which possess measured or implied standard errors as large as seven-fold. This is not, in principle, an insurmountable problem, because 63 compounds in Table 2(a), column 4, already have thresholds evaluated with standard errors less than two-fold. Equal, or better, accuracy could readily be attained by new experimental measurements on the deficient compounds.

The ability of members of the population to detect a given odor is strongly influenced by the innate variability of different persons' olfactory powers, their prior experience with that odor, and by the degree of attention they accord to the matter. The thresholds listed in column 3 of Table 2(a) represent the most favorable conditions for testing. The subjects were well aware that these were tests of their sense of smell, they were attentive and they were trying their best to detect the presence of the odor. Even so, the odor-detecting ability of different people varies over quite a wide range. The compilation of individual sensitivities to a given compound typically yields a Gaussian or bell-shaped curve,¹⁷ provided that a logarithmic concentration scale is employed. For this normal distribution, the standard deviation is a measure of the spread of odor sensitivity in the population. We have evaluated this standard deviation with seven odorants: isobutyl isobutyrate, isovaleric acid, 1-pyrroline, trimethylamine, isobutyraldehyde, androst-16-en-3-one and pentalactone, each tested with 18-443 normal observers. The average standard deviation was ± 1.97 binary steps, which may be rounded off at two binary steps.¹⁸ The standard deviation indicates that 68% of people tested, on the average, will have a personal threshold that lies within the range from one-fourth of the mean, to four times the mean, threshold of the population.

The effect of distracted attention

In connection with testing the efficacy of certain odorants as warning agents for fuel gas, Whisman *et al.*¹⁹ conducted a thorough study of the influence of various degrees of distraction on the responsiveness of people to these well-known warning odors. Their 'directed' test corresponds with usual laboratory conditions, in which the attention of the subject is purposely focused on the sole objective of detecting an odor. In the 'semi-directed' test, the subjects were asked to report on visual, tactile, aural and nasal stimuli in the test room. In the 'undirected' test, the subjects were given no indication of the object of the exercise. In the 'misdirected' test, the attention of the participants was deliberately distracted by asking each to try to read some print in a dim light and to judge the temperature of the room. All except the directed tests were performed with inexperienced subjects recruited by a mobile laboratory arriving unannounced at shopping centers, and each volunteer was used for one test only at one odorant concentration.

Whisman *et al.* found that the responsiveness of the subjects to a given concentration of odorant was sub-

stantially decreased in the semidirected, undirected and misdirected tests, compared with their performance in the directed test mode. The misdirected test was probably the most difficult set of conditions imposed upon the subjects. In our opinion, the misdirected test is the most appropriate of the available models for evaluating the effects of conditions encountered in industrial practice. A factory worker would not be familiar with odor-threshold testing techniques, but would hopefully be aware that chemical vapors may be hazardous, and might know that a distinct smell indicates the presence of appreciable vapor in the air. On the other hand, the worker is likely to be concentrating on following instructions, reading charts, controlling equipment and generally trying to get the work done. Such a degree of mental distraction, as Whisman *et al.* showed, is ample to divert attention away from any but the most obvious of odors.

In Fig. 1, the results of Whisman *et al.*¹⁹ for their directed and misdirected test modes are presented in log/probit coordinates, which have the advantage of exhibiting an approximately linear relationship between olfactory stimulus and response. Each data point in the directed tests was obtained from 22 subjects, and in the misdirected tests from over 100 subjects. The data points were fitted by a logarithmic transformation linear regression, from which the slope and 50% response intercept were obtained. The directed test threshold for ethyl mercaptan, at which 50% of the subjects would respond, was found by extrapolation to be 0.17 ppb. In the misdirected test situation, however, the 50% response threshold was at 4.8 ppb, or 28 times higher. Furthermore, the slope of the regression line is shallower, so that disproportionately higher concentrations are required to elicit a response from 90% of the participants. The results for thiophane (tetrahydrothiophene) are virtually superimposable upon those for ethyl mercaptan, except that about double the concentration of odorant is needed to achieve a given level of response. That is, 0.35 ppb for detection threshold and 8.7 ppb for misdirected threshold, or 24 times higher.

The good agreement between the results for ethyl mercaptan and for thiophane encourages us to generalize the data, so as to provide a practical guide for interpreting threshold ratios and odor safety factors (Fig. 2). This graph is set in log/probit coordinates. Since neither the logarithmic nor the probit scales go to zero, the origin of the graph is considered to be the intersection of threshold multiple 1.0 on the x axis, with 50% persons responding on the y axis. This, by definition, is the average detection threshold, measured under laboratory conditions, i.e. a directed test. The logarithmic binary step concentration scale and the standard deviation intervals are also entered in Fig. 2. It was previously demonstrated¹⁸ that the sensitivities of people to various odorants exhibit standard deviations close to 2.0 binary steps. Hence, the detection line in Fig. 2 is based on this generalization, and constructed by drawing a line with a slope of 2.0 binary steps per standard deviation unit, through the origin of the graph. The detection line is shown as a broken line above 95% response, because there are some indications that a small percentage of the population has specific anosmias to one or more of the sulfurous odorants.¹⁷ Such persons, while they may perceive most other odors normally, are found to have an innate lower sensitivity or 'odor blindness' to the typical gas odorants.

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The warning line in Fig. 2 is based on the average of the misdirected data for both ethyl mercaptan and thiophane. It was constructed as follows. The results for ethyl mercaptan and for thiophane (Fig. 1) showed that the ratios of the 50%-detection thresholds in the misdirected and directed test protocols were 23.1 and 24.5, respectively. Their geometric mean is 26.3, which was rounded off to 26 for the threshold multiple. In Fig. 2, the warning line is drawn to intersect the 50% response level at the threshold multiple value of 26-fold. The slope of the warning line was likewise determined by averaging the slopes of the regression lines for the misdirected tests in Fig. 1. The averaged warning line has a slope of 3.5 binary steps per standard deviation unit.

Therefore, in order to be perceived by 50% of distracted subjects, the concentration of gas odorant had to be raised to 26 times the concentration that could be detected by 50% of attentive subjects in laboratory test conditions. This illustration lends emphasis to the compelling conclusion of Whisman *et al.*¹⁹ that there is a substantial difference between the level of odorant that can be detected, and the level that will be detected, in a given set of circumstances. The available data do not permit extrapolation of the warning line in Fig. 2 below the 50% response level.

Odor safety classification of chemicals

Figure 2 represents a provisional synthesis of the best available data. The slope of the detection line appears quite soundly established, and to be applicable to many chemicals. For those uncommon chemicals that exhibit a pronounced and frequently occurring specific anosmia among members of the population,²⁴ the curve is expected to flatten at higher response percentages. The slope and intercept of the warning line, however, are based on only two, quite closely related, fuel gas odorants. Intuitively, we feel that the results for ethyl mercaptan and thiophane represent a relatively favorable case, because, thanks to the public awareness developed by the suppliers of household and bottled gas, it is a widely known fact that the 'smell of gas' is an indication of danger. In other words, gas odorants may have a better chance of penetrating the consciousness of a distracted person than many other odors that are not mentally associated with harmful consequences.

Until more data become available, we propose that the relationships in Fig. 2 can be used to set up a provisional classification of the 214 chemicals, according to the level of safety indicated by their odors. For this purpose, we are adopting the 10%, 50% and 90% response levels as practical guides. According to Fig. 2, the obvious benchmarks are the detection threshold at which 50% of people can perceive the odor, and the higher warning threshold at which 50% of people will notice the odor even when they are distracted. Secondary criteria are provided by the concentrations at which 10% of attentive people can detect the odor, and the other extreme where 90% of distracted people get a warning of the odor. These four borderlines are indicated by vertical lines in Fig. 2.

Our tentative odor safety classification is presented in Table 3. At their threshold limit value concentration, class A compounds will be perceived by 90% of distracted persons. To achieve this rating, the odor safety factor must be at least 550; i.e. the threshold limit value for the compound is more than 550 times higher than its odor

threshold. At the other extreme, class E compounds at their TLV concentration can be detected by less than 10% of attentive persons. In this category, the odor safety factor is below 0.18. The quantitative ranges for the intermediate B, C and D classifications are as indicated in Table 3. The zones of odor safety factor for the five classes are also labeled on Fig. 2. The odor safety class of each of the 214 compounds, for which adequate data are available, are entered in column 7 of Table 2(a). Class A compounds provide the strongest odorous warning of their presence at the TLV level, whereas class E compounds are practically undetectable by odor at their TLV concentration.

The effect of sleeping

Although it is not considered relevant to most workplace situations, the power of an odorant to waken a sleeping person is significant where industrial products can escape into a residential area. This is an obvious risk with household gas, and the question was included in a study by Fieldner *et al.*²⁰ Their data for several odorants are displayed in log₁₀/probit coordinates in Fig. 3. They tested three compounds (ethyl mercaptan, phenyl ether and isoamyl acetate) which can be regarded as more or less purely olfactory stimulants, i.e. they have little or no irritating power for the trigeminal nerve. Each data point in Fig. 3 was calculated from the results of tests with three to eight sleepers. The points were then fitted by linear regression. The performances of these three odorants seem fairly concordant, and imply that an odorant concentration about 20000 times the normal detection threshold is required to awaken 50% of soundly sleeping persons. That is more than 700 times stronger a stimulus than suffices to serve as a warning for wakeful, but misdirected, observers (Fig. 2). If this result were applicable to all odorants, it would mean that virtually none of the 214 compounds examined in Table 2(a) would awaken the average person, without exceeding the TLV.

There is, however, a complicating factor. Some odorants, besides stimulating the olfactory nerve, also irritate the trigeminal nerve. Two examples are included on the left side of Fig. 3. These substances were far more effective in waking the sleepers. A 50% response was obtained at 27 times the odor threshold of crotonaldehyde, and at only three times the odor threshold of allyl alcohol. From the comments of those that woke up, it is obvious that the irritation was the determining factor. It is an interesting observation that the trigeminal nerve has some sort of a 'hot line' directly into the subconscious, that is denied to the olfactory nerve.

Some data on irritant thresholds

Trained normal observers can report distinct concentration levels at which a vapor produces nasal or eye irritation, quite apart from its odor. Katz and Talbert²¹ tabulated considerable data, from which we have selected those compounds that are on the ACGIH list (Table 4). We have also added a few compounds from our own work, in which nasal irritation thresholds were obtained from an anosmic person lacking the ability to perceive true odors as opposed to irritants. The ratio of the irritation and odor

thresholds for these compounds ranges from 33 000 for acetaldehyde, to less than unity for *o*-chloroacetophenone. Where this ratio is relatively small, it seems very likely that irritation would become an important factor in determining the intercept and slope of the warning line in Fig. 2.

If irritation of the trigeminal nerve can wake a sleeping person so effectively, it seems very likely also to be able to preempt the attention of a distracted person. No quantitative treatment of this factor is possible at present, because irritant thresholds are available for so few of the compounds on the TLV list, and no tests have been reported on perception of irritants by distracted persons. It may, however, be worth noting the irritation hazard factor in column 5 of Table 4. These figures indicate the degree to which the TLV is being exceeded, if there is appreciable eye or nose irritation for an attentive subject.

Threshold in water dilution

Many of the odor thresholds found in our literature survey had been measured by sniff-tests from the head-space above aqueous dilutions. Theoretically, the air-dilution threshold and the water-dilution threshold are simply related by the air-water partition coefficient of the odorant, provided the concentrations are measured in equivalent weight per volume units. This expectation has been borne out in comparisons made for *n*-butyl alcohol, pyridine and isovaleric acid,¹⁴ and has been further supported by the data for many compounds listed in Table 2(b). For example, the data for *n*-butyl alcohol in Table 1 exhibit, for the reported olfactory thresholds, more than a 1000-fold range, yet the group means of the 20 air thresholds and the nine water thresholds differ by a factor of only about three-fold, and this is not considered significant ($P > 0.1$). Odor thresholds measured in air and water dilutions are generally concordant, unless the water-air distribution ratio is less than approximately ten. In that case, the reported water-dilution threshold concentration is liable to be too high, due to substantial evaporative loss of odorant from the solution during the course of conducting the odor threshold tests.

The air-dilution thresholds in column 3 of Table 2(a) are based on a pool of all available data from both air- and water-dilution measurements, omitting water thresholds for compounds with unfavorable water-air distribution ratios. The water dilution thresholds in column 10 of Table 2(b) were generally calculated from the data in column 3 of Table 2(a), by applying the water-air distribution ratio. In this way, we have been able to calculate water-dilution thresholds for many compounds for which only air-dilution threshold data were previously available. By applying the same distribution ratio, the water equivalent concentrations were also calculated for the TLV, and are listed in column 8 of Table 2(b). With odorants that are ionizable (acids and bases), these calculations are strictly valid only within specified pH limits, as explained in the Methods section.

We felt that it would be informative to provide the theoretical water threshold and TLV data, even for compounds with distribution ratios of less than ten. The equilibrium air concentration can develop and persist in conditions of high liquid-vapor volume ratio and low vapor loss, such as a closed vessel or a sewer. TLV and threshold data for odorants with distribution ratios less than ten are in parentheses in Table 2(b). This is to indicate that

those solutions lack enough persistence to serve as reliable standards in settling up water dilution sniff-tests for training or testing personnel.

CONCLUSION

The interpretation of these data in any particular safety or pollution problem will depend markedly on the individual circumstances. The threshold data in the Tables and Figures are based on averages for samples of the population, presumably in good health. Individuals can differ quite markedly from the population average in their smell sensitivity, due to any of a variety of innate, chronic or acute physiological conditions.^{23,24,25} Likewise, the time-weighted average threshold limit values are for workers, who by the mere fact of being able to work evidently represent a generally healthy segment of the population.

Continuing exposure to an odor usually results in a gradual diminution or even disappearance of the smell sensation. This phenomenon is known as olfactory adaptation or smell fatigue.²⁶ If the adaptation has not been too severe or too prolonged, sensitivity can often be restored by stepping aside for a few moments to an uncontaminated atmosphere, if available. Unfortunately, workers chronically exposed to a strong odor can develop a desensitization which persists up to two weeks or more after their departure from the contaminated atmosphere. In such cases, it should be the responsibility of supervisors and inspectors to note the odor and take appropriate action.

Hydrogen sulfide and perhaps other dangerous gases can very quickly lose their characteristic odor at high concentrations. At levels of H_2S above 100 ppm (over 10 000 times the average detection threshold), the sense of smell is rapidly abolished, so that potentially lethal concentrations may not be detected by odor at all.²¹ Certain commercial diffusible odor masking or suppressing agents may reduce the perceptibility of odors, without removing the chemical source. The use of such agents might interfere with the capability of the nose to provide a warning at the expected concentration level.

There are many potential applications of these data in chemical safety and in air- and water-pollution control, some of which have been mentioned previously. In addition, we believe that the data might find some less apparent uses: Table 2 is also a guide to what data are in the literature on odor thresholds, on TLV-listed substances, is unavailable, unconfirmed or erratic. Readily prepared water dilutions could be used to test the individual smell thresholds of workers to the chemicals they handle. A water TLV dilution of an odorant could be prepared to demonstrate quickly to workers the practical experience of its TLV concentration. The general experimental procedures for preparing and testing aqueous solutions of odorants have been described.²² These concepts could improve the reliability of odor breakthrough as an indication of when to change the organic vapor cartridge in a respirator. The feasibility might be considered of using class A or B compounds as warning odorants to be added to class D or E substances, or to pesticides. The water-air distribution ratios could also be a guide to the possible success of water-scrubbing as a means of removing vapors from effluent gases.

The TLVs used in Table 2 and discussed in this paper are those recommended by the ACGIH in its 1982 listing.¹ The values are re-published annually, and are subject to revision, usually with two years notice of intended changes. The US Government Occupational Safety and Health Administration (OSHA) and many State Administrations have established their own lists of permitted exposures. While the values adopted are often based on the ACGIH recommendations, they may not coincide with current ACGIH TLVs, and quite different standards may be set for certain compounds. Some foreign governments issue guidelines with independently derived limits. If the applicable exposure limit for a particular compound is different from the TLV cited in Table 2, column 1, it will be necessary to adjust the values in columns 5, 6 and 8 by the appropriate ratio, and perhaps reassign the odor safety class (column 7). Values in Table 4, column 5 may also have to be altered.

Every chemical that can be detected by smell exhibits a property that can be turned to advantage as an aid in maintaining safe operating conditions. It must be recognized that background odors, odor fatigue, preoccupation and individual insensitivity may combine to reduce the margin, if any, between odor detection and safe operating conditions. No odor safety factor is large enough to justify condoning the presence of a fleeting odor, let alone a persistent stench, unless professional assurance has been obtained that the working conditions are safe.

The first detectable odor should be a sure signal that something abnormal has happened somewhere. It may be the

last warning. During chemical operations, when an odor is detected, the source should be located and the concentration determined. Then effective steps can be taken to prevent the escape of vapor, and restore a neutral and healthful odor background. Even in the unnatural environment of the industrial workplace, our sense of smell has much to offer as a natural safety warning system.

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DOW INDUSTRIAL HYGIENE GUIDES (IHGs)

COMPLETE CURRENT LISTING**

M. G. Swank

October, 1986

For your info.

Bill Lafford

I. CHEMICAL AGENTS

Material	IHG	Date
Acetone cyanohydrin	1 ppm Ceiling-Skin	1980
Acetylene tetrabromide	see 1,1,2,2-tetrabromoethane	
N-Acetyl-p-aminophenol	10 mg	1976
Acrylamide	0.03 mg-Skin	1984
Acrylic acid	2 ppm-Skin	1980
Acrylonitrile	1 ppm-Skin; 10 ppm Excursion	1981
Alka cellulose	2 mg. as NaOH	1975
Amablast Yellow-Indandione	0.05 mg	1975
Amablast Yellow PFL	0.05 mg	1975
Aminoethyl ethanolamine	2 mg-Skin	1980
Amtrone	0.1 mg	1976
Ammonium bromide	10 mg	1980
Ammonium persulfate	5 mg	1976
Amoxycillin	2 mg	1980
Ampicillin	2 mg	1982
Aspirin	10 mg	1976
Atrazine	3 mg	1977
Benzene	10 ppm Ceiling	1977
BIPPE (Biphenyl phenyl ether)	10 mg	1975
3,3-Bis(bromomethyl)oxetane	1 mg	1976
Bis (2-chloroethyl) ether	0.5 ppm	1977
Bis (2-chloroisopropyl) ether	use WEEL	
Bisphenol A	5 mg	1976
Brine	10 mg	1975
Bromochloromethane	15 ppm	1976
Bromophos	10 mg	1978
1,3-Butadiene	50 ppm, 200 ppm Excursion	1982
4-tert-Butylcatechol	5 ppm-Skin	1980
Butylene oxide	40 ppm, 100 ppm Excursion	1980
**n-Butylisocyanate	0.02 ppm-Skin	1986
tert-Butyl perbenzoate	0.1 ppm	1975
p-tert-Butylphenol	2 mg	1975
Butyl stearate	150 ppm	1980
p-tert-Butylstyrene	10 ppm	1978
Cab-O-Sil	1 mg respirable	1976

NOTESUnits given as "mg" = mg/m³.

**Indicates changes or new additions since last list.

Glossary of terms is on last page of this list.

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Material	IHG	Date
Calcium bromide	10 mg	1980
Calcium chloride (32% brine)	10 mg	1975
Calcium stearate	10 mg	1975
Calco alzarine cyanine	0.05 mg	1975
Calco Chinoline Yellow ZSD	0.05 mg	1975
Calco Red (4775)	0.05 mg	1975
Calco Red ZIR (5020)	0.05 mg	1975
Catechol	5 mg-Skin	1979
**Chloramphenicol (and esters)	use WEEL	
Chloroacetyl chloride	10 ppb-Skin, 50 ppb Excursion	1981
1-(3-Chloroallyl)-3,5,7,-triazol-1- azonadadamantone chloride	1 mg	1977
Chloromethyl methyl ether	0.1 ppm	1976
p-Chloro-p-cresol	1 ppm	1976
o-Chlorophenol	0.2 ppm	1975
p-Chlorophenol	1 ppm	1975
Chlorophenylphenol	see DOWICIDE* 32	
1-Chloro-2-propanol	see Propylene chlorohydrin	
2-Chloropropionic acid	1 ppm	1977
**Chlorosulfonic acid	use WEEL	
Chlorpheniramine maleate	0.1 mg	1981
Citric acid	10 mg	1975
Cobalt chloride	0.1 mg as Co	1975
Cyanogen bromide	0.3 ppm Ceiling, Skin	1984
Cyanuric chloride	0.03 mg	1976
Daabon	see Dowpon	
Dearborn 922 inhibitor	1 mg	1975
Decabromodiphenyl ether	use WEEL	
Dibromacetoneitrile	0.1 ppm Ceiling, Skin	1984
1,2-Dibromo-3-chloropropane	0.1 ppm-Skin	1976
Dibromomethane	see Methylene bromide	
Dibromoneopentyl glycol	7 mg	1978
Dibromonitrilopropionamide	2 mg Ceiling	1979
Dichloroacetic acid	400 ppb-Skin	1977
1,1-dichloro-2,2-difluoroethylene	see Freon 1112-A	

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Material	IHG	Date
2,4-Dichlorophenol	1 ppm	1975
3,6-Dichloropicolinic acid	10 mg	1979
2,3-Dichloropropene	1 ppm-Skin	1980
2,2-Dichloropropionic acid, sodium salt	see Dowpon	
Dielectric Fluid C4	10 mg	1976
2-(Diethylamino)ethanol	10 ppm	1975
Diethylbenzene, mixed isomers	10 ppm	1977
Diethyl disulfide	1 ppm	1979
Diethylene glycol butyl ether	35 ppm	1982
Diethylene glycol ethyl ether	30 ppm	1982
Diethylene glycol methyl ether	30 ppm	1982
Diethyl phosphorochloridothioate (DEPCT)	0.1 ppm-Skin	1977
1,1-difluoroethane	see Freon 152-A	
1,2-difluorotetrachloroethane	see Freon 112-A	
Diisopropylbenzene, meta, para isomers	10 ppm	1977
Dimethyl disulfide	3 ppm	1979
**Dimethyl ether	use WEEL	
Dimethyl phosphorochloridothioate (DMPCT)	0.1 ppm-Skin	1977
Dimethyl sulfide	10 ppm	1976
Dinitro-o-sec-butylphenol	0.3 mg-Skin	1980
Dioctyl adipate V9	see V9 DOA	
2,6-Di-tert-butyl-p-cresol	see Iono	
2,4-Di(sec-butyl)phenol	5 mg	1975
2,4-Di(tert-butyl)phenol	5 mg	1975
2,6-Di(tert-butyl)phenol	5 mg	1975
2,4-Di(tert-butyl)phenol, sodium salt	5 mg	1975
Diphenyl sulfide	1 ppm	1977
Distearyl thiodipropionate	10 mg	1975
DOWANOL® DB	see Diethylene glycol butyl ether	
DOWANOL DE	see Diethylene glycol ethyl ether	
DOWANOL DM	see Diethylene glycol methyl ether	
DOWANOL EE	see Ethylene glycol monoethyl ether	
DOWANOL EM	see Ethylene glycol monomethyl ether	
DOWANOL EPh	see Ethylene glycol phenyl ether	
DOWCO® 290	see 3,6-Dichloropicolinic acid	

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Material	IHG	Date
DOWCO* 356	1 ppm	1979
Dow Corning Fluid 550	10 mg	1976
DOWFAX* 2A1 surfactant	5 mg, as active ingredient	1976
Dowlake calcium chloride (77%, solid)	10 mg	1975
DOWICIDE* 1	see o-phenylphenol	
DOWICIDE A	5 mg	1975
DOWICIDE 32	1 ppm	1976
DOWICIL* 75, 100 and 200	see Chloralyltriazazoneadamantone chloride	
DOWPON*	3 mg	1976
DOWTHERM* G	use TLV for phenyl ether	
DOWTHERM J	see Diethylbenzene	
DOWTHERM SR-1	use TLV for ethylene glycol	
**Erythromycin	use WEEL	
ETHOCEL*	10 mg	1975
Ethoprophos	0.01 ppm-Skin	1978
Ethyl chloroacetate	100 ppb-Skin	1977
Ethylene dibromide	0.5 ppm-Skin	1980
Ethylene glycol monoethyl ether	5 ppm-Skin, 10 ppm Excursion	1981
Ethylene glycol monomethyl ether	3 ppm-Skin, 6 ppm Excursion	1981
Ethylene glycol phenyl ether	25 ppm-Skin	1984
2-Ethyl hexyl acrylate	25 ppm	1976
2-Ethyl-2-oxazoline	3 ppm	1976
Ethyltoluene (meta, para isomers)	10 ppm	1977
FR65*	see pentabromochlorocyclohexane	
FR1138	see dibromoneopentyl glycol	
Freon 112-A	50 ppm	1975
Freon 152-A	500 ppm	1975
Freon 1112-A	50 ppm	1975
Freon E-65	1000 ppm	1975
Fumaric acid	10 mg	1976
GARLON*	see Trichloro-2-pyridyloxyacetic acid	
Gasoline	use TLV	
Glyoxal	2 ppm	1975
**Haloxypol ethoxyethyl	0.05 mg-Skin	1986
**Haloxypol methyl	0.05 mg-Skin	1986

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Material	IHG	Date
Hansa Yellow 4R (4421)	0.05 mg	1975
Hexachlorobenzene	150 ppb in the blood (Biological Limit Guide)	1978
Hexadiene	use WEEL	
Hydrogen iodide	3 ppm	1976
p-Hydroxybenzaldehyde	10 mg	1975
2-Hydroxyethyl acrylate	1 ppm-Skin	1976
Hydroxyethyl cellulose	10 mg	1975
Hydroxyethyl methyl cellulose	10 mg	1975
Hydroxypropyl cellulose	10 mg	1975
Hydroxypropyl methyl cellulose	10 mg	1975
Ionol	10 mg	1975
Irganox 1010	10 mg	1975
Irganox 1076	10 mg	1980
Iron	10 mg	1975
Isobutane	600 ppm	1978
Isobutylene	see Methylpropene	
2-Isocyanatoethyl methacrylate	25 ppb Ceiling-Skin	1978
Isoniazid	1 mg	1980
2-Isopropenyl-2-oxazoline	0.1 ppm-Skin	1979
Isopropyl chloroformate	0.1 ppm-Skin	1978
Kerosene	10 mg	1979
LONTREL*	see 3,6-Dichloropicolinic acid	
Magnesium hydroxide	10 mg	1975
Methacrylic acid	20 ppm-Skin	1976
METHOCEL*	10 mg	1975
Methoxyflurane	10 ppm	1975
Methyl biphenyl	0.2 ppm	1980
Methyl chloride	25 ppm, 75 ppm Excursion	1984
Methyl chloroacetate	100 ppb-Skin	1977
2-Methyl-4-chlorophenoxyacetic acid	5 mg	1976
Methyl chlorpyrifos	see RELDAN*	
Methylene bisacrylamide	3 mg	1976
Methylene bromide	15 ppm	1980
2-Methylpropene	1000 ppm	1975
Metoclopramide	0.3 mg	1980

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Material	IHG	Date
Monochloroacetic acid	use WEEL	
Monoethyl phosphorodichloridithioate (MEPCT)	0.1 ppm-Skin	1977
Naphtha	350 mg-Vapor, 10 mg-Aerosol	1979
p-Nitrobenzaldehyde	3 mg	1981
o-Nitrophenol	1 mg	1977
p-Nitrophenyl serine racemic methyl ester threo	10 mg	1981
1-Nitroso-4-methyl piperazine	2 ppm	1978
Nopcowax 22-DS	10 mg	1975
Nopcowax DS-101	10 mg	1975
Novobion	3 mg	1980
Paraplex G-62	10 mg	1975
**Pentabromocyclohexane	3 mg	1986
Pentachlorobenzene	0.1 ppm	1976
Pentachlorobenzene	7 mg	1977
Petrolatum	5 mg	1975
Phenate brine	5 ppm	1975
Phenylephrine hydrochloride	0.5 mg	1981
o-Phenyphenol	5 mg	1977
p-Phenyphenol	5 mg	1977
o-Phenyphenol sodium salt	see DOWICIDE A	
Phenylpropanediamine hydrochloride	1 mg	1981
Phenyl salicylate	10 mg	1975
Phthalocyanine Blue #4783	0.05 mg	1975
Phthalylsulphathiazole	10 mg	1980
Thiophen-Picoline	use WEEL	
Polyacrylamide	10 mg	1976
Polyglycols	use WEEL	
Polystyrene latex, Dry 949	10 mg	1975
Polyvinyl alcohol	10 mg	1979
Potassium bromate	use WEEL	
Potassium bromide	10 mg	1980
Potassium carbonate	10 mg	1975
Potassium chloride	10 mg	1975
Potassium iodate	5 mg	1975
Potassium iodide	5 mg	1975

Material	IHG	Date
Potassium persulfate	5 mg	1976
Potassium sulfate	10 mg	1975
Probucol	10 mg	1979
Propachlor	0.5 mg	1980
Propionaldehyde	5 ppm	1978
d-Propoxyphene hydrochloride	1 mg	1978
Propylene chlorohydrin	3 ppm Ceiling-Skin	1979
**Propylene glycol	use WEEL	
Propylene oxide	20 ppm; 100 ppm Excursion	1980
RELDAN (Methyl chlorpyrifos)	0.1 mg-Skin	1976
Rifampicin	2 mg	1977
Rifampicin SV	5 mg	1977
Saccharin, sodium salt	10 mg	1981
Salicylaldehyde	5 mg	1975
Salicylic acid	2 mg	1975
Salol	see phenyl salicylate	
Santonox	10 mg	1975
Sodium acetate	10 mg	1975
Sodium bicarbonate	10 mg	1975
Sodium borohydride	2 mg	1978
Sodium bromate	5 mg	1980
Sodium bromide	10 mg	1980
Sodium carbonate	10 mg	1976
Sodium chloride	10 mg	1975
Sodium chlorite	0.5 mg	1976
Sodium hexametaphosphate	10 mg	1980
Sodium hydrosulfide	3 mg	1976
Sodium monochloroacetate	1 mg	1977
Sodium persulfate	5 mg	1976
Sodium phenate	5 ppm	1975
Sodium polyacrylate	3 mg	1976
Sodium sulfate	10 mg	1975
Sodium thiosulfate	10 mg	1976
Sodium trichloroacetate	1 mg-Skin	1976
Stearic acid	10 mg	1975

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Material	IHG	Date
Streptomycin	1 mg	1977
Styrene dimers and trimers	100 ppm	1975
Sulfadimethoxine	2 mg	1980
Sulfolane	4 ppm	1981
Terfenadine	1 mg	1984
Tetrabromobisphenol A	5 mg	1976
**1,1,2,2-Tetrabromoethane	0.1 ppm	1978
2,3,7,8-Tetrachlorodibenzo-p-dioxin	0.01ug	1975
1,2,3,4-Tetrachlorobenzene	0.4 ppm	1977
1,2,4,5-Tetrachlorobenzene	0.4 ppm	1977
1,1,2,2-Tetrachloroethane	0.1 ppm-Skin	1977
3,4,5,6-Tetrachloropicolinic acid	2 mg-Skin	1979
2,3,5,6-Tetrachloropyridine	2 mg	1977
Tetracycline	1 mg	1976
Thiophosphoryl chloride	0.1 ppm	1976
Thiourea	0.1 mg-Skin	1980
Tinuvin P	10 mg	1975
Titanium tetraiodide	0.1 ppm, as iodine	1975
Toluene diisocyanate	0.02 ppm, Ceiling	1984
Topanol CA	10 mg	1975
Tribromoneopentyl alcohol	5 mg	1976
Trichlopyr	see Trichloro-pyridoxyacetic acid	
2,4,5-Trichloroanisole	10 mg	1975
2,4,5-Trichlorophenol	1 ppm	1976
2,4,6-Trichlorophenol, sodium salt	5 mg	1975
3,5,6-Trichloro-2-pyridinol	7 mg	1977
**Trichloropropane	1 ppm-Skin	1986
1,2,3-Trichloropropene	1 ppm-Skin	1978
3,5,6-Trichloro-2-pyridinol, sodium salt	7 mg	1977
3,5,6-Trichloro-2-pyridyl dimethyl phosphate	1 mg-Skin	1977
3,5,6-Trichloro-2-pyridyloxyacetic acid	10 mg	1981
3,5,6-Trichloro-2-pyridyloxyacetic acid, DOWANOL EB ester	10 mg, as acid equivalent	1981
3,5,6-Trichloro-2-pyridyloxyacetic acid, methyl ester	10 mg, as acid equivalent	1981
3,5,6-Trichloro-2-pyridyloxyacetic acid, triethylamine salt	10 mg, as acid equivalent	1981
Trichlorphon	10 mg	1976

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Material	IHG	Date
Trisodium phosphate	use WEEL	
Ultramarine Blue (5045)	10 mg	1975
V9/DOA (Diethyl adipate V9)	500 ppm	1975
Vinyl benzyl chloride	0.5 ppm Ceiling. Skin	1984
Vitamin C	10 mg	1976
VORANOL* CP700	10 mg	1975
Z-6	1 mg	1977
Z-11 methyl ester	1 ppm	1977
Z-200	0.5 ppm	1977
Zinc bromide	5 mg	1980
Zinc sulfide diffuser 2693	10 mg	1975

II. PHYSICAL AGENTS

Noise

Hearing conservation (8-hr day):
85 dBA with 5 dB exchange rate.

Engineering controls (8-hr day):
90 dBA with 5 dB exchange rate.

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GLOSSARY

- Ceiling - This concentration should not be exceeded, even for brief periods.
- Excursion - Excursion guides, as opposed to ceilings, are not intended as absolute limits in either concentration or time. They indicate that sustained exposures at or above the guide number are not appropriate. Excursion exposures should last minutes, not hours, but do not need to be arbitrarily limited to any specific time period. Likewise, the concentration at any given time might exceed the guideline by a moderate amount, but should average out to the excursion guide level over the period of the excursion. The longer the excursion, the more important it is for the average level during the excursion to be at or below the guideline. Excursions should not follow quickly one after another and the shift-length time-weighted average (TWA) should not be exceeded. This definition does not preclude decisions to arbitrarily set definite time limits or more conservative concentration limits in particular plant situations.
- IHG - The Industrial Hygiene Guide (IHG) is the internal Dow guideline for 8-hour TWA exposures to airborne concentrations of materials. These guidelines were prepared by industrial hygienists in cooperation with toxicology, medical, production and product department representatives and were approved by the Dow Industrial Health Board.
- Skin - This material may be absorbed through the skin in amounts sufficient to cause toxic effects. Although the IHG is for inhalation exposures, skin contact with this material can contribute to the overall exposure and invalidate the TWA exposure evaluations. It is recommended that skin contact be avoided.
- TLVs and
WEEL Guides - The exposure guidelines established by the ACGIH (TLVs) or the AIHA (WEELs) are used by Dow unless a lower Dow IHG already exists or a new, higher IHG is adopted. Therefore, some IHGs have been replaced by TLVs or WEELs. Those IHGs which will no longer be used are indicated in this list and will be dropped from future lists.

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MS/maf

DO A 039816
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WORKPLACE

ENVIRONMENTAL

EXPOSURE

LEVEL

GUIDE

AMERICAN
INDUSTRIAL
HYGIENE
ASSOCIATION

AIHA WEEL® GUIDES - 1986

Agent	8-Hr TWA	Short-Term TWA
Benzaldehyde	2 ppm	4 ppm, 15 min
Bis-(2-chloroisopropyl) ether	3 ppm	—
Chloramphenicol	0.5 mg/m ³	—
Chlorosulfonic acid	0.3 ppm	—
Chlorotrifluoroethylene	5 ppm	—
Decabromodiphenyl oxide	5 mg/m ³	—
Diethylene glycol	50 ppm, total 10 mg/m ³ aerosol only	—
Diisobutylene	600 ppm	—
Dimethyl ether	500 ppm	—
Dimethyl terephthalate	10 mg/m ³ , total 5 mg/m ³ , respirable	—
Erythromycin	3 mg/m ³	—
Hexadiene	100 ppm	—
Hexanediol diacrylate	1 mg/m ³	—
Lithium hydroxide	—	1 mg/m ³ , 1 min
Lithium oxide	—	1 mg/m ³ , 1 min
3-Methoxypropylamine	10 ppm	20 ppm, 15 min
Monochloroacetic acid	0.3 ppm, Skin	1 ppm, 15 min
1-Octanol	50 ppm	—
Pentaerythritol triacrylate	1 mg/m ³	—
Picoline	2 ppm, Skin	5 ppm
Piperidine	1 ppm	—
Polyethylene glycols	10 mg/m ³	—
Polypropylene glycols	10 mg/m ³	—
Potassium bromate	0.1 mg/m ³	—
Propylene glycol	50 ppm, total 10 mg/m ³ , aerosol only	—
Quinoline	0.1 ppm, Skin	—
Tetraethyleneglycol diacrylate	1 mg/m ³	—
p-Toluene sulfonyl chloride	—	5 mg/m ³ , 15 min
Trimethyleneglycol diacrylate	1 mg/m ³	—
Trimethylamine	1 ppm	—
Trimethyloxypropane triacrylate	1 mg/m ³	—
Trimethyloxypropane trimethyldiacrylate	1 mg/m ³	—
Trisodium phosphate	—	5 mg/m ³ , 15 min
Urea	10 mg/m ³	—

Revised 5-86

Workplace Environmental Exposure Level Guides (WEELs) are developed by the AIHA WEEL Committee for agents which have no current exposure guidelines established by other organizations. They represent the workplace exposure levels to which, it is believed, nearly all employees could be repeatedly exposed without adverse effect. All WEEL's are expressed as time-weighted average concentrations; however, different time periods are specified depending on the properties of the agent.

An 8-hr TWA indicates a time-weighted average concentration for a normal 8-hr workday and 40-hr workweek. When it is believed that excursion levels should be more limited, a one to 30 minute TWA may be recommended, either in conjunction with, or in place of, an 8-hr TWA value. The time specified is relevant to exposure, not necessarily to sampling.

The word "Skin" indicates that the material may be absorbed through the skin. Therefore, skin contact can contribute to the overall exposure and invalidate the TWA exposure evaluations.

NOTE: For convenience, may be cut to fit inside a pocket manual.

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