

Odor Thresholds and Irritation Levels of Several Chemical Substances: A Review

JON H. RUTH

Wausau Insurance Companies, 550 California Street, San Francisco, CA 94120.

A collation of odor threshold data for approximately 450 chemical substances is presented. The range of odor thresholds reported in the literature is shown along with any reported threshold of irritation to humans. These data can assist the industrial hygienist in determining when an "odor" may be in excess of the Threshold Limit Value®, when an organic vapor respirator is not acceptable due to the lack of an odor warning at the end of a cartridge life, and where odors may not indicate a hazard due to extremely low odor thresholds which may be well below the respective TLVs.

Introduction

Although the sense of smell cannot be relied upon to evaluate the hazards of chemicals used in the workplace, the industrial hygienist can use the odor threshold of a chemical in the recognition phase as a rough estimation of airborne concentration. The purpose of this effort is to gather together, in one listing, the odor threshold and irritation level data published in several less accessible formats. The range from the lowest reported odor threshold to the highest reported odor threshold is reported. A brief review of the information available on our sense of smell and odors is presented along with a short review of several methods of defining a threshold of odor. Through an understanding of how the odor data have been developed and knowing the range of odor thresholds, the industrial hygienist can use these odor thresholds intelligently as a tool in the recognition of potential hazards.

Methodology

The odor thresholds and irritation levels of several hundred chemicals were taken from the industrial hygiene literature⁽¹⁻¹⁰⁾ and other compilations of odor threshold data.⁽¹¹⁻²⁴⁾ The odor thresholds were recorded as a range from the lowest to the highest concentration reported. Whenever information was discovered with a reported odor threshold lower or higher than the current data base range, the appropriate value was changed. The concentration level where irritation begins was recorded where available. Subjective descriptions of the odors were also included where they have been determined. Finally, the American Conference of Governmental Industrial Hygienists - Threshold Limit Value⁽²⁵⁾ was added to the computer data base where a TLV has been assigned. These data were entered into a personal computer data base program (Apple II+ using DB Master software) for manipulation (conversion of ppm data into mg/m³), alphabetization and custom report generation (e.g., potential for separation of chemicals into groups with odors below the TLV vs. those with odors above the TLV).

In Table I, the data are presented in alphabetical order with both the lowest and highest thresholds given in mg/m³. The range of odor thresholds reported for a given chemical

should allow the industrial hygienist to interpret the odor with a proper sense of caution. A description of the odor and the threshold of irritation are also presented. The TLVs, available in the computer data base, have not been included in Table I since they are not directly used in this format for the data.

History

In early times, Plato categorized odors as either pleasant or unpleasant. Several centuries later, Linnaeus, a Swedish scientist, proposed seven odoriferous qualities: 1) aromatic, 2) fragrant, 3) musky, 4) garlicky, 5) goaty, 6) repulsive, and 7) nauseous. A 20th Century Dutch physiologist added ethereal (fruity) and empyreumatic (burnt organic matter) plus several subdivisions to the previous classifications.⁽²⁶⁾ In those early times, the research consisted of categorizing various chemicals based on the description of their odor quality. More recent research has concentrated on determination of the odor threshold, or the quantitative amount of chemical in air which can be detected by the human sense of smell.

Physiology of Smell

For a person to smell something, air containing odoriferous molecules must reach a tiny cluster of specialized nerve cells well inside the nasal cavity. These nerve cells, the olfactory neurons, are at the top of the nose, just above the bridge, and are positioned out of the major airstream. Each nasal cavity has about five million of these receptors which are the only nerve cells in the body which have the ability to regenerate. Inhaled air first passes across a series of small bones, the turbinates, which create turbulence and cause a small amount of air to reach the odor receptors. Sniffing creates strong eddy currents that force more air into the upper portion of the nose and greatly increases the sense of smell.^(17,26) Together with the actual flow rate of the air in the nose, it has been shown that air temperature and relative humidity also affect the perception of odors.⁽²¹⁾

The ten million olfactory neurons can perceive some 4000 different odors.⁽¹⁷⁾ A Yale University study has shown that the average person can correctly name only a handful of common odors. This limitation, however, seems to be a result of an inability to think of the name of the substance rather than a failure to detect the differences between the odors.⁽²⁶⁾ Although women are not better able to detect odors than men, they are more aware of the odor environment and can identify more odors than men.⁽²⁶⁾ Constant exposure to odors can induce non-perception as the olfactory neurons become fatigued. People tend to become accustomed to odors, even those which they initially find unpleasant. Two different odors presented simultaneously can be distinguished from one another if their characteristic odors are sufficiently different from each other. Chemicals used to mask odors can eventually be detected separately from the odor these chemicals were supposed to be masking.

Determination of Threshold

The method of defining and determining the threshold of odor varies widely, giving rise to a significant range from low to high in the odor thresholds reported. A wide variation in threshold definition, sample presentation, panel selection, purity of chemicals used and data interpretation have resulted in data that seem to lack consistency.⁽²¹⁾

A classical definition of odor threshold is the minimum concentration of an odorant which produces a noticeable change in the odor of the system.⁽²¹⁾ The threshold is often designated as the lowest concentration perceived after no anomalies occur.⁽²⁷⁾ Common anomalies are the perception of an odor when a blank or zero concentration sample is presented and not perceiving an odor at a concentration

higher than that at which an odor was previously noticed. Another definition sometimes used is the recognition odor threshold: the minimum concentration at which the odor quality (description of smell) of the compound can be described. Minor differences in concentration are beyond olfactory discrimination. It takes approximately a 30% to 60% increase in the concentration to allow the subject panel to consistently identify the higher concentration as higher.^(17,21)

Samples may be presented in several fashions. Most simply, the odor concentrations may be presented in simple order of increasing concentration from zero to the concentration level first perceived. Another protocol randomly mixes blanks, or zero concentration samples, in with the odor samples which are presented otherwise in simple order of increasing concentration. These presentations in order of increasing concentration are called serial tests.⁽²⁸⁾ Finally, the odor concentrations may be presented in a random fashion to minimize any sample order bias. Where odor recognition is the definition of the threshold, a triangle test is used most often, in which two odors are presented and compared.^(20,28) Panel selection ranges from trained "sniffers" to the general population. A quick sniff of the sample yields a better perception of the odor than a slow, even inhalation. Trained "sniffers" would understand how to sniff for the odor and be more experienced in describing the quality of the odor.

Data may be interpreted in several different ways. The odor threshold may be set at the lowest concentration perceived by a single subject (absolute threshold), which, of course, would yield the lowest concentration of an odor threshold. Other researchers determine the threshold as that concentration where 50% of the test subjects notice the odor

TABLE I
Odor Thresholds and Irritation Concentrations of Chemicals

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Acenaphthene	0.5048	0.5048		
Acetaldehyde	0.0002	4.1400	Green, sweet, fruity	90.00
Acetic acid	2.5000	250.0000	Sour, vinegar-like	25.00
Acetic anhydride	0.5600	1.4400	Sharp odor, sour acid	20.00
Acetone	47.4666	1613.8600	Minty chemical, sweet	474.67
Acetonitrile	70.0000	70.0000	Ether-like	875.00
Acetophenone	0.8347	2.9460	Sweet, almond	
Acetyl acetone	0.0409	0.0409		
Acetylene	657.2000	657.2000		
Acrolein	0.0525	37.5000	Burnt, sweet	1.25
Acrylic acid	0.2820	3.1200	Rancid, sweet	
Acrylonitrile	8.1000	78.7500	Onion-Garlic pungency	
Aldrin	0.2536	0.4027		
Allyl alcohol	1.9500	5.0000	Pungent, mustard	12.50
Allyl Alcohol (N-)	150.0000	150.0000		
Allyl amine	14.5080	14.5080		187.20
Allyl chloride	1.4100	75.0000	Green, garlic, oniony	75.00
Allyl disulfide	0.0005	0.0005		38.06
Allyl glycidyl ether	44.0000	44.0000	Sweet	1144.00
Allyl isocyanide	0.0610	5.4240	Sweet, repulsive	17.02
Allyl isothiocyanate	0.0325	1.7052	Mustard oil	17.05
Allyl mercaptan	0.0002	0.0515	Garlic-like	454.50
Allyl sulfide	0.0007	0.0007		6500.64
Ammonia	0.0266	39.6000	Pungent, irritating	72.00

TABLE I
Odor Thresholds and Irritation Concentrations of Chemicals

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Carbon tetrachloride from CH ₄	300.0000	1500.0000	Sweet, pungent	
Caryophyllene	0.5350	0.5350		
Cellosolve	2.0350	185.0000		
Cellosolve acetate	0.3024	270.0000	Sweet, musty	
Cellosolve solvent	1.1040	2.0240		
Chloral	0.2825	0.2825	Sweet	
Chlordane	0.0084	0.0419		
Chlorinated Camphene Toxaphene	2.3689	2.3689		
Chlorine	0.0300	15.0000	Bleachy, pungent	9.00
Chlorine Dioxide	0.3000	0.3000	Sharp, pungent	15.00
Chloroacetaldehyde	3.0000	3.0000	Sharp, irritating	3.00
Chloroacetophenone (alpha-)	0.1020	0.1500	Sharp, irritating	0.05
Chlorobenzene	0.9800	280.0000	Sweet, almond-like	933.33
Chlorobenzylidene malonitrile (ortho-)			Peppery	1.52
Chlorobromomethane	2100.0000	2100.0000	Sweet	
Chloroform	250.0000	1000.0000		20480.00
Chlorophenol	0.0189	6.5224	Medicinal, empyromatic	6801.18
Chloropicrin	5.4600	7.7000	Sharp, penetrating	2.10
Chlorotoluene	0.2350	0.2350	Pungent, irritating	
Citral	0.3738	0.3738		
Coumarin	0.0020	0.0120	Pleasant, vanilla	
Cresol	0.0012	22.0000	Sweet, creosote, tar	
Crotonaldehyde	0.1050	3.0000	Pungent, suffocating	23.01
Cumene	0.0392	6.3700	Sharp, aromatic	
Cyanogen	500.0000	500.0000	Pungent	32.00
Cyanogen chloride	2.0000	2.0000		
Cyclobutylamine	97.1750	340.8600		
Cycloheptylamine	309.2600	573.4000		
Cyclohexane	1.4350	1.4350	Sweet, aromatic	1050.00
Cyclohexanol	400.0000	400.0000	Camphor-like	200.00
Cyclohexanone	0.4800	400.0000	Sweet, pepperminty	100.00
Cyclohexylamine	106.0000	448.0000		
Cyclopentadiene	5.0667	5.0667		
Cyclopentyl acetate	0.1031	0.1031		
Cyclopentylamine	676.4000	2278.4000		
Cyclopropylamine	153.5170	153.5170		
DDT	5.0725	5.0725		
Decaborane	0.3600	0.3600		
Decalin	565.0000	565.0000		565.00
Decanoic acid	11.9510	112.4800		
Decanol	0.0006	43.2820		
Diacetone alcohol	1.3440	480.0000	Sweet	240.00
Diacetyl	0.0035	0.0880		
Diallyl sulphide	0.0005	0.1491	Garlicky	
Dibenzofuran	0.7752	1.6150		
Diborane	2.0000	4.0000	Repulsively sweet	
Dibromo-3-chloropropane (1,2-)	0.0965	0.2895		1.93
Dibutylamine	0.4224	1.4256		
Dibutylamine (N-)	0.4232	2.5392	Fishy, amine	
Dichloroacetic acid	1.2144	1.2144		
Dichloroanisole (2,6-)	0.0003	0.0003		
Dichlorobenzene (ortho-)	12.0000	300.0000		150.00
Dichlorobenzene (para-)	90.0000	180.0000	Mothballs	240.00
Dichloroethane	445.5000	810.0000	Chloroform-like	
Dichloroethyl ether	90.0000	2160.0000		600.00
Dichloroethylene (1,2-)	0.3358	1975.0000	Acrid, ethereal	
Dichlorophenol (2,4-)	1.4007	1.4007		
Dicyclo pentadiene	0.0297	0.0540	Sharp, sweet	2.70
Diethyl disulfide	0.0195	0.0195		
Diethyl ethanolamine	0.0536	0.1948	Amine	
Diethyl ketone	3.1725	49.3500		
Diethyl pyrazine (2,5-)	0.0336	0.1120		
Diethyl selenide	0.0617	0.0617	Putrid	

TABLE I (cont.)

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Amyl acetate (N-)	0.0265	37.1000	Fruity, banana, pear	530.00
Amyl acetate (sec-)	0.0107	0.0107		
Amyl alcohol (iso-)	25.2000	25.2000		
Amyl alcohol (N-)	0.4332	72.2000	Sweet	
Amyl alcohol (tert-)	0.8303	0.8303		
Amyl amine (N-)	56.6040	132.0760		
Amyl mercaptan	0.0001	0.0018		
Amyl mercaptan (iso-)	0.0018	0.0018		
Aniline	0.0002	350.0000	Pungent, amine-like	
Anisole	0.2210	0.2210		
Apiole	0.0570	0.0570		
Arsine	0.8400	2.0000	Garlic-like	
Azetidine	51.9200	169.9200		
Azine	31.6480	66.2400		
Azole	134.2600	295.9200		
Benzaldehyde	0.0008	0.1823	Pleasant, bitter	20.01
Benzene	4.5000	270.0000	Sweet, solventy	9000.00
Benzene hexachloride	0.0015	142.8000		
Benzenethiol	0.0012	279.0000		
Benzothiazole	0.4424	2.2120		
Benzyl chloride	0.2350	1.5500	Solventy	41.00
Benzyl mercaptan	0.0132	0.2028	Unpleasant	22.81
Benzyl sulfide	0.0184	0.0184	Sulfidy	
Biphenyl	0.0062	0.3000		7.50
Boron trifluoride	4.5000	4.5000	Pungent, irritating	
Bromine	0.3290	24.5000	Bleachy, penetrating	2.10
Bromoacetophenone	0.1221	1.3838	Unpleasant	0.33
Bromochloromethane	1680.0000	1680.0000		
Bromoform	5300.0000	5300.0000	Similar to chloroform	
Butadiene (1,3-)	0.3520	2.8600		
Butadiene dioxide	17.6000	17.6000		35.20
Butane	2.8500	14.6300		
Butenethiol (2-)	0.0001	0.0001		
Butyl acetate (iso-)	0.0090	90.0000	Pleasant, fruity	1350.00
Butyl acetate (N-)	33.1333	94.6666	Fruity	473.33
Butyl acrylate (iso-)	0.0110	0.0660	Sweet, musty	
Butyl alcohol (iso-)	0.3600	225.0000	Mild, non-residual	300.00
Butyl alcohol (N-)	0.3600	150.0000	Sweet	75.00
Butyl alcohol (secondary-)	131.1500	131.1500	Strong, pleasant	
Butyl alcohol (tertiary-)	219.0000	219.0000	Camphor-like	
Butyl amine (N-)	0.2400	6.0000	Ammonical	30.00
Butyl cellosolve	0.4800	288.0000	Sweet, ester	
Butyl cellosolve acetate	0.7194	1.3080	Sweet, ester	
Butyl chloride (N-)	3.3352	6.3293	Pungent	
Butyl ether (N-)	0.3731	2.5051	Fruity, sweet	
Butyl formate	70.8900	83.4000		
Butyl furan (2-)	50.8000	50.8000		
Butyl lactate (N-)	35.0000	35.0000		
Butyl mercaptan	0.0016	0.0033	Stinks!	
Butyl sulfide	0.0897	0.0897		
Butyl toluene (P-, tertiary-)	30.0000	30.0000	Gasoline-like	48.00
Butylamine	3.0000	378.0000	Ammonia, fishy	30.00
Butylene	54.9600	54.9600	Gassy	
Butylene oxide	0.2058	2.0874	Sweet, alcohol	
Butylthiazole (2, iso-)	0.0202	0.0202		
Butyraldehyde	0.0136	26.5500	Sweet, rancid	
Butyric acid	0.0010	9.0000	Sour, perspiration	
Butyric acid (iso-)	29.1600	29.1600		
Camphor (synthetic)	7.8000	1200.0000		10.62
Caprolactam	28.0000	28.0000		
Capryl alcohol			Sweet, pungent	
Carbitol	1.1508	6.0280	Sweet, musty	
Carbitol acetate	0.1872	1.8936	Sweet	
Carbon disulfide	0.0243	23.1000	Disagreeable, sweet	
Carbon tetrachloride from CS ₂	60.0000	128.4000	Sweet, pungent	

TABLE I (cont.)

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Diethyl sulphide	0.0177	0.0117	Foul, garlickly	
Diethyl trisulfide	0.0044	0.0044		
Diethylamine	0.0600	114.0000	Fishy, ammonical	150.00
Diglycidyl ether	25.0000	25.0000		50.00
Diisobutyl carbinol	0.1885	0.9424	Sweet, alcohol	
Diisobutyl ketone	0.6600	1.8600	Sweet, ester	150.00
Diisopropyl amine	0.5200	3.4000	Fishy, amine	100.00
Dimethoxy dimethyl pyrazine	1.2366	1.2366		
Dimethyl acetamide	161.0000	163.8000		
Dimethyl amine	0.0846	0.0846		174.60
Dimethyl disulfide	0.0001	0.3465		
Dimethyl ethanolamine	0.0546	0.1638	Amine	
Dimethyl formamide (N,N-)	300.0000	300.0000		
Dimethyl naphthalene	0.0428	0.0428		
Dimethyl sulfide	0.0025	0.0508	Decayed cabbage	
Dimethyl trisulfide	0.0062	0.0062		
Dimethyl trithiocarbonate	0.0331	0.0331		
Dimethylacetamide (N,N-)	163.8000	163.8000	Amine, burnt, oily	
Dimethylamine	0.0378	55.8000	Fishy, ammonical	
Dimethylformamide (N,N-)	300.0000	300.0000	Fishy, pungent	
Dimethylhydrazine (1,1-)	12.0000	20.0000	Ammonical, amine-like	
Dioxane (1,4-)	0.0108	612.0000	Ether-like	792.00
Dioxane (para-)	20.1600	972.0000		720.00
Dioxolane (1,3-)	44.5400	335.3600	Sweet, musty Lemon-like	
Dipentene				
Diphenyl ether (perfume)	0.6950	0.6950	Pleasant, geraniums	
Diphenyl sulfide	0.0026	0.0358	Burnt, rubbery	
Dipropylamine	0.0826	227.1500	Ammonical, amine	
Dipropylamine (N-)	0.4140	0.8280	Ammonical, amine	
Dipropylene glycol methyl ether	210.0000	6000.0000	Ether-like	450.00
Dodecanol (1-)	0.0152	0.0533		
Dodecyl Mercaptan (N-)	4222.8000	4222.8000		
Dowtherm A	0.7000	7.0000	Aromatic, disagreeable	21.00
Endrin	0.2808	6.3963		
Epichlorohydrin	50.0000	80.0000	Chloroform-like	325.00
Ethane	184.5000	1105.7700		
Ethanolamine	5.3333	10.6666	Ammonia	13.33
Ethoxy 3,4 dihydro 1,2 pyran (2-)	3.1440	3.1440	Sweet, fruity	
Ethoxy 3,4-dihydro 1,2 pyran	0.1048	3.1440	Sweet, fruity	
Ethyl acetate	0.0196	665.0000	Fruity, pleasant	350.00
Ethyl acrylate	0.0008	32.0000	Earthy, acrid, plastic	16.00
Ethyl alcohol (synthetic)	0.3420	9690.000	Sweet, alcoholic	9500.00
Ethyl amine	0.4860	396.0000	Sharp, ammonical	180.00
Ethyl amyl ketone	31.2000	31.2000	Mild, fruity	260.00
Ethyl benzene	8.7000	870.0000	Aromatic	870.00
Ethyl benzoate	3.8068	3.8068		
Ethyl bromide	890.0000	890.0000	Ether-like	28925.00
Ethyl butanol (2-)	0.2919	3.2109	Musty, sweet	
Ethyl ether	0.9900	3.0000	Sweet, ether-like	300.00
Ethyl formate			Fruity	990.00
Ethyl hexanol (2-)	0.3990	0.7342	Musty	
Ethyl hexyl acetate	0.5132	1.4763	Sweet	
Ethyl hexyl acrylate (2-)	0.5497	1.3554	Sharp, musty	
Ethyl isothiocyanate	6.0520	6.0520	Mustard, unpleasant	65.15
Ethyl lactate	67.6200	67.6200		
Ethyl mercaptan	3.2×10^{-5}	0.0920	Garlic	
Ethyl methyl disulfide	0.0487	0.0487		
Ethyl methylamine	21.6900	79.5300		
Ethyl morpholine (N-)	0.3680	1.1500	Ammonia	184.00
Ethyl phenylacetate	4.3615	4.3615		
Ethyl propyl amine	60.5200	181.5600		
Ethyl selenide	0.0003	0.003		
Ethyl selenomercaptan	8.0×10^{-6}	0.0054	Foul	
Ethyl silicate	722.5000	722.5000	Alcohol-like, sharp	5950.00
Ethyl sulfide	0.0009	0.0103		

TABLE I (cont.)

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Ethyl valerate	0.0266	0.0266		
Ethyl vinyl ketone	0.0004	0.0069		
Ethylene	299.0000	4600.0000	Olefinic	
Ethylene diamine	2.5000	28.0000	Ammonical, musty	250.00
Ethylene dibromide	76.8000	76.8000	Mild, sweet	
Ethylene dichloride	24.0000	440.0000	Sweet	
Ethylene glycol	62.5000	62.5000	Sweet	
Ethylene glycol dinitrate				0.18
Ethylene oxide	520.0000	1400.0000	Sweet, olefinic	
Ethylenediamine	25.0000	28.0000	Musty, ammonical	500.00
Ethyleneimine	4.0000	4.0000	Ammonical	200.00
Ethylidene norbornene	0.0700	0.3650	Sweet, aromatic	30.00
Fluorine	6.0000	6.0000		50.00
Formaldehyde	1.4700	73.5000	Pungent, hay	1.50
Formamide	150.0000	150.0000		
Formic acid	0.0450	37.8000	Pungent, penetrating	27.00
Furfural	0.0240	20.0000	Almonds	48.00
Furfuryl alcohol	32.0000	32.0000		
Glycol diacetate	0.5552	1.8626	Fruity, acid	
Heptachlor	0.3060	0.3060		
Heptanal	0.0140	0.0932		
Heptane	200.0000	1280.0000	Gasoline-like	
Heptyl alcohol (N-)	98.3250	98.3250		
Heptyl isobutyrate	0.0989	0.0989		
Heptyl propionate	0.0281	0.0281		
Hexachlorobutadiene	12.0000	12.0000		
Hexachlorocyclopentadiene	1.5000	3.3000		
Hexadiene	1.6750	127.3000		
Hexane (N-)				1800.00
Hexanol (1-)	0.0417	21.6840	Sweet, alcohol	
Hexyl acetate (secondary-)	0.0120	600.0000	Unpleasant	600.00
Hexyl isobutyrate	0.0422	0.0422		
Hexyl propionate	0.0514	0.0514		
Hexylene glycol	250.0000	250.0000		250.00
Hydrazine	3.0000	4.0000	Ammonical, fishy	
Hydrochloric acid	7.0000	49.0000	Irritating, pungent	49.00
Hydrofluoric acid	0.0333	0.1333	Strong, irritating	4.17
Hydrogen bromide	6.6667	6.6667	Sharp, irritating	10.00
Hydrogen cyanide	0.9000	5.0000	Bitter almond	
Hydrogen peroxide			Slightly sharp	150.00
Hydrogen selenide	0.0016	12.0000	Decayed horseradish	6.00
Hydrogen sulfide	0.0007	0.0140	Rotten eggs	14.00
Iodine	9.0000	9.0000		2.00
Iodoform	0.0062	0.0833		
Ionone	4.63 × 10 ⁻⁷	573.0500		
Isoamyl alcohol	36.0000	126.0000		360.00
Isobutyl 2-methoxypyrazine	13.5800	13.5800		
Isobutyl 3-methoxypyrazine	1.3 × 10 ⁻⁵			
Isobutyl 3-methyl pyrazine	0.2146	0.2146		
Isobutyl butyrate	12.3690	17.6700		
Isobutyl mercaptan	0.0020	0.0020		
Isobutyl pyrazine (2-)	2.2080	2.2080		
Isodecanol	0.1292	0.2713	Musty, alcohol	
Isopentanoic acid	0.0209	0.1084	Goaty	
Isophorone	1.0000	50.0000	Sharp, objectionable	50.00
Isopropyl acetate	0.1900	1520.0000	Fruity	380.00
Isopropyl alcohol	7.8400	490.0000	Pleasant	490.00
Isopropyl amine	0.5040	480.0000	Pungent, ammonia	24.00
Isopropyl ether	0.0714	1260.0000	Sweet, sharp, ether	1260.00
Isopropyl glycidyl ether	1440.0000	1440.0000		
Kerosene	0.5517	0.5517		122.60
Ketene			Sharp	41.40
Lauraldehyde	0.0151	0.0151		
Linalyl acetate	50.5260	50.5260		
Malathion	13.5000	13.5000		
Maleic anhydride	1.8400	1.9600	Acrid	5.48

TABLE I (cont.)

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Mercaptobenzothiazole	12.0208	12.0208		
Mercaptoethanol	0.3828	2.0416		
Mesityl Oxide	0.0680	100.0000	Sweet	100.00
Methyl 2, cyanoacrylate	4.0000	12.0000		12.00
Methyl acetate	610.0000	915.0000	Fragrant, fruity	30496.90
Methyl acetylene-propadiene MAPP gas	180.0000	180.0000	Foul, objectionable	
Methyl acrylate	70.0000	70.0000	Sharp, sweet, fruity	262.50
Methyl acrylonitrile (alpha-)	6.0000	42.0000		6.00
Methyl alcohol	13.1150	26840.0000	Sweet	22875.00
Methyl amine	0.0252	12.0000		24.00
Methyl amyl acetate	0.4123	2.3560	Sweet, ester	
Methyl amyl alcohol	1.3761	2.1684	Sweet, alcohol	
Methyl anthranilate	0.0581	0.0581		
Methyl benzyl alcohol	7235.5000	5235.5000		
Methyl bromide	80.0000	4000.0000	Sweetish	
Methyl butanol (2-)	0.0450	0.8280	Sour, sharp	
Methyl butenoic acid (2-)	0.0528	0.0528	Body odor	
Methyl butyl acetate	0.0266	0.0266		
Methyl cellosolve	0.2880	288.0000	Mild, non-residual	368.00
Methyl cellosolve acetate	1.6320	240.0000	Sweet, ester	
Methyl chloride	21.0000	21.0000	Sweet, ethereal	1050.00
Methyl chloroform	542.8570	3800.0000	Chloroform-like	5428.57
Methyl cyclohexane	2000.0000	2000.0000	Faint, benzene-like	
Methyl cyclohexanol	2350.0000	2350.0000	Weak, coconut oil	2350.00
Methyl disulfide	0.0012	0.0039		
Methyl ethanolamine	3.0700	10.4380	Musty, ammoniacal	
Methyl ethyl ketone	0.7375	147.5000	Sweet, acetone-like	590.00
Methyl ethyl pyridine	0.0297	94.0500	Sour, pungent	
Methyl formate	500.0000	6875.0000	Pleasant	8750.00
Methyl furan (2-)	90.4500	90.4500		
Methyl glycol	186.6000	279.9000		
Methyl heptanoate	0.0236	0.0236		
Methyl hexyl ketone	1299.5200	1299.5200		
Methyl hydrazine	1.7500	5.2500		
Methyl iodide				21500.00
Methyl isoamyl alcohol	0.2919	0.8340	Pungent	
Methyl isoamyl ketone	0.0576	0.3360		
Methyl isobutyl carbinol	2.0800	200.0000	Sweat, mild odor	100.00
Methyl isobutyl ketone	0.4100	192.7000	Sweet, sharp	410.00
Methyl isocyanate				5.00
Methyl isopropenyl ketone	1.0222	1.0222		
Methyl mercaptan	4.0×10^{-5}	0.0820	Sulfidy	
Methyl methacrylate	0.2050	1.3940	Arid, fruity, sulfidy	697.00
Methyl n-amyl carbinol	0.0989	0.3378	Sweet, alcohol	
Methyl n-amyl ketone	0.0940	0.0940		
Methyl n-propyl ketone	28.0000	45.5000		
Methyl naphthalene (2-)	0.0581	0.2905		
Methyl parathion	0.1328	0.1328		
Methyl pentaldehyde (2-)	0.3681	0.5562	Sweet, rancid	
Methyl pentane (2-)	0.2886	0.2886		
Methyl propanol (2-)	0.0027	0.1303		
Methyl propene (2-)	45.8000	45.8000	Gassy	
Methyl pyrazine (2-)	231.0000	231.0000		
Methyl salicylate	0.6220	0.8708		
Methyl styrene (alpha-)	0.2496	960.0000	Sweet, aromatic	960.00
Methyl thiocyanate	0.7475	0.7475	Sweet, unpleasant	480.19
Methyl vinyl ketone	0.5720	0.5720		
Methylamine	0.0252	12.0000	Fishy, pungent	30.00
Methylene chloride	540.0000	2160.0000	Sweet	8280.00
Methylene chlorobromide	2120.0000	2120.0000		
Methylene glycol	76.2000	76.2000		
Mineral spirits	157.5000	787.5000		
Monochlorobenzene	0.9800	0.9800	Chlorinated, mothball	
Morpholine	0.0350	0.4900	Fishy, amine	

TABLE I (cont.)

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Musk oil	3.8×10^{-6}	0.0487		
Mustard gas	0.0150	0.0150		
Myrcene	0.0723	0.0723		
Naphthalene	1.5000	125.0000	Mothball, tar-like	75.00
Nickel carbonyl	0.2100	21.0000	Musty	
Nitric acid	0.7500	2.5000		155.00
Nitric oxide	0.3600	1.2000		
Nitrobenzene	0.0235	9.5000	Shoe polish, pungent	230.00
Nitroethane	620.0000	620.0000	Mild, fruity	310.00
Nitrogen dioxide	2.0000	10.0000	Sweetish, acrid	20.00
Nitromethane	250.0000	250.0000	Mild, fruity	500.00
Nitropropane (1-)	1080.0000	1080.0000	Mild, fruity	360.00
Nitropropane (2-)	17.5000	1029.0000		
Nonane	3412.5000	3412.5000		
Nonanol (2-)	0.0005	20.6150		
Octadiene (1,3-)	54.0000	90.0000		
Octane	725.0000	1208.3300	Gasoline-like	1450.00
Octyl alcohol	0.6916	0.6916		
Oxygen difluoride	0.2000	1.0000	Foul	
Ozone	0.0010	1.0200	Pleasant, clover-like	2.00
Parathion	0.4760	0.4760	Garlic-like	
Pentaborane	2.5000	2.5000	Strong, pungent	
Pentachlorophenol			Pungent when hot	10.90
Pentane	6.6000	3000.0000	Gasoline-like	
Pentanedione (2,4-)	0.0409	0.0982	Sour, rancid	
Pentanol (n-)	0.7560	1.1160	Sweet, alcohol	
Perchloroethylene	31.3560	469.0000	Chlorinated solvent	1340.00
Perchloromethyl mercaptan	0.0075	0.0075		
Perchloryl fluoride	46.6666	46.6666	Sweet	
Phenol	0.1786	22.4200	Medicinal, sweet	182.40
Phenyl ether	0.0070	0.7000	Disagreeable	21.00
Phenyl ethyl alcohol (beta-)	35.0000	35.0000		
Phenyl sulfide	0.0026	0.0358		
Phenylacetaldehyde	0.0010	0.0196		
Phosgene	2.0000	4.0000	Musty hay, green corn	8.00
Phosphine	0.0280	3.6000	Oniony, mustard, fish	10.67
Phthalic Anhydride				30.00
Picoline (2-)	0.0532	0.1748	Sweet	
Picric acid	0.0005	0.0005		
Propane	1800.0000	36000.0000		
Propionaldehyde	0.0225	0.4029	Sweet, ester	
Propionic acid	0.0840	60.0000	Sour	
Propyl acetate (n-)	0.2100	105.0000	Sweet, ester	
Propyl alcohol	75.0000	500.0000		13750.00
Propyl alcohol (n-)	0.0750	150.0000	Sweet, alcohol	
Propyl mercaptan	0.0002	0.0746		
Propyl nitrate (n-)	210.0000	210.0000	Ether-like	
Propyl sulfide	0.0531	0.0531		2801.40
Propylene	39.5600	116.2720	Aromatic	
Propylene diamine	0.0424	0.2030	Sharp, amine	
Propylene dichloride	1.1667	606.6660	Sweet	
Propylene glycol dinitrate	1.2000	1.5600		
Propylene glycol isobutyl ether	60.5000	60.5000		121.00
Propylene glycol methylether	360.0000	360.0000		3600.00
Propylene oxide	24.7500	500.0000	Sweet, alcoholic	1125.00
Pyridine	0.0090	15.0000	Burnt, sickening	90.00
Pyrrolidine	58.0000	187.3400		
Quinone	0.4000	0.4000	Acrid	2.00
Rotenone	5.7960	5.7960		
Safrole	1.4586	1.4586		
Silicon tetrafluoride	4.2500	4.2500		42.50
Skatole	4.0×10^{-7}	0.2680	Perfume	
Stoddard solvent	5.2500	157.5000	Kerosene-like	2100.00
Styrene (inhibited)	0.4300	860.0000	Solventy, rubbery	4300.00
Styrene (uninhibited)	0.2021	860.0000	Solventy, rubbery	430.00
Styrene oxide	0.3093	1.9640	Sweet	

TABLE I (cont.)

Chemical Compound	Odor Low mg/m ³	Odor High mg/m ³	Description of Odor	Irritating Conc. mg/m ³
Sulfur dichloride	0.0042	0.0042	Sulfidy	
Sulfur dioxide	1.1750	12.5000	Yechn	5.00
Sulfur monochloride			Nauseating	12.00
Sulfuric acid	1.0000	1.0000		1.10
Tetrachloroethane (1,1,2,2-)	21.0000	35.0000	Sickly sweet	1302.00
Tetrachloroethylene	31.3560	469.0000	Chlorinated solvent	710.20
Tetraethyl orthosilicate	30.6360	61.2720	Sweet, alcohol	
Tetrahydrofuran	7.3750	177.0000	Ether-like	
Tetralin	97.2000	97.2000		
Tetramethylenediamine	79.2000	79.2000		
Thiophene	0.0026	0.0026	Aromatic	
Thiophenol mercaptan	0.0012	382.5000		
Toluene petroleum	8.0250	150.0000	Rubbery, mothballs	750.00
Toluene from coke	17.5500	262.5000	Floral, pungent	750.00
Toluene 2,4 diisocyanate TDI	3.2000	17.1200	Sweet, fruity, acrid	4.00
Toxaphene	2.3660	2.3660		
Trichloro fluoromethane Freon 11	28.0000	1170.4000	Sweet	
Trichloro trifluoroethane Freon 113	342.0000	1026.0000	Sweet	
Trichlorobenzene (1,2,4-)	24.0000	24.0000		40.00
Trichloroethylene TCE	1.1340	2160.0000	Solventy	864.00
Trichloropropane (1,2,3-)			Strong, acrid	300.00
Tricycloketone	1.8660	870.8000		
Triethyl amine	0.3600	1.1200	Fishy, amine	200.00
Trimethyl amine	0.0008	0.0008	Fishy, pungent	
Trimethyl phosphite	0.0005	0.0005	Pyridine-like	
Trimethylenediamine	3757.2000	11968.5000		
Trinitro tert-butylxylene musk oil	3.8×10^{-6}	0.0487		
Turpentine	560.0000	1120.0000		560.00
Valeric acid	0.0026	0.0026		
Vanillin	2.0×10^{-7}		Perfume	
Vinyl acetate	0.3600	1.6500	Sour, sharp	
Vinyl amyl ketone	0.5150	0.5150		
Vinyl butyl ketone	0.0321	0.0321		
Vinyl propyl ketone	0.0201	0.0201		
Vinyl pyridine	1.1670	1.9450	Nauseating	
Vinyl toluene	240.0000	240.0000	Disagreeable	240.00
Vinylidene chloride	2000.0000	4000.0000	Sweet, chloroformish	
VM&P naphtha	3.8700	3.8700		
Xylene	0.3480	174.0000	Sweet	435.00
Xylidene	0.0240	0.0240	Weak, amine-like	

or recognize and describe the odor. Finally, some researchers look for a 100% panel response. This latter method would generate higher concentration levels as the defined threshold. One study, which reported both the absolute threshold and the 100% recognition threshold, showed the 100% recognition threshold to be approximately two to ten times higher than the absolute threshold.⁽²⁴⁾

The influence of chemical contaminants may explain some of the variation in thresholds observed.⁽²¹⁾ Note the differences in odor thresholds in Table I of toluene manufactured from two different raw materials, or carbon tetrachloride from different sources, or inhibited vs. uninhibited styrene. There has been a tendency for lower thresholds to be identified in the more recent research, which has been attrib-

uted to greater purity of samples and better techniques of sample presentation.

Discussion

It must be remembered that the data listed in Table I are essentially for the single chemical constituent with no other chemicals present in the air. Mixtures of different chemicals have received very little study.⁽²⁸⁾ The question is whether two chemicals at concentrations below their odor thresholds (R_A and R_B) can add up to constitute one combined "odor" (R_{AB}) which is perceived, or whether the olfactory receptors react very specifically to each chemical so that no odor is perceived⁽¹⁷⁾ (Figure 1 - Independence). There have been several studies where two mixed chemicals, each at 50% of its

odor threshold, have produced an odor which was perceived by test subjects⁽¹⁷⁾ (Figure 1 - Addition). While mixed chemicals may be totally independent of one another or produce simple additive effects, it is also possible that the mixture produces an enhanced or a suppressed reaction from what might be predicted. An enhanced reaction would result from two mixed chemicals, each at less than 50% of its odor threshold, which produce a perceived odor (Figure 1 - Synergism). A suppressed reaction, or counteraction, would result when two mixed chemicals, each at 100% of its odor threshold, fail to produce a perceptible odor among test subjects (Figure 1 - Counteraction).

Independence
 $R_{AB} = R_A \text{ or } R_B$

Addition
 $R_{AB} = R_A + R_B$

Synergism
 $R_{AB} > R_A + R_B$

Counteraction
 $R_{AB} < R_A \text{ or } R_B$

where R_{AB} = odor threshold of mixture of chemical A and chemical B,

R_A = odor threshold of pure chemical A, and

R_B = odor threshold of pure chemical B.

Figure 1 — Mixed Chemicals Odor Relationships.⁽²⁸⁾

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