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The Health Risks of Chemicals in Personal Care Products and Their Fate in the Environment

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The Health Risks of Chemicals in Personal Care Products and Their Fate in the Environment

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Abstract

Personal care products are everyday consumer products used to cleanse, enhance, or alter the appearance of the body, including, but not limited to, shampoos, body washes, lotions, and cosmetics. The regulations and safety information surrounding personal care products are severely lacking. The laws regulating the environmental fate of these chemicals and the harmful effects they can have on environmental ecosystems or organisms that are exposed to them are even more limited. However, studies have shown that the chemicals can have a dizzying array of health risks, including diseases on the rise in human populations such as diabetes, obesity, autism, ADHD, learning disabilities and other neurological disorders, infertility, and some cancers. Many of these health effects have also been observed in other organisms exposed to these chemicals in the environment. Some exposures have even been shown to be toxic to certain species at high enough concentrations. This paper looked at four main classes of chemicals, phthalates, parabens, triclosan, and fragrances, in personal care products. Many of these chemicals are known endocrine disruptors, and appear in personal care products or the environment at hormone relevant concentrations, leading to adverse neurological, developmental, or sexual developmental effects, which can be extremely detrimental to a fetus or to younger organisms. Determining the fate of these chemicals in the environment and the rates of exposure are crucial to fully understanding the overall safety and environmental effects of these chemicals, and for providing more complete information for consumers on the personal care products they choose to buy and use everyday.

Introduction:

“Personal care product” is a term that is not legally defined. However, the general consensus is that a personal care product is any consumer good that is used to cleanse, alter, or enhance the appearance of the body. Personal care products can be considered both a drug (mouthwashes, acne medications, steroid creams, lip balms, hand sanitizers and soaps, etc.) and a cosmetic (lotions, makeup, perfume, etc.) ("Are all "personal care products" regulated as cosmetics?"). The term personal care product is separate from consumer products, which refers to any products bought for personal or household use such as cleaning agents, detergents, food storage containers, etc. Many of the chemicals used in personal care products are also used in consumer goods, or present as food contaminants. It is important to note that, because of their use in multiple types of products, people and the environment can be exposed to these chemicals through various means. In addition, personal care products are not well regulated. Most of the regulations and safety testing is self-regulated by the product or fragrance manufacturers ("Ingredients > Fragrances in Cosmetics."). There are no specific safety tests required for chemicals used in personal care products, so the manufacturer can pick and choose which tests are performed and what conditions are considered safe. While the FDA regulations were being created, many of these manufacturing companies fought back. To pacify these companies, the chemicals in use at the time were grandfathered in resulting in hundreds of untested chemicals allowed in personal care products. Determining both the initial health risks of these chemicals as well as their fate in the environment is extremely important.

Many of these chemicals are also considered endocrine disrupting compounds, and occur in these products or in the environment at hormone-relevant levels. The concentrations of contaminants required to cause adverse effects varies with the individual species and chemical, though hormones occur at very low levels in the body, and many of the concentrations of these hormone-mimicking chemicals are found at similar concentrations in consumer products or, because of dilution, in the environment (generally in concentrations of $\mu\text{g/L}$) (Brausch and Rand 1518-1532). The endocrine system is a collection of glands that produce hormones, including estrogen, testosterone, and thyroid hormones. This system helps regulate the body's physical, neurological, and sexual development, as well as other metabolic activities such as maintaining blood sugar levels. Endocrine disruptors can mimic hormones that are used to regulate metabolic processes, leading to health effects such as physical, neurological, and sexual disorders including autism, infertility, and altered thyroid function, which in turn can lead to obesity and diabetes (Sun et al. 339-344; De Coster and van Larebeke 713696; Langer et al. 78-87). Certain cancers in sexual organs, including breast cancer, have also been linked to endocrine disruptors.

Endocrine disrupting compounds beyond their array of health affects, are particularly concerning because they can have drastically different effects during different periods of development. For example, exposure to sexual hormone mimicking compounds can have dramatic results when an embryo is exposed to them in the womb. Even a one-day difference in exposure to one of these compounds can be the difference between normal development vs. hermaphroditism or infertility. Endocrine disrupting compounds can also be virtually harmless to adults, but can have huge effects on teenagers or menopausal woman due to the changes in hormones during these phases of life (Colborn 1996). Another major concern with endocrine

disrupting compounds is that they have health effects at small concentrations, equivalent to hormone concentrations in the body. These small concentrations are the levels in which many of these chemicals are found in all sorts of products, including personal care products, or in the environment due in part to the dilution of pollutant chemicals.

Humans are exposed to these chemicals from personal care products primarily dermally, though some chemicals like those found in fragrances can be inhaled. After application of the product on the body, some of the chemicals in the product may be taken up by absorption into the skin. Some lotions even contain penetration enhancers that help these chemicals enter the skin and penetrate farther into the body than expected (Guo and Kannan 14442-14449). Once taken up by the body these chemicals can enter the blood system and travel throughout the body, including passing through the blood brain barrier and through the placenta into the womb (Zhang et al. 857-869). They can then remain unaltered or can be metabolized and then excreted from the body. Some chemicals are highly attracted to fat and resistant to removal from, or metabolism from, the body. Such toxins can then accumulate in the fatty tissues of the body.

The amount of personal care product chemicals entering the body depends on the product type (more chemicals can be absorbed from leave-on products such as lotions than from rinse-off products like shampoos), the amount of product used and the number of repeated uses, as well as the duration of the product on the body. Portions of these dermally applied products can be rinsed off in subsequent washings, so the timing of applying these products can have an effect on the amount of chemicals introduced into the body. For example using a leave-on product immediately before going to sleep compared to during the day allows for longer periods of dermal contact without rubbing or rinsing off portions of the

product. Once these products have been rinsed off from the body, they are able to enter the environment through the wastewater treatment process, and can become potential environmental hazards.

Personal care products are able to reach the wastewater system through multiple routes. Products such as shampoos, body washes, and toothpastes are directly washed down the drain during and after use. Products like cosmetics and hand lotions can be washed down the drain as well during a regular routine. The chemicals that are able to penetrate the body and are then excreted are also able to enter the wastewater system through the toilet. Once in the wastewater system these chemicals have multiple routes through the treatment process. After initially removing all noticeable large objects such as tree branches from the wastewater, the water is aerated and agitated to increase the aerobic breakdown of many chemicals and microbes in the water (Baird and Cann 2012). During this phase of the treatment process many of the volatile chemicals, such as fragrances, are released and enter the environment as air pollutants. Once in the air, these chemicals can either react with other air-borne chemicals (mainly hydroxyl radicals), breakdown in sunlight, or settle back out of the air on dust particles into surface waters or on land, from which they can seep into groundwater. These volatile chemicals have also been shown to be taken up from the air by plants.

The non-volatile chemicals left in the wastewater can be broken down or undergo many transformation steps during the aeration process, including undergoing photochemical transitions due to energy from the sun. These chemicals are also subject to biological and chemical breakdowns from the addition of microbes and chemicals to the water. However, the anti-microbials present in many personal care products are resistant to breakdown of these

added microbes and have been shown to reduce the microbe's ability to breakdown other chemicals while exposed to these anti-microbials. Some chemicals such as phosphates are purposefully added to the water to help settle suspended particles out of the water. Each wastewater treatment plant treats the water differently, so the added microbes and chemicals, as well as other factors such as the amount of aeration and the timing of each step is unique to each treatment plant. Therefore the amounts of chemicals removed from the water entirely, or simply transformed, can vary greatly between plants.

Most wastewater treatment plants chlorinate the water at the end of the treatment process for the purpose of disinfecting the water. The addition of free chlorines to some of the chemicals in the wastewater during treatment can create even more toxic compounds. In fact, many of the transformations or the by-products of these transformations can actually be more toxic than the original water contaminants. The addition of free chlorines to some of the contaminants can allow the chemical to resemble polychlorinated biphenyls, which are persistent in the environment, bioaccumulating, and toxic (Dann and Hontela 285-311). These potential toxic transformations are not the only harmful effects these chemicals can have in the environment.

After the aeration step of the water treatment process, the water is allowed to sit so that solids may settle out of the water. Many of the chemicals found in personal care products are lipophilic, meaning they do not want to interact with water and prefer interacting with fatty, or other lipophilic, compounds. As these compounds are washed down the drain and into wastewater treatment facilities, they do not remain suspended in the water, but instead sorb onto any lipophilic compound or organism that comes nearby. In the wastewater treatment plant a large portion of the lipophilic chemicals are physically removed from the water due to

their sorption onto lipophilic suspended particles in the water, which later settle out as a substance known as sludge. This sludge, once removed, is either placed in a landfill, on wasteland, or used as fertilizer in fields. From each of these areas the lipophilic chemicals are able to leach out of the sludge and into ground or surface water. The chemicals in the sludge placed on land can be taken up by plants, sorb into the fatty tissues of soil organisms, or accumulate in the organism that eats those plants or soil organisms (Api 97-108). They may also be degraded in the soil by microbes, be photo-chemically degraded or volatilized out of the very top layer of sun-exposed soil, or they can persist in the soil and remain in the environment. Some of the lipophilic chemicals and their transformed products manage to remain in the wastewater and are released into surface waters with the wastewater effluent. These chemicals, which are still lipophilic, sorb into the fatty tissues of fish and algae as soon as they are able to, or settle into the lipophilic sediment at the bottom of the water body. These chemicals still carry some of the same health effects for other organisms as those seen in humans. Although the small body size of these organisms compared to humans can cause the compounds to be more toxic at the same concentrations. The anti-microbial compounds present in personal care products can be particularly harmful to algae. Anti-microbials are designed to kill small organisms, and many are lipophilic. Therefore these compounds like to be taken up by small organisms like algae, but are designed to kill similarly sized organisms. As a result, some anti-microbials have been shown to be fatal to algae and other microbes at high enough concentrations. These compounds can also be fairly persistent in the environment due to the fact that microbes, a common source of environmental degradation, are generally unable to breakdown these compounds (Yamamoto et al. 102-111). Sediment fish can also

experience some of the worst health effects due to their foraging habits in waterbed sediments, which stir up plumes of these settled lipophilic chemicals at a time.

Humans can also get re-exposed to lipophilic chemicals present in the environment through recreational use of contaminated surface waters, or as contaminants in their drinking water and foods. The lipophilic nature of a chemical is determined by a measurement known as pK_{ow} , which measures the likelihood of the chemical associating with water over a less-polar molecule, octanol. A compound is deemed lipophilic enough to enter the body if its pK_{ow} falls within the range of 3-7. Higher pK_{ow} values are more lipophilic, but generally too lipophilic, or too large of molecules, to be able to absorb into the body. Lipophilic compounds that have pK_{ow} 's that fall within the 3-7 range are able to enter the body, where they associate with the fatty tissue and are difficult for the body to remove. Because of this lipophilic compounds can easily accumulate in the fatty tissue of organisms if they have the correct pK_{ow} 's; this process is known as bioaccumulation. Over the lifetime of the organism higher concentrations of these compounds can be found in the body. Organisms higher up in the food chain can experience an accumulation of these lipophilic compounds, even if they are not exposed to them, through the contamination of their food. A lipophilic compound may accumulate in a smaller organisms fat, and then when a larger organism eats this organism, the lipophilic compound, which is still hard to remove from the body, transfers from the fatty tissue of the one organism into the fatty tissue of the other organism. In fact, organisms, like humans, which are higher up in the food chain can experience higher concentrations of lipophilic compounds in their bodies, since they eat larger quantities of organisms contaminated with these compounds. This process is known as biomagnification. Lipophilic compounds are also known to be taken up by plants exposed to them (Baird and Cann, 2012).

Therefore humans can be exposed to such compounds directly through their daily use of products containing these chemicals, from their recreational activities in contaminated environments, and through both their aquatic and terrestrial based food sources.

Due to the persistence of these chemicals and the health effects associated with these products at environmentally relevant concentrations, it is important to fully study and understand the health risks associated with the chemicals found in personal care products as well as their fate in water treatment facilities and the environment. This paper looks in depth at four main types of chemicals frequently used in personal care products that have been banned or partially banned for use in such products in the European Union (EU). This paper follows the type of personal care products these chemicals are used in, the reasons for their use in these products, the exposure data for consumers of these products, the environmental fate of these chemicals, and the health risks associated with them both in humans and other species, primarily aquatic organisms.

Phthalates:

What Are Phthalates and Why Are They Used:

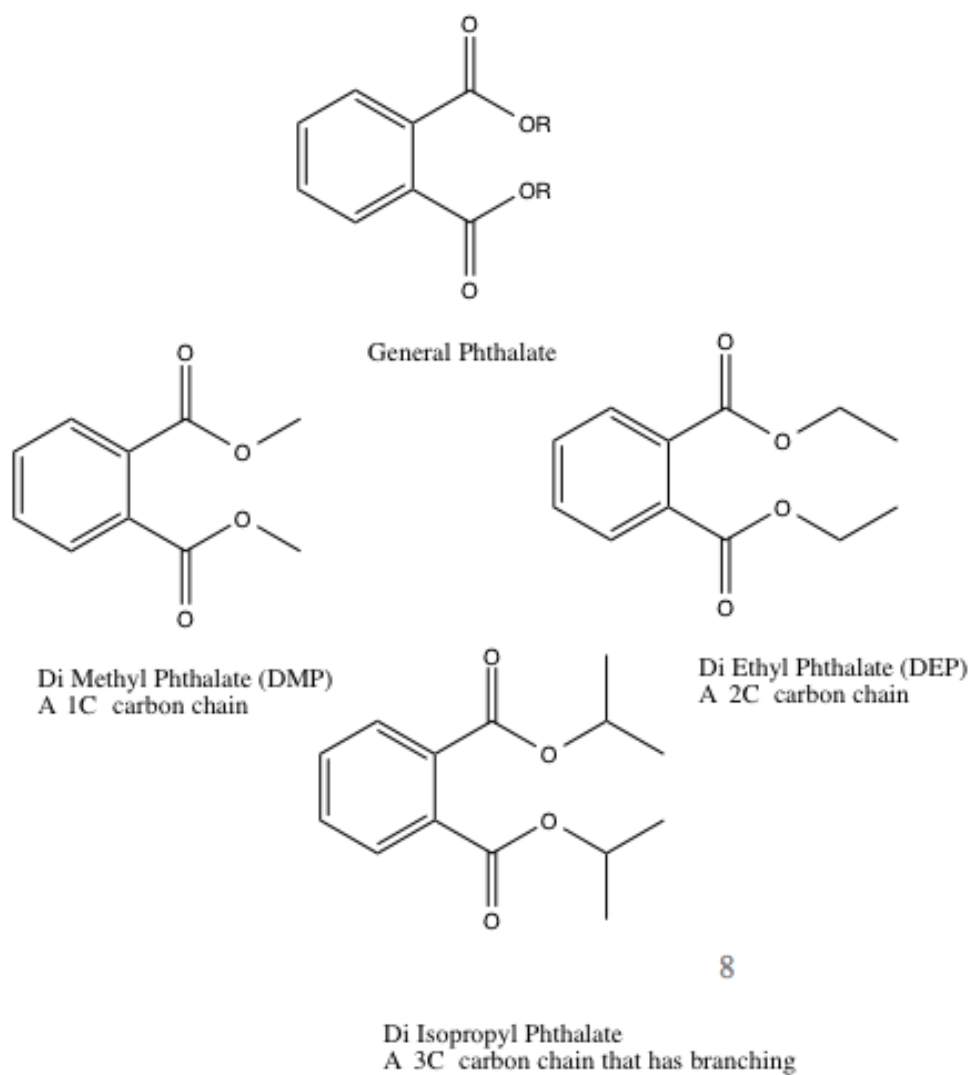


Figure 1: Structures of some selected phthalates that depict growing chain length and increased branching.

Phthalates refers to a large group of chemicals, phthalic esters, each with a unique number of carbons in the carbon side chain portion of the ester (Figure 1). Phthalates are an

extremely versatile class of industrial chemicals and are used in many everyday products including personal care products. In personal care products phthalates play many roles. One such role is as a solubilizer, which helps dissolve the other chemicals present in products such as shampoos, and allows that product to exist in as well as retain its liquid form. Phthalates are also commonly used as humectants, which help to retain moisture, or sometimes actively attract it, as emollients, which help to soften the skin, and as skin penetration enhancers. Penetration enhancers allow both the humectant and emollient abilities of products such as hand lotion, to infuse the softness and moisturizing abilities of the product deep within the skin (Guo and Kannan 14442-14449; "Phthalates | Cosmetics Info."). Another characteristic of phthalates is their ability to act as plasticizers (Koniecki et al. 329-336). Plasticizers are additives in plastics that increase the plastics' flexibility. Thus phthalates are commonly found in the plastic bottles that hold personal care products, due to its ability to increase the plastics' flexibility and allow for easier removal of the product from the bottle.

Due to the many and versatile properties mentioned above, phthalates are commonly seen in all sorts of consumer products, including high usage in personal care products such as shampoos, deodorants, lotions, hair products, nail polishes and particularly fragrances or perfumes (Koniecki et al. 329-336; Guo and Kannan 14442-14449). Phthalates are present in shampoos due to their ability to act as solubilizers, meaning phthalates are used in many personal care products simply to help dissolve the active ingredients and maintain the product's texture. Phthalates are used in lotions as moisturizing agents since they are able to produce softer skin, as well as help retain moisture in the skin. They are also able to penetrate the skin, allowing the product to work deeper, and infuse softness deeper in the skin. Phthalates are also commonly used as plasticizer additives in nail polishes, allowing the polish

to be more flexible. More flexible nail polish allows for better application of the polish, and allows the polish to bend slightly with the nail, reducing the amount of chipping of the polish (Braun, Sathyanarayana, and Hauser 247-254; "Phthalates | Cosmetics Info."). The ability of phthalates to allow the resins in nail polishes more flexibility is one of the few uses of phthalates' plasticizing abilities used directly in personal care products. However outside the personal care industry, phthalates are routinely used as plasticizers to soften plastics, and are commonly found in the plastic bottles that contain personal care products.

The use of plasticizers to soften everyday plastic containers is a common practice, and many of these plasticizers, including phthalates, have been shown to leach out of such plastic containers readily. In fact phthalates have been observed in small amounts in personal care products that contain no phthalates in their ingredients list due to their migration out of plastic bottles containing the product (Braun, Sathyanarayana, and Hauser 247-254; Guo and Kannan 14442-14449). This suggests that the average user of personal care products may be exposed to phthalates unintentionally and unknowingly due to the leaching effects of soft plastic containers used to store personal care products. Unfortunately, the potential contamination from leaching cannot be prevented by a concerned consumer since the leaching of chemicals from plastics is a common occurrence of soft plastics, and the ingredients present in such plastic bottles can be difficult or impossible to determine. Therefore even if a personal care product consumer is actively avoiding phthalates, he or she can still become contaminated by the chemical if it is also used as a plasticizer. Many of the chemicals present in personal care products, particularly those used as plasticizers, are also present in many other consumer goods, so contamination from other daily sources of the chemical can also readily occur.

Fortunately due to recent health concerns phthalates are being used less commonly now, particularly in many plastic container formulations.

Exposure:

Table 1: Phthalate concentrations (µg/g) in cosmetic and personal care products (Koniecki et al. 329-336).

Product Type (n ¹)	Subtype (n ¹)		DMP	DEP	DiBP	DnBP	DEHP
Detection Limit			0.5	0.5	0.1	0.1	0.5
Fragrance (30)	Fragrance (30)	Detection	0	21	0	0	3
		Median	ND	1679	ND	ND	ND
		Max	ND	25542	ND	ND	521
Hair care (24)	Hair spray (11)	Detection	0	8	1	2	1
		Median	ND	3.1	ND	ND	ND
		Max	ND	1223	1.1	36	1.6
	Mousse (7)	Detection	0	6	2	5	0
		Median	ND	19	ND	2.0	ND
		Max	ND	566	1.3	20	ND
	Hair gel (6)	Detection	0	3	0	0	0
		Median	ND	ND	ND	ND	ND
		Max	ND	445	ND	ND	ND
Deodorant (31)	Deodorant (18) (excluding antiperspirant)	Detection	1	9	1	0	0
		Median	ND	3.7	ND	ND	ND
		Max	72	3634	4.5	ND	ND
	Antiperspirant (13)	Detection	0	5	0	0	0
		Median	ND	ND	ND	ND	ND
		Max	ND	818	ND	ND	ND
Nail polish (20)	Nail polish (20)	Detection	0	0	1	3	2
		Median	ND	ND	ND	ND	ND
		Max	ND	ND	0.4	24304	1045
Lotion (29)	Body lotion (20)	Detection	0	7	1	0	0
		Median	ND	ND	ND	ND	ND
		Max	ND	5549	4.1	ND	ND
	Body cream (9)	Detection	0	3	0	0	0
		Median	ND	ND	ND	ND	ND
		Max	ND	3444	ND	ND	ND
Skin cleanser (20)	Skin cleanser (20)	Detection	0	8	3.0	2	1
		Median	ND	ND	ND	ND	ND
		Max	ND	277	1.0	6.6	30
Baby product (98)	Baby lotion (25)	Detection	0	9	0	0	1
		Median	ND	ND	ND	ND	ND
		Max	ND	571	ND	ND	15
	Baby oil (19)	Detection	0	5	0	0	0
		Median	ND	ND	ND	ND	ND
		Max	ND	15	ND	ND	ND
	Diaper cream (31)	Detection	0	5	0	0	0
		Median	ND	ND	ND	ND	ND
		Max	ND	2566	ND	ND	ND
	Baby shampoo (23)	Detection	0	15.0	0.0	2	0
		Median	ND	2.1	ND	ND	ND
		Max	ND	320	ND	1.8	ND

1–n: the total number of samples.

DMP=dimethyl phthalate, DEP=diethyl phthalate, DiBP=diisobutyl phthalate, DnBP=di-n-butyl phthalate, DEHP=di(2-ethylhexyl) phthalate.

Because of the versatility and common usage of phthalates, humans are continuously exposed to surprisingly high levels of phthalates (Koniecki et al. 329-336). Phthalates are used in a large variety of personal care products including body lotion, hand lotion, hair products (mouse and hair spray), deodorants, nail polish, lipsticks, and in the fragrances used in personal care products, as well as colognes and perfumes. The average quantities of five phthalates in a select group of personal care product types are listed in Table 1. Because of this widespread use over 90% of the human population is exposed to phthalates on a daily basis, with the main sources of exposure being hand lotions, deodorants, and products containing fragrances (Koniecki et al. 329-336; Guo and Kannan 14442-14449). The extent of exposure to phthalates present in personal care products is highly dependent on the individual use and frequency of personal care products. Some estimated average dermal exposure data for various categories of personal care products are seen in Table 2. However, exposure can vary greatly and is dependent on the particular personal care products the individual uses, the amount and frequency of use of such products, as well as the timing/duration of the application of the product (Guo and Kannan 14442-14449; Koniecki et al. 329-336). For example if a hand lotion containing phthalates is applied to wet skin, as opposed to dry skin, different levels of phthalates are absorbed into the skin (Koniecki et al. 329-336). In addition, if the individual washes his or her hands shortly after applying hand lotion, some of the product will be rinsed off, reducing the phthalate exposure. Conversely if a product is applied directly before bed, it can be in contact with the skin for 8 hours or more, allowing for more absorption of the chemicals present in the lotion into the body. The different combinations of chemicals that can be present in an individual product, or from usage of various mixtures of products, has also been suspected of altering the rates, amounts, and health effects of the

chemicals absorbed into the skin (Dodson et al. 935-943). These highly individualized exposure scenarios are true for any personal care product, or any chemical, not just phthalates, and can result in drastically different exposure amounts between individuals.

Table 2: Estimation of daily dermal exposure dosage of Canadians in three different age groups to phthalates in cosmetic and personal care products (Koniecki et al. 329-336).

Product type	Product applied (g/use)	Frequency of application (times/d)	Retention factor	Exposure estimates (µg/kg bw/d) ^a				
				DMP	DEP		DnBP	DEHP
				Max	Median	Max	Max	Max
Fragrance	0.61	3	1		2.6	39.0		0.8
Lotion	8	1	1			37.0		
Hair care	5	1	0.1			0.5	0.015	
Deodorant	0.5	1	1	0.030		1.5		
Nail polish	0.25	0.28	1				0.34	0.01
Skin cleanser	2.5	2	0.1			0.12		0.01
Total (adult female)^b				0.03	2.6	78	0.36	0.82
Baby lotion	1.4	0.14	1			0.37		0.01
Baby shampoo	0.51	0.27	0.01			0.001		
Baby diaper cream	1.4	1.72	1			20		
Baby oil	1.3	1.57	1			0.10		
Total 0.5-4 yrs^c						20		0.01
Baby lotion	1.4	0.14	1			0.75		0.02
Baby shampoo	0.51	0.27	0.01			0.003		
Baby diaper cream	1.4	1.72	1			41		
Baby oil	1.3	1.57	1			0.21		
Total 0-6 mo.^d						42		0.02

DMP = dimethyl phthalate, DEP = diethyl phthalate, DiBP = diisobutyl phthalate, DnBP = di-n-butyl phthalate, DEHP = di(2-ethylhexyl) phthalate.

^a For concentrations see Table 4. Exposure was not estimated when phthalates were detected at traces (10 µg/g or less).

^b Assuming body weight (bw) of 60 kg (EC, 1998).

^c Assuming body weight of 15.5 kg (EC, 1998).

^d Assuming body weight of 7.5 kg (EC, 1998).

In addition to different types of and combinations of product usage, the sex and age of the individual user can have a significant effect on the exposure to chemicals in personal care products. For example, females tend to use more personal care products, including cosmetics, than men, so females tend to have larger exposures and therefore larger blood concentrations of such chemicals than men (Koniecki et al. 329-336). Additionally, studies have found that adolescent girls tend to have slightly higher chemical exposures than women due to the fact that they are experimenting with the type of products they use and the brands they favor,

resulting in increased usage of products in general. Another study has shown that most adolescent girls who wear makeup, also tend to wear larger quantities of and more types of make up than adult women. This helps explain the increased exposure levels to such chemicals in adolescent girls. This higher use of products in adolescents is particularly worrisome for particular chemicals present in personal care products, which have been determined or are suspected of being endocrine disruptors. Endocrine disruptors can have larger effects during periods of human development, especially sexual development, such as adolescence.

Health Effects:

Phthalates are one of the most well known endocrine disrupting compounds present in personal care products. The term “Phthalates” refers to a group of chemicals with similar structures, only differing in the length of the carbon chain (Figure 1). Not all the phthalates have been declared endocrine disruptors, though some have. Of the phthalates that have been determined to be endocrine disruptors, the primary effects observed have been in the male reproductive system. Di-butyl phthalate (DBP) and di 2-ethylhexyl phthalate (DEHP) shown in Figure 2, in particular have been correlated to sperm malformation and decrease in sperm production and mobility as their blood concentrations have increased in the body (Guo and Kannan 14442-14449). In fact adverse effects on male reproductive systems in laboratory animals due to phthalate exposure is common enough that the adverse effects have been coined “phthalate syndrome” (Witorsch and Thomas 1-30). Di-methyl phthalate (DMP) and DEHP have been shown to be reproductive and developmental toxins (Koniecki et al. 329-

336). Due to the potential health risks, particularly the impairment of fertility and the developmental toxicity in humans, DEHP has been banned from use in cosmetics and personal care products in the EU. DEHP is still used in personal care products in the US, and is predominately found in leave-on personal care products, such as hand lotions (Guo and Kannan 14442-14449). The longer the phthalate has contact with the skin, the higher the level of phthalate absorbed by the body is. Thus leave-on personal care products can lead to higher concentrations of chemicals in the body than rinse-off products. Due to the higher risk of DEHP entering the body via leave-on products, the harmful effects of DEHP on male reproduction, and the concerns of its use in products in Europe, many manufactures in the US have begun to phase out the use of DEHP in their products. However DEHP is also used as a plasticizer, and has been detected in personal care products due to its migration from the plastic packaging into the product (Guo and Kannan 14442-14449).

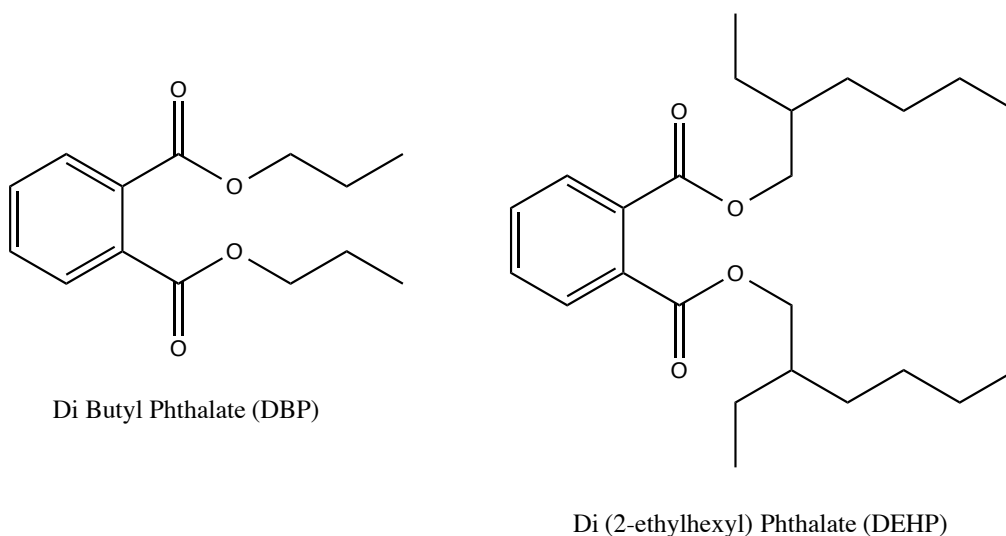


Figure 2: Di-butyl phthalate and di-ethylhexyl phthalate, two phthalates known to be endocrine disrupting compounds, that have known adverse effects in humans.

The most commonly used phthalates in cosmetics are di-ethyl phthalate (DEP), di-butyl phthalate (DBP), and di-methyl phthalate (DMP). DMP and DEP have been determined to be the most readily absorbed phthalates in the skin, with 25.5% of the product applied absorbing into the skin of lab rats in one study (Koniecki et al. 329-336). Phthalates have been found to readily transfer from personal care products into the body, and eventually enter the blood supply, even when the skin is only exposed to the product for short periods of time. The least lipophilic phthalates, or the phthalates with the shortest carbon side chains (DMP & DEP), are able to enter the skin faster than other phthalates despite their slightly low pK_{ow} values (~ 2) (Janjua et al. 5564-5570; Berge et al. 8057-8076). Hence DEP and DMP are two of the most readily absorbed phthalates despite other phthalates having pK_{ow} values within the optimal absorption range. Unfortunately, they are also two of the most common phthalates found in cosmetics, which tend to be leave-on products, allowing the phthalates enough time to easily absorb into the skin (Koniecki et al. 329-336; "Phthalates | Cosmetics Info."). DMP is a common ingredient in deodorants, and DEP is a common ingredient in many fragrances used in products, including actual perfumes and colognes (Guo and Kannan 14442-14449). In fact, greater than 99% of the exposure to DEP in humans is expected to come from perfumes and other fragrances based on one study (Guo and Kannan 14442-14449). Another study found that in products that contained the word "parfum" (the EU ingredient label equivalent of "fragrance"), on the ingredients list had over 1000 μg of DEP/g of product (Koniecki et al. 329-336). This same study also determined that due to the high concentrations of DEP in such products, the average use of these products would lead to a total daily maximum exposure to DEP of about 78 $\mu\text{g}/\text{kg}$ of body weight/day (Koniecki et al. 329-336).

In addition to potential reproductive effects, exposure to phthalates has also been shown to increase the risk of developing allergies, asthma, and eczema in patients (Koniecki et al. 329-336; Guo and Kannan 14442-14449; Braun, Sathyanarayana, and Hauser 247-254). Phthalate exposure has also been linked to reduced cognitive function and decreased social responses, with some of the most common effects observed being ADHD, autism, and reduced masculine behavior in boys (Martina, Weiss, and Swan 1427-1433; Braun, Sathyanarayana, and Hauser 247-254). Some of these studies and potential health effects are still highly disputed.

Phthalates are considered to have short half-lives in humans. Phthalates are readily metabolized and excreted from the human body, with a removal half-life rate of a few hours to a day depending on the study. In addition phthalates are readily hydrolyzed, meaning that they are able to be metabolized by the body and can then be excreted rather than accumulate in the body's fat cells ((Braun, Sathyanarayana, and Hauser 247-254; Guo and Kannan 14442-14449). Both the short half-lives of phthalates and the ability of the body to excrete them reduces the length of exposure to phthalates. However, most of the exposure to phthalates from personal care products comes from dermal absorption. By absorbing a chemical dermally, the chemical is able to circumvent the normal liver metabolism, and instead enters the blood stream directly (Martina, Weiss, and Swan 1427-1433). This dermal, rather than ingested exposure route, can affect the rate and ability of the body to metabolize phthalates, though the effects of dermal exposure are not yet well understood. Despite the fact that phthalates are not expected to accumulate, and generally rapidly leave the body, some scientists suspect that that in reality, small portions of the phthalates that are dermally absorbed are able to accumulate in the fatty tissue and are then slowly released into the body

over time (Martina, Weiss, and Swan 1427-1433). These are most likely the phthalates with the longer carbon side chains (DEHP) that have higher pK_{ow} 's (~7-9) closer to the optimal absorption range and range most likely to accumulate in the body (Berge et al. 8057-8076).

Another major issue with phthalates, despite their suspected short half lives, is that the average individual is continuously exposed to phthalates throughout their daily lives, and so phthalates are constantly present in the body, whether they are able to accumulate or not. This constant exposure to phthalates, and their versatile ability to be in products designed for all areas of our bodies (shampoos, lotions, lipsticks, deodorants, etc.) has allowed phthalates to be present not just continuously in our bodies, but also throughout our bodies. Phthalates have been detected in breast tissue, including breast milk, plasma, urine (which would be expected due to our general ability to excrete the product), and even in amniotic fluid (Koniecki et al. 329-336; Guo and Kannan 14442-14449; Braun, Sathyanarayana, and Hauser 247-254). Detecting phthalates in amniotic fluid means that phthalates have the ability to cross the placenta, thereby exposing the fetus to the phthalates the mother has been exposed to. Sadly, high concentrations of phthalates are considered to have potential adverse affects on normal human development (Braun, Sathyanarayana, and Hauser 247-254). Thus not only can high concentrations of phthalates be considered bad for the mother's health, but they are able to cross the placental barrier and expose the fetus to potentially more harmful health effects as well.

High levels of phthalate exposure in the womb have been associated with reduced fetal testosterone (Hotchkiss et al. 235-259). Exposure of a fetus to endocrine disrupting compounds has been shown to have vastly different effects, at even very low concentrations, depending on the developmental state of the fetus at the time of the exposure (Schug et al.

204-215). For example, if a fetus has already developed its reproductive system, then exposure to reproductive toxins will have little effect. However if the exposure occurs during the time of genital development, then the reproductive system can be greatly altered. This trend continues throughout the organisms' life, with some phases of life (adolescence and menopause) being more susceptible to endocrine disruptors than other phases of the organisms' lifetime.

Phthalates in the Environment:

Almost all personal care products are washed down the drain due to the nature of their use. Phthalates can be washed down the drain during application of rinse-off personal care products in the shower (shampoo). Phthalates may also be washed down the drain after the application of leave-on products (lotions or cosmetics), as those products are washed off the skin. In addition, any chemical that enters the body can subsequently be flushed down the drain, as the chemical is removed from the body through excretion. As well as being present in personal care products that are washed down the drain, phthalates are also able to enter the body, and thus can enter domestic wastewater in multiple everyday scenarios. The daily use of phthalates by humans continuously introduces phthalates into domestic wastewater, meaning that phthalates are also a constant and ubiquitous contaminant in the environment.

Many water treatment facilities are unable to properly remove most of the chemicals found in personal care products, particularly phthalates from wastewater. The wastewater treatment process may be able to remove some, just not all, of the chemical pollutants. It may alter the chemical structure of a single pollutant in order to “remove” the original pollutant

from the water, or as a way to make the original pollutant easier to treat, by targeting the newly altered chemical, rather than the original, for removal from the wastewater. In some cases the water treatment process may simply be unable to remove the chemical from the wastewater at all. Because of these limitations in wastewater treatment facilities, the chemical originally found in the wastewater, and any additional metabolites of the original chemical, may be present after the treatment process is complete. At this point the effluent, or treated water, is added back into natural aquatic areas, which introduces these chemicals into aquatic environments. Many chemicals that are washed down the drain in homes, commonly reach the environment through wastewater treatment plants, where they can become air, water, or soil contaminants (Figure 3).

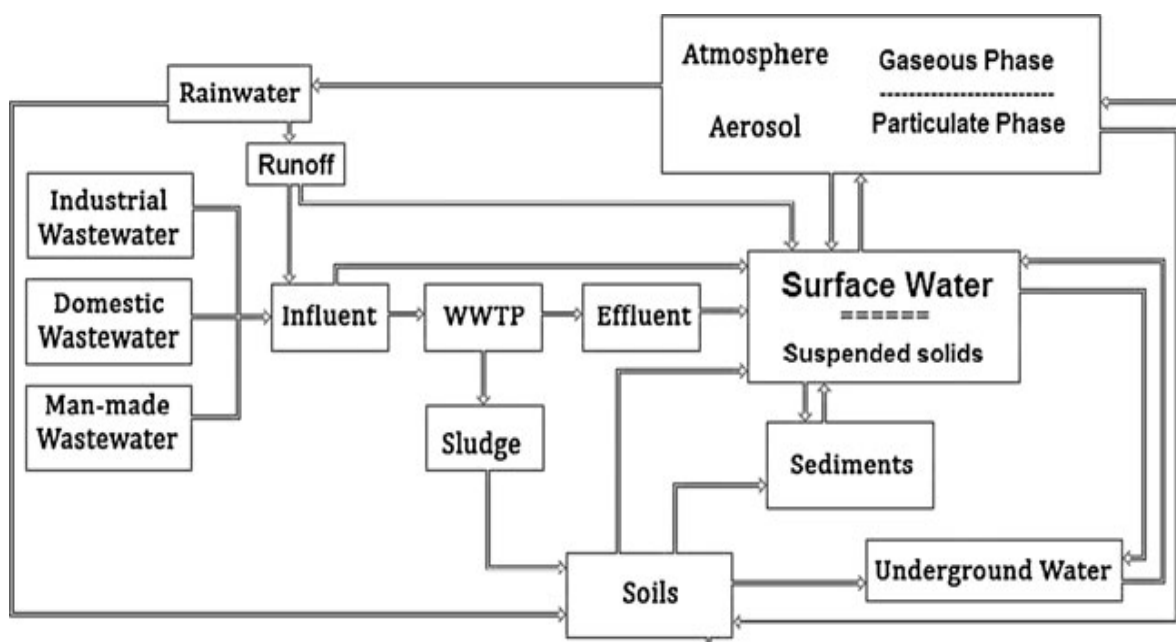


Figure 3: A schematic of the different environmental domains chemicals leaving a wastewater treatment plant (WWTP) can enter, and how those domains interact with each other (Berge et al. 8057-8076).

The routine usage of phthalate containing personal care products results in a continuous presence of phthalates in wastewater effluent, which in turn leads to chronic

exposure of aquatic organisms to phthalates as the effluent is released into aquatic ecosystems. Exposure of aquatic organisms to the same chemicals as humans, suggests similar potential health risks as those observed in humans. In fact, some animal studies have shown that the exposure to phthalates and their metabolites can have the same harmful effects on the male reproductive system of aquatic organisms, as those observed in humans. The health effects can even be more severe in aquatic organisms due to their smaller size compared to humans. Smaller organisms can experience the same health effects seen in humans at lower exposure levels, so even lower exposure rates can have adverse effects on these organisms. Beyond environmental exposure, many hydrophilic water pollutants tend to enter the bodies of aquatic organisms and accumulate, since they preferentially associate with fatty tissue over water. Thus aquatic organisms can be subject to large body burdens of lipophilic water pollutants, which they are unable to remove from their fatty tissue. These pollutants can quickly accumulate in the bodies of aquatic organisms, leading to higher, and chronic, exposures. These lipophilic compounds can transfer from the fatty tissue of smaller organisms into the fatty tissues of larger organisms, higher in the food chain, which eat these contaminated smaller organisms. Organisms higher in the food chain may have larger concentrations of contaminants in their bodies due to the quantity of smaller contaminated organisms they eat.

As Figure 3 shows, phthalates are not just released into the environment as water contaminants. The wastewater treatment process can also create air pollutants. As the wastewater is churned to aerate it, which aids in the breaking down of many chemicals, small aerosols of water and chemical droplets can become airborne and chemicals present in the wastewater can volatilize into a gaseous form. Both processes can allow water pollutants to

become atmospheric pollutants (Berge et al. 8057-8076). DEHP, the phthalate that was restricted in European cosmetics because of its health concerns, is one of the phthalates detected in the aerosols emitted by wastewater treatment facilities. It has been found to be one of the most abundant phthalates in the air. This same study determined that although phthalates can be found in aerosols, they prefer the gaseous phase. Between 30-70% of phthalates have been found as air pollutants are in the gaseous phase, with the shorter chained phthalates (DMP & DEP) being the most abundant air pollutants (Langer et al. 78-87). Both the aerosol and gaseous forms of phthalate air pollution can deposit out of the air, onto the ground, or back into different aquatic systems. Atmospheric phthalates are easily degraded in the atmosphere, and an average degradation between 7-15 days has been determined.

The main removal of phthalates from wastewater is considered to be sorption onto sludge. Wastewater includes hydrophobic solids, collectively known as sludge, that are physically removed prior to any other form of water treatment in many water treatment plants. Thus sorption onto these solids can be a major route of removal for many hydrophobic chemicals present in wastewater, which do not remain in aqueous settings. Phthalates, which have low water solubilities, tend to sorb onto the sludge present in wastewater. This sludge may then be spread on land as a form of fertilizer, allowing phthalates to enter the soil, be taken up by plants, or enter the bodies of soil organisms like earthworms (Api 97-108). Not every phthalate is equally distributed between land and water. Figure 4 depicts the different percentages of six phthalates distributed among different aspects of the environment.

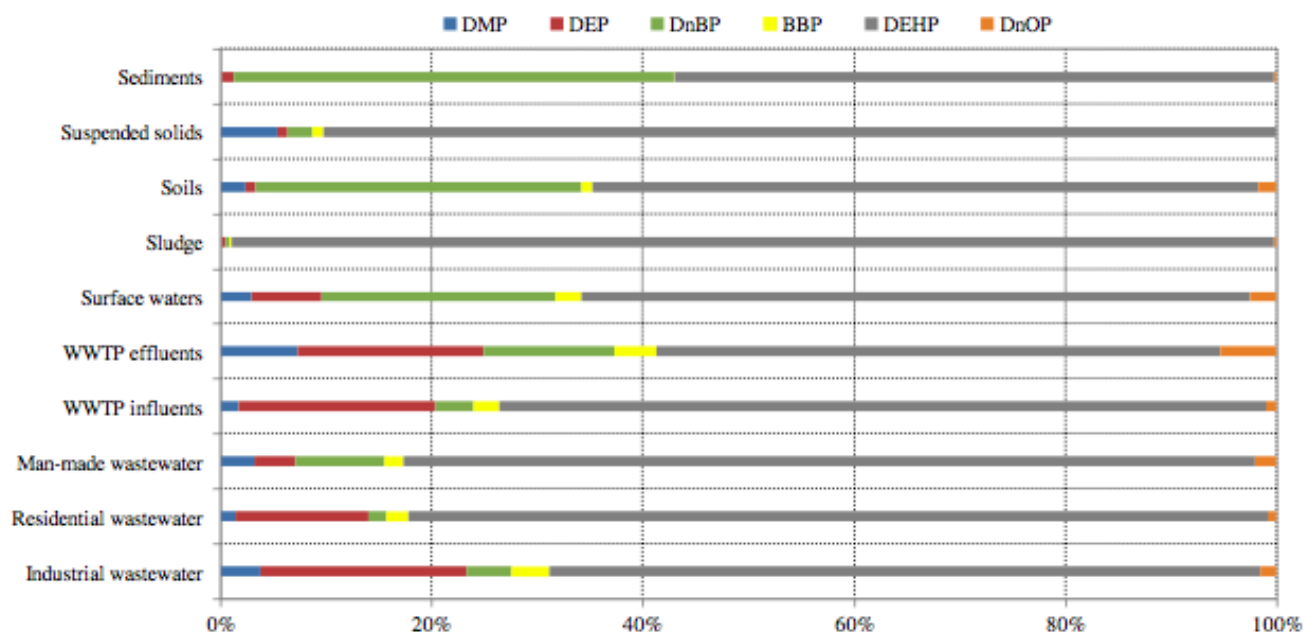


Figure 4: A comparison of the distribution of six phthalates in different aspects of the environment due to wastewater treatment (Berge et al. 8057-8076)(Zolfaghari et al. 281-293).

The more abundantly used phthalates in personal care products tend to have shorter carbon chains. These compounds containing shorter length chains are more likely to volatilize and enter the environment through the air. They are also more soluble in water than their longer chained counterparts and thus might be less likely to sorb onto sludge or into an aquatic organism than the longer length carbon chain phthalates. These longer chain phthalates, though less abundant, are unfortunately also the phthalates that are more likely to have the worst health effects, and are also more likely to be endocrine disruptors. These phthalates are also the ones that are more hydrophobic, and so are more likely to enter aquatic organisms or sorb onto sludge and soils. Therefore, the phthalates with the worst potential health affects, are also the phthalates most likely to enter and bioaccumulate in organisms' fatty tissues. It is also important to note that environmental contamination is not just harmful to the plants and organisms exposed to phthalates, but that exposure and uptake of phthalates

in aquatic organisms and plants, can also re-expose humans to these harmful pollutants through food (Figure 5).

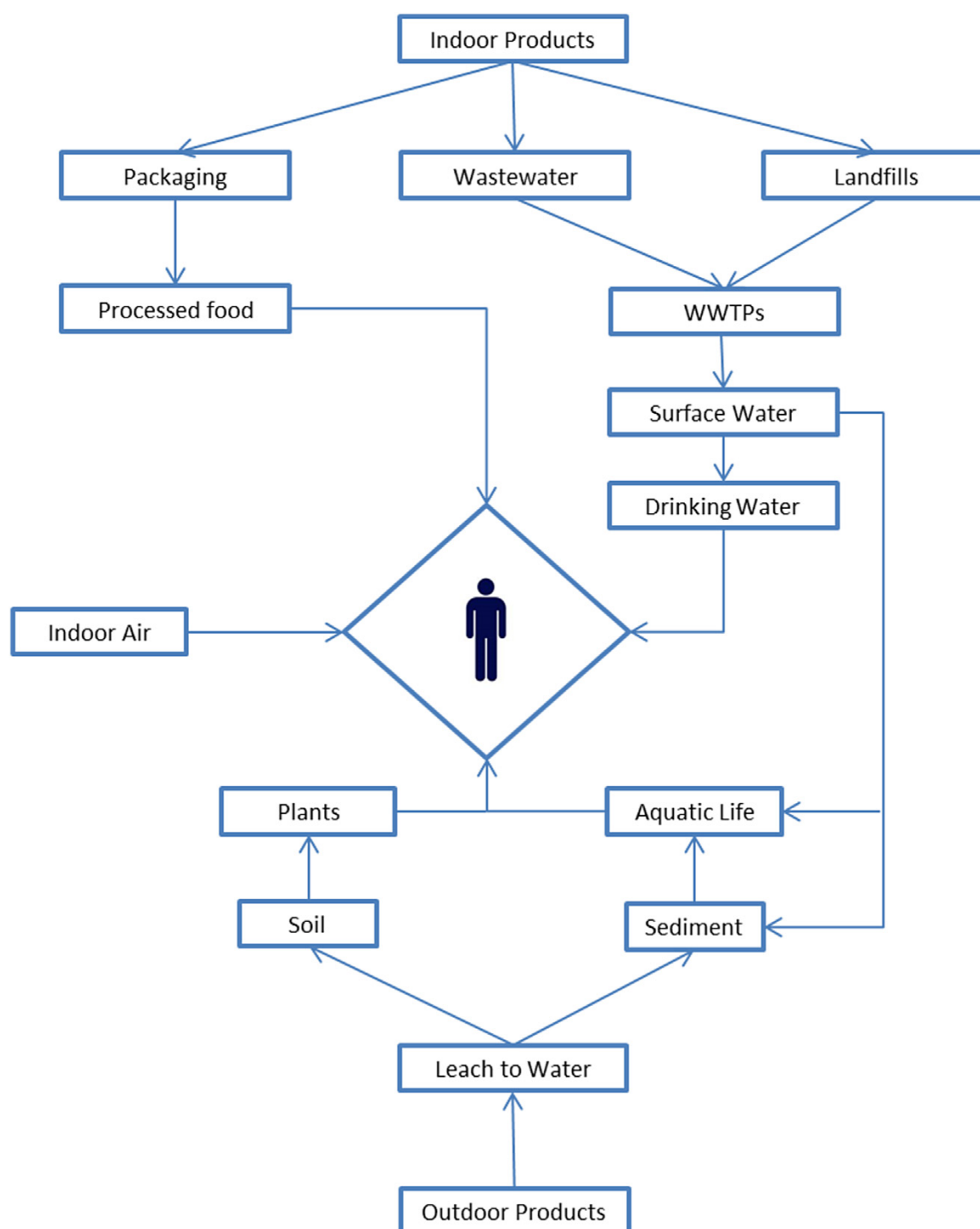


Figure 5: A schematic of the different routes of exposure to phthalates for humans (Zolfaghari et al. 281-293).

Parabens:

Paraben Usage:

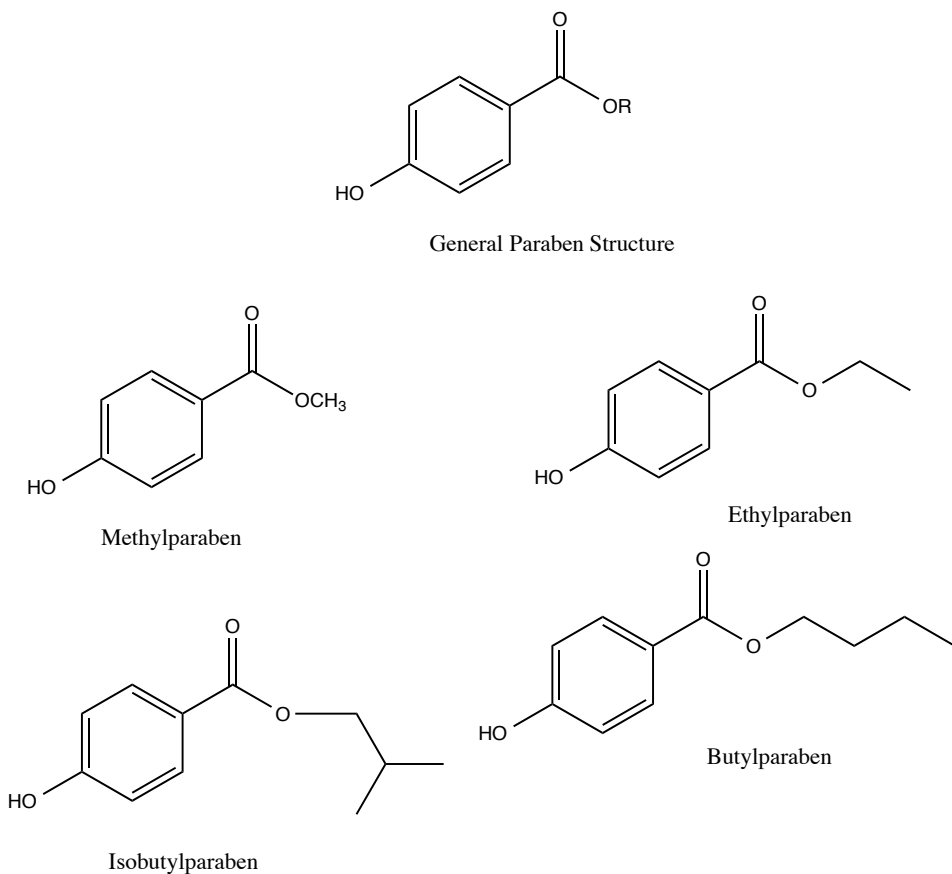


Figure 6: The chemical structures of four parabens, depicting how carbon side chain length and branching can change.

Parabens have similar chemical structures to phthalates, as can be seen in Figure 6. Like phthalates, the term paraben refers to a class of chemicals that can vary based on the length of their carbon side chain. Parabens are used as preservatives and antimicrobials in a variety of consumer products, including cosmetics, to help preserve the shelf life of the

product. Parabens are commonly used in cosmetics due to their antibacterial activity and their stability at different temperatures and pH's. This allows parabens to be used in a variety of different products without concern that the storage temperature of the product will degrade the antimicrobial activity of the paraben. In addition, parabens do not alter or react with the active ingredients in products, due to the fact that parabens are fairly inert. However, the real driving force behind the large usage of parabens is that they are extremely inexpensive (Karpuzoglu, Holladay, and Gogal 321-335). Due to the wide range of stabilities and the relatively low costs, parabens are commonly used as the antimicrobial agent in a large variety of cosmetics and personal care products including foundations, powders, eye shadows, mascaras, lip glosses, lipsticks, nail polishes, lotions, sunscreens, deodorants, toothpastes, shampoos, and other hair care products (Karpuzoglu, Holladay, and Gogal 321-335; "Paraben Information | Cosmetics Info."). In fact, in 1984 it was reported that more than 13,000 cosmetic products alone contained parabens, and in 1987, that 7,000 kg of parabens were used to make personal care products specifically (Karpuzoglu, Holladay, and Gogal 321-335). Methyl and ethyl paraben are the two most commonly used parabens in cosmetic products (Soni et al. 1335-1373). Both the number of products containing parabens and the amount of parabens used overall in such products are suspected to have greatly increased since those studies were performed in the 1980's. Tables of the usage of five different parabens in personal care products and cosmetics from the 1980's study can be seen in Tables 3 & 4. Due to the frequent use of parabens in personal care products, humans have a high rate of exposure to parabens. Determining the safety of parabens in humans and the environment is therefore crucial to understanding the full effects of parabens.

Table 3: Frequency of use and percent concentration of five parabens in personal care products (PCP) (Karpuzoglu, Holladay, and Gogal 321-335).

PCP (number of products)	Methylparaben		Propylparaben		Ethylparaben		Butylparaben		Isobutylparaben	
	Frequency of use	Percent in product	Frequency of use	Percent in product	Frequency of use	Percent in product	Frequency of use	Percent in product	Frequency of use	Percent in product
Cleansing creams, lotions, or gels (1009)	533	0.16–0.4%	403	0.03–0.3%	181	0.0006–0.54%	195	0.0006–0.54%	67	0.003–0.1%
Moisturizers (1200)	787	0.07–0.4%	591	0.05–0.35%	268	0.001–0.3%	278	0.06–0.2%	67	0.0002–0.02%
Face and neck skin care (546)	317	0.2–0.44%	215	0.03–0.35%	169	0.03–0.3%	157	0.09–0.4%	75	0.02–0.09%
Body skin care (creams, lotions etc.) (992)	631	0.15–0.4%	478	0.1–0.4%	153	0.001–0.4%	157	0.09–0.4%	52	0.02–0.4%
Night skin care (229)	167	0.1–0.5%	135	0.001–0.3%	64	0.0001–0.25%	65	0.04–0.15%	14	—
Deodorants (281)	35	0.0008–0.3%	29	0.002–0.2%	10	0.002–0.1%	10	0.002%	3	0.002%
Sunscreen skin care (Creams, gels, sprays, lotions) (138)	63	0.15–0.4%	61	0.1–0.3%	22	0.04–0.2%	28	0.03–0.4%	9	0.02%
Shampoos (1022)	381	0.1–0.4%	227	0.04–0.4%	108	0.03–0.2%	108	0.01–0.25%	38	0.02–0.1%
Hair conditioners (715)	331	0.1–0.4%	183	0.03–0.2%	33	0.001–0.3%	49	0.02–0.25%	12	0.01–0.02%

Table 4: Frequency of use and percent concentration of five parabens in cosmetic products (Karpuzoglu, Holladay, and Gogal 321-335).

Cosmetic products	Methylparaben		Propylparaben		Ethylparaben		Butylparaben		Isobutylparaben	
	Frequency of use	Percent in product	Frequency of use	Percent in product	Frequency of use	Percent in product	Frequency of use	Percent in product	Frequency of use	Percent in product
Eyes (number of products)										
Eye shadow (1061)	613	0.15–0.5%	541	0.1–0.5%	295	0.06–0.49%	199	0.05–0.3%	3	0.05–0.4%
Mascara (308)	213	0.25–0.54%	190	0.1–0.32%	127	0.00002–0.4%	80	0.00002–0.21%	17	0.000007–0.1%
Eyeliner (liquid or pencil) (639)	485	0.13–0.6%	477	0.05–0.4%	23	0.03–0.4%	398	0.05–0.2%	9	0.02–0.1%
Eyebrow pencil (124)	77	0.1–0.35%	83	0.13–0.2%	5	0.4%	60	0.05–0.1%	4	0.06%
Eye makeup remover (114)	67	0.07–0.4%	45	0.05–0.15%	17	0.03–0.3%	27	0.07–0.15%	6	0.02%
Face (number of products)										
Foundations (530)	296	0.16–0.7%	325	0.05–0.4%	150	0.001–0.5%	96	0.06–0.2%	15	0.00001–0.06%
Makeup Base (i.e., primers) (273)	189	0.1–0.3%	193	0.02–0.5%	35	0.00006–0.35%	51	0.00006–0.1%	1	0.00003–0.02%
Powders (447)	282	0.1–0.5%	250	0.1–0.5%	119	0.04–0.5%	67	0.07–0.14%	6	0.00001–0.04%
Blushes (cream or powder) (459)	338	0.17–0.6%	308	0.1–0.6%	84	0.04–0.3%	35	0.07–0.2%	2	0.00001–0.04%
Lips										
Lipstick (1681)	286	0.15–1%	520	0.1–0.62%	72	0.0002–0.2%	218	0.0008–0.1%	11	0.0001–0.4%
Baby products (number of products)										
Shampoos (38)	4	—	4	0.1%	1	—	2	—	1	—
Creams, lotions, oils, or powders (67)	33	0.2–0.4%	31	0.2%	12	—	21	0.05%	5	—

Health Effects:

Like phthalates, parabens are also known endocrine disrupting compounds, and have been found to affect the sexual reproduction of males. Parabens have been observed to reduce sperm production and to decrease the length of the reproductive tract in animal studies. The

longer and more branched the carbon chain of the paraben is, the more effective the antimicrobial ability of the paraben additive is. Unfortunately, the longer and the more branched the chain length is, the more estrogenic activity the paraben has been reported to have (Witorsch and Thomas 1-30; Karpuzoglu, Holladay, and Gogal 321-335; Boberg et al. 301-312).

Butylparaben has been shown to adversely affect the reproductive development of males exposed to the chemical while in the womb or during infancy. Adverse effects of parabens have been observed below the recommended safety level of 1000 mg/kg of body weight/day (Boberg et al. 301-312). In fact the effects of parabens have been observed at environmentally relevant concentrations (Karpuzoglu, Holladay, and Gogal 321-335). This means that the average exposure of parabens from everyday environmental exposure is high enough to cause adverse effects. The environmental concentrations of parabens are so high that even groups of people who have little or no paraben exposure from their daily product practices, have high enough concentrations of parabens from environmental exposure to cause adverse effects in their bodies.

Parabens are able to enter the body, and it is expected that they are removed quickly from the human body rather than accumulate in the fatty tissue, since even the pK_{ow} 's of the parabens with the longest carbon side chain are below 4 (Tavares et al. 1-7). Although parabens are so commonly used in a variety of products, that continuous exposure from repeated use of one product, or usage of a mixture of products that contain parabens has the potential to cause accumulation of parabens in the body, since the rate of parabens entering the body is faster than the rate the body can remove them. There is the potential for a continuous presence of parabens in the human body due to the frequency of use of paraben-

containing products. One study has suggested that chronic topical application of parabens has the potential to lead to prolonged estrogenic effects.

The longer and the more branched the carbon side chain is, the longer the paraben is expected to stay in the body, and the greater the endocrine disrupting activity of the paraben is. Therefore the parabens that have the greatest health risks are the parabens that remain in our bodies for the longest period of time. However, the longer the chain length, the less likely the paraben is expected to be absorbed into the body, though some longer-chained parabens have been observed in humans. Some studies have suggested that the skin penetration enhancers added to most hand lotions to increase the depth of the smoothing and moisture retention activities of the hand lotions, also allows these longer chained parabens to penetrate a normally impenetrable skin barrier. Studies in adult mice have also shown that exposure to parabens have the potential to alter brain development, damage the development of the immune system, and alter the development of social behaviors such as explorative, emotional, and learning behaviors (Karpuzoglu, Holladay, and Gogal 321-335). Parabens have also been detected in the placenta, meaning they are able cross from the mother's blood, into the blood of the fetus, exposing the fetus to the parabens' potential harmful health effects. As well as the health effects the mother can experience from endocrine disrupting compounds, exposure to these chemicals in the womb has been linked to developing childhood obesity and diabetes (De Coster and van Larebeke 713696)

Interestingly, the health effects of parabens have been determined to be more extreme on one side of the body. This is suspected to be due to a right-hand bias. A majority of the population is right-handed, and prefer to apply personal care products with their right hands, leading to a right-handed bias, in which one side of the body receives more application of

personal care products than the other. The larger application of products in turn corresponds to a larger concentration of chemicals on that side of the body, and thus to increased health effects. This right-handed bias is most likely present for all chemicals in personal care products, though it has only been referred to in relation to parabens.

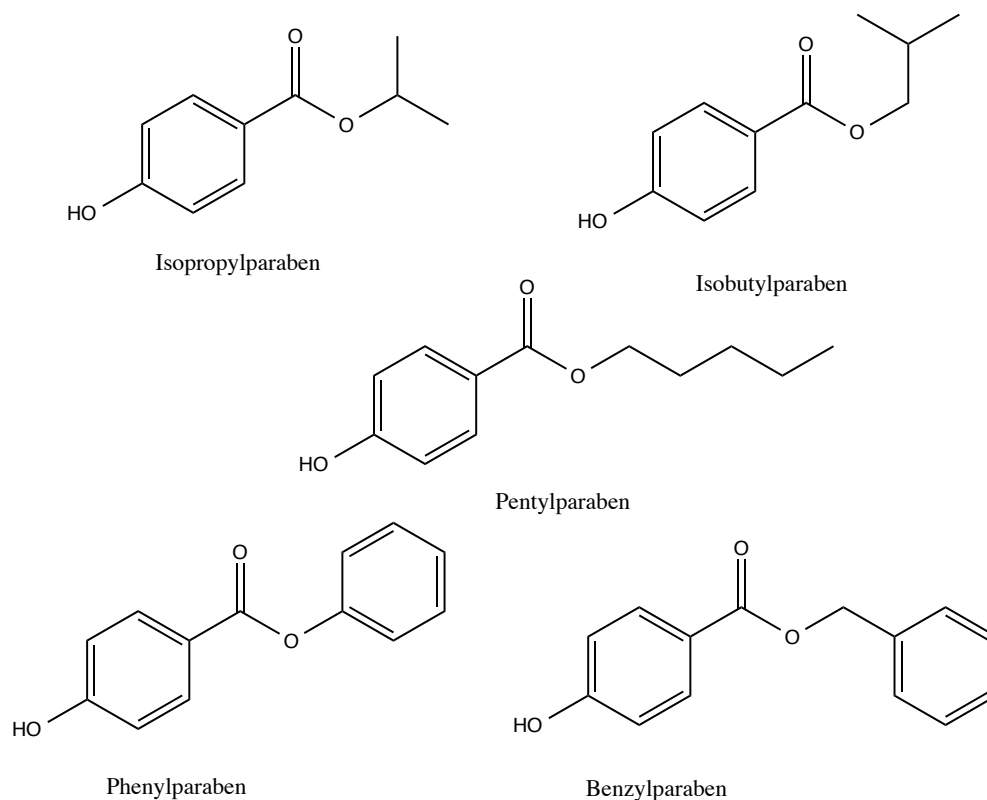


Figure 7: Five parabens available for use in personal care products in the US but banned for use in the European Union.

The overall safety of parabens is highly disputed. The general consensus is that the health effects of parabens and their endocrine-disrupting abilities are negligible. However one study has shown that high enough concentrations of parabens were dermally absorbed, after application of an average dosage of a paraben-containing lotion product, to cause significant estrogen mimicking effects. This could be due to the effects a difference in formulation of

products can cause. A realistic risk assessment should take into account the combined amount of a single paraben from the use of multiple personal care products, as well as the mixture effects (potential additive effects) of other parabens and other chemicals present in the product. The various routes of exposure to the same chemical can also alter the effect the chemical has. The EU has banned five different parabens, which can be seen in Figure 7, due to their lack of sufficient testing data, in part including the lack of data on the effects of repeated usage, chemical mixtures, and alternate routes of exposure (Karpuzoglu, Holladay, and Gogal 321-335).

Parabens and Breast Cancer:

One of the most disputed health effects of parabens is breast cancer. Breast cancer has been increasing throughout the world in a linear fashion. This is an unnatural increase in the number of natural cancers, but does correspond with the increased usage of underarm cosmetics, particularly in developed countries such as the US and the UK. In addition to the incidence of breast cancer dramatically and continuously increasing, only certain types of breast cancers are increasing. This includes an increase in the frequency of breast cancers seen in the upper outer quadrant of the breast, the region in which underarm cosmetics are applied to the body (Darbre and Harvey 561-578). These underarm cosmetics are intended to be left on the skin, and thus the chemicals present in such products have time to absorb into this region of the body. Many of the chemicals, including parabens, observed in that region of the breast tissue are oestrogenic (estrogen active hormone) compounds, which have been shown to trigger breast cancer. In fact parabens have been found intact in breast tissue and breast

milk. The parabens have been found to be able to pass through the skin into the body un-metabolized, as is common for many dermally absorbed chemicals.

Methylparaben is the most commonly used paraben, and the paraben used in the highest concentrations in personal care products. Despite being the least lipophilic paraben, methylparaben has been found to be the paraben that is able to penetrate the furthest into the human body after dermal application. Methyl paraben is supposedly the paraben that is the easiest and quickest to remove from the body. One animal study showed that 60% of methylparaben present in a dermally applied product was able to be absorbed into the body intact within 8 hours. However, human skin is suspected of metabolizing parabens slower than animal skin, suggesting that the animal studies underestimate the actual concentration of parabens present in, and absorbed into, the human body. This suggests that 60% or more of the methylparaben present in a leave-on-product such as deodorant, would be able to penetrate into the breast tissue throughout the day (Darbre and Harvey 561-578). The mechanisms causing breast cancers to form in the upper outer quadrant of the breast is not yet fully known, although it is thought that the risk of cancer is increased due to cell damage from topically applied cosmetics. There is a potential that the higher the amount of chemicals absorbed into this region of the skin from personal care products, the greater the risk of developing breast cancer in that region is.

Other factors are able to increase the absorption of parabens into the skin. The formulation of dermally applied cosmetic products has been shown to affect the dermal penetration of chemicals in these products, though the effects of the different formulations are currently unknown. This is a commonly observed problem with all personal care products. The different mixtures of chemicals can significantly alter the amount of absorption of

different chemicals into the body, as well as their health effects, especially if they are known endocrine disruptors. Mixtures of endocrine disruptors can have additive (increased) or negative (decreased) effects in which the endocrine disrupting powers of the individual chemicals can either be enhanced or decreased due to the presence of other endocrine disrupting chemicals. In fact the presence of phthalates and triclosan in personal care products, has been shown to increase the absorption of the parabens into the body. Furthermore alcohols present in personal care products have been shown to inhibit the skin's ability to metabolize parabens, allowing the parabens to pass into the body intact (Darbre and Harvey 561-578).

Parabens in the Environment:

Parabens, like phthalates, are regularly used and therefore a constant environmental contaminant. The constant presence of parabens in the environment has raised a growing concern of the potential long-term effects parabens may have in wildlife. Parabens are released into aquatic environments through wastewater effluent, much the same way phthalates are able to enter the water system through daily usage and human excretion, before entering the environment as wastewater effluent. During the treatment process, wastewater is treated with chlorine as a disinfectant. However, the chlorine is able to react with parabens to create several chlorinated byproducts that have yet to be tested for health effects (Tavares et al. 1-7). These byproducts can enter the environment or incoming treated domestic water supplies, and expose humans to their potential health risks during regular daily activities.

In aquatic systems, parabens are expected to enter into the sediment or the bodies of aquatic organisms due to their hydrophobic nature. Since parabens are not likely to remain suspended in water, they are expected to accumulate in the water-free areas of aquatic ecosystems over time, particularly in sediments, which unlike aquatic organisms are unable to remove any of the parabens naturally. Parabens also tend to accumulate in the fatty tissue of aquatic organisms. This accumulation exposes aquatic organisms to the same potential health effects seen in humans. Bottom dwelling organisms, which rummage through sediment, or larger fish which accumulate parabens through their diets of smaller, contaminated organisms, can have larger concentrations of parabens in their bodies. Higher body concentrations can worsen the health effect of the paraben. Reproductive effects, similar to those seen in humans, have already been observed in male rainbow trout, which is higher up in aquatic food chains.

Alternatively organisms that are low on the food chains, such as daphnia and algae can be greatly adversely affected by exposure to parabens as well. As small organisms, smaller concentrations of parabens are required to cause the same adverse health effects seen in larger organisms. In addition, hydrophobic compounds suspended in water are more likely to enter smaller organisms, than larger organisms or sediments, in part due simply to the fact that these compounds will most likely encounter, and absorb into, smaller organisms like algae first. Ecotoxicological data has shown that parabens can be toxic to daphnia and algae partly because of their smaller size. Compounds like triclosan and parabens are also used in personal care products as preservatives. Their antimicrobial activities can affect small organisms, and has been shown to be particularly toxic to algae. Even the least lipophilic, therefore the least likely to enter an aquatic organism, and the lowest anti-microbial activity parabens, methyl

and ethyl paraben, have been shown to be toxic to daphnia and algae (Yamamoto et al. 102-111; Brausch and Rand 1518-1532).

Most hydrophobic compounds, which enter sediments are generally persistent, since they tend to be fairly stable once in the sediment, and generally do not re-enter the water unless disturbed. Most sediments are also deep enough in the waterbed to be protected from sunlight and therefore photo-degradation, though these photo-transformations can generally affect hydrophobic compounds suspended in water. With the exception of parabens, most hydrophobic compounds that are able to remain suspended in the water for a long enough time, can be affected by direct sunlight and transformed or degraded. However, laboratory studies have shown that parabens are resistant to sunlight or other forms of degradation, such as microbial, and thus persist in environments (Yamamoto et al. 102-111). Not only do parabens accumulate in organisms and sediments over time, but they are resistant to degradation and are difficult to remove after contamination. The resistance of parabens to photo-degradation is additionally concerning, since parabens are unable to be broken down in atmospheric, aquatic, or terrestrial environments.

Hydrophobic compounds during the wastewater treatment process tend to sorb onto the solid waste present, in the same manner as they sorb into aquatic sediments, as a way to partition themselves out of the aqueous phase. This solid waste can be used as fertilizer for agricultural fields, or simply placed on unused land as waste, allowing the hydrophobic compounds to enter the terrestrial ecosystem as well as aquatic ecosystems. Once on land, these compounds can enter the soil and organisms inhabiting the soil, or be taken up by plants and then distributed into the organisms by ingestion of the contaminated plants. These organisms are then subject to the same potential health risks as humans and aquatic organisms

through their exposure. In this way parabens, and other hydrophobic compounds like phthalates, can become ubiquitous environmental contaminants.

The persistence and accumulation of parabens in the environment, as well as their suspected health effects and toxicity is deeply concerning. Ecological risk assessments for seven individual parabens have suggested parabens only pose a low risk in the environment, despite the reproductive effects already observed in fish (Yamamoto et al. 102-111). However, these risk assessments only looked at individual parabens, and did not include a holistic and more realistic assessment of parabens in combinations or in mixtures with additional chemical contaminants.

4. Triclosan:

What is Triclosan and Why is it Used:

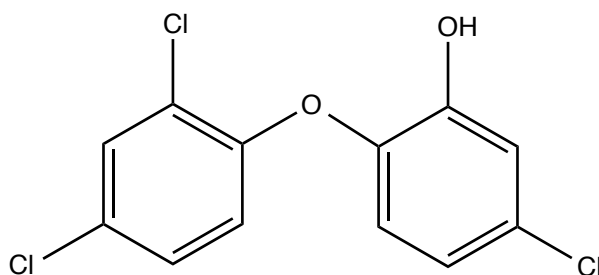


Figure 8: The structure of triclosan, an anti-microbial commonly used in personal care products.

Triclosan, shown in Figure 8, is an anti-microbial used in many soaps, deodorants, shampoos, and face washes, including some cosmetics to prevent bacterial growth. In the case

of soaps and facial cleansers, triclosan is used to reduce bacteria on the body in addition to preventing bacterial growth in the product over time. The most common use of triclosan is in toothpastes and other oral care products. In fact, triclosan is the most commonly used antibacterial agent in oral care products. In addition to being used in products as an anti-microbial, triclosan is also present in some plastic formulations, as a way to help prevent the growth of bacteria in the product held inside the plastic ("Triclosan | Cosmetics Info."). Though not highly regulated, triclosan is known to have a low acute toxicity and as such is generally accepted as a safe compound for use.

Health Effects:

Triclosan is hydrophobic due to its pK_{ow} of 4.8 (Thompson et al. 63-67; Brausch and Rand 1518-1532), but has a limited accumulation in the body, with a majority of the chemical expected to be excreted from the body. However, triclosan has been found in breast milk, meaning that if triclosan is lipophilic enough to enter the fatty breast tissue and milk, it could possibly be lipophilic enough to accumulate in the fatty breast tissue and other parts of the body due to its pK_{ow} value within the 3-7 range. The presence of triclosan in breast milk also means that babies are exposed to triclosan during crucial early phases of development. Throughout the gestational period and infancy, humans are extremely vulnerable to the adverse effects of potential endocrine disruptors like triclosan.

Personal care products that contain triclosan constitute the primary route of exposure to the chemical. However, a majority of the triclosan a consumer is exposed to is rinsed off along with the rest of the product. Only limited amounts of triclosan are expected to remain on

the skin and even less is suspected of being able to penetrate the skin. Thus, though human exposure is prevalent, and expected to rise with the increased interest in antibacterial products, the amount of triclosan actually entering the human body is limited, and the ability to remove triclosan from the body is high. Triclosan is a potential endocrine disruptor, due to its structural similarity to thyroid hormones. Despite its ability to disrupt thyroid homeostasis in humans, and its potential for increasing rates of allergies, triclosan is considered relatively safe in humans. The real health concerns of triclosan exposure include its environmental effects, transformations products, and carcinogenic by-products.

Waste Water Treatment:

Triclosan is among one of the top ten most commonly detected organic compounds found in treated wastewater effluent due to both its frequency in use and high concentrations. Studies have found that 96% of consumer products containing triclosan, which is the primary use of triclosan, are rinsed down the drain, where the chemical subsequently travels to wastewater treatment plants. During the wastewater treatment process, triclosan is either transformed, mainly into methyl-triclosan, or is able to make its way through the treatment process intact (Figure 9). After treatment, triclosan, methyl-triclosan, and many of triclosan's other transformations that are formed during the wastewater treatment process, are dumped into various aquatic environments as wastewater effluent (Dann and Hontela 285-311). Methyl-triclosan has a pK_{ow} of 5 (or 5.2 depending on the study), making it more lipophilic and more likely to accumulate in the fatty tissue of aquatic organisms than triclosan (Lozano et al. 103-108).

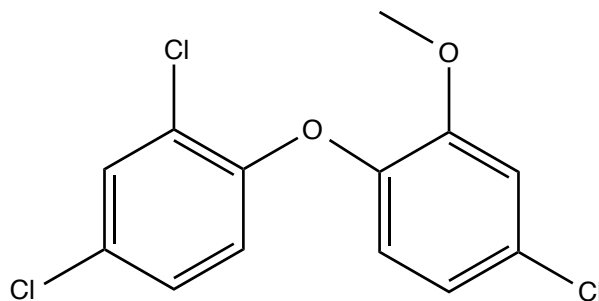


Figure 9: The structure of methyl-triclosan, the most common, transformation of triclosan in the water treatment process.

Triclosan is also able to contaminate the land and soil organisms like earthworms, in a similar manner to parabens, as sludge created during the wastewater treatment process.

Triclosan and other hydrophobic compounds end up in the sludge produced by wastewater treatment plants due to the organic nature of the sludge. This sludge is then usually spread on land as compost, or enters terrestrial lands by wastewater treatment facilities dumping the removed sludge onto unused or wasteland. Triclosan is able to enter plants and soil organisms on land in the same manner parabens and other hydrophobic compounds present in sludge are able to.

Compounds present in wastewater, that are not removed along with the sludge initially, go through the rest of the water treatment process where they can be transformed into new compounds, ultimately removed, or pass through the process unaffected. Triclosan is easily degraded in aerobic conditions, though virtually untouched in anaerobic conditions, both of which can be used to treat wastewater. Due to this polarized degradation characteristic, triclosan's fate through wastewater facilities is extremely dependent on the methods used by the plant to clean the water. Thus the amount of triclosan present in wastewater effluent is extremely variable across water treatment facilities, with the range of removal of triclosan from wastewater between 100% effective to 100% ineffective, depending on the treatment plant and process. Even plants that are able to remove the parent compound

triclosan effectively from the water can still be leaving methyl-triclosan behind as an unwanted transformation product. Methyl-triclosan, though the most common, is not the only transformation or by-product associated with triclosan.

Dioxins and furans, both harmful and environmentally persistent chemicals, are frequently present in products containing triclosan as unintended byproducts created during manufacturing. In addition to being unwanted byproducts, dioxins are also a common photolysis transformation of triclosan, meaning that as triclosan is exposed to sunlight, the molecule breaks down into dioxin, a much more toxic chemical. Two major transformations of triclosan are methyl-triclosan and polychlorinated biphenyls. Polychlorinated biphenyls are created during the wastewater treatment process by undergoing reactions with chlorine, as well as in aquatic environments through photochemical degradation. The two primary polychlorinated biphenol transformations of triclosan, created through light exposure and the chlorination step in the wastewater treatment process, have been marked as priority pollutants by the US EPA due to their toxicity and persistence in the environment over time. Methyl-triclosan is primarily created unintentionally during the wastewater treatment process. In fact methyl-triclosan is such a common transformation product, that it is found in virtually all wastewater treatment plant effluent, and has even been used as an indicator for the presence of treated wastewater effluent.

Triclosan in the Environment:

Table 5: Concentrations of triclosan (TCS) in different aquatic environments (Dann and Hontela 285-311).

Medium	Sample description	Location	Concentration of TCS	Reference
Surface water	Natural streams/rivers	USA	ND ^a to 2.3 $\mu\text{g l}^{-1}$	Kolpin <i>et al.</i> (2002); Morrall <i>et al.</i> (2004)
		Switzerland	ND to 0.074 $\mu\text{g l}^{-1}$	Lindström <i>et al.</i> (2002)
		Germany	ND to 0.01 $\mu\text{g l}^{-1}$	Bester (2005)
		Sweden	ND	Bendz <i>et al.</i> (2005)
		Australia	0.075 $\mu\text{g l}^{-1}$	Ying <i>et al.</i> (2007)
		Japan	<0.0006–0.059 $\mu\text{g l}^{-1}$	Nakada <i>et al.</i> (2008)
	Streams with inputs of raw wastewater	Switzerland	0.011–0.098 $\mu\text{g l}^{-1}$	Singer <i>et al.</i> (2002)
		USA	1.6 $\mu\text{g l}^{-1}$	Halden and Paull (2005)
		USA	0.0075 $\mu\text{g l}^{-1}$	Fair <i>et al.</i> (2009)
Sediment	Freshwater	Switzerland	53 $\mu\text{g kg}^{-1}$	Singer <i>et al.</i> (2002)
		Spain	ND to 35.7 $\mu\text{g kg}^{-1}$	Morales <i>et al.</i> (2005)
	Estuarine	USA	ND to 800 $\mu\text{g kg}^{-1}$	Miller <i>et al.</i> (2008)
	Marine	Spain	0.27–130.7 $\mu\text{g kg}^{-1}$	Agüera <i>et al.</i> (2003)
Sewage sludge	Activated sludge	USA	0.5–15.6 $\mu\text{g g}^{-1}$	McAvoy <i>et al.</i> (2002)
		Spain	0.4–5.4 $\mu\text{g g}^{-1}$	Morales <i>et al.</i> (2005)
		Germany	1.2 $\mu\text{g g}^{-1}$	Bester (2003)
		Canada	0.62–1.45 $\mu\text{g g}^{-1}$	Chu and Metcalfe (2007)
		Australia	90–16 790 $\mu\text{g kg}^{-1}$	Ying and Kookana (2007)
		USA	10 500–30 000 $\mu\text{g kg}^{-1}$	Kinney <i>et al.</i> (2008); Heidler and Halden (2007)
	Biosolids	Spain	1508 $\mu\text{g kg}^{-1}$	Morales <i>et al.</i> (2005)
		Canada	680–12 500 $\mu\text{g kg}^{-1}$	Lee and Peart (2002); Chu and Metcalfe (2007)
WWTP influent	In-flowing waste water	USA	2.70–26.80 $\mu\text{g l}^{-1}$	McAvoy <i>et al.</i> (2002); Halden and Paull (2005); Heidler and Halden (2007); Fair <i>et al.</i> (2009)
		Canada	0.01–4.01 $\mu\text{g l}^{-1}$	Lishman <i>et al.</i> (2006)
		Germany	1.2 $\mu\text{g l}^{-1}$	Bester (2003)
		Sweden	0.38 $\mu\text{g l}^{-1}$	Bendz <i>et al.</i> (2005)
		Japan	2.7–11.9 $\mu\text{g l}^{-1}$	Nakada <i>et al.</i> (2010)
WWTP effluent	Treated water	Switzerland	0.042–0.213 $\mu\text{g l}^{-1}$	Singer <i>et al.</i> (2002)
		Germany	0.01–0.6 $\mu\text{g l}^{-1}$	Bester (2003, 2005)
		Canada	0.01–0.324 $\mu\text{g l}^{-1}$	Lishman <i>et al.</i> (2006)
		USA	0.03–2.7 $\mu\text{g l}^{-1}$	McAvoy <i>et al.</i> (2002); Heidler and Halden (2007); Halden and Paull (2005); Fair <i>et al.</i> (2009)

As an extremely common chemical present in wastewater effluent, methyl-triclosan is also an extremely common environmental contaminant, and has been found in many aquatic systems, particularly those near water treatment plants (Table 5). Methyl-triclosan is

problematic in the environment since it is able to bioaccumulate in aquatic organisms due to its high lipophilicity and optimal pK_{ow} value (~ 5). Like parabens, methyl-triclosan is also resistant to photo-degradation, meaning it is persistent as well as accumulative in the environment. Both methyl-triclosan and triclosan have been found in fish tissue (Table 6), though only methyl-triclosan has been shown to bioaccumulate in aquatic organisms. However, both chemicals have been shown to bioaccumulate in aquatic plants. Algae are particularly sensitive to the two chemicals, which have shown high algal toxicity due to the antibacterial characteristics of the chemicals. The difference between methyl-triclosan and triclosan with respect to bioaccumulation has been linked to the varying stability of the two chemicals at different pH levels, with methyl-triclosan favored in more acidic waters, and the higher pK_{ow} of methyl-triclosan compared to triclosan.

Table 6: Concentrations of triclosan (TCS) in aquatic organisms (Dann and Hontela 285-311).

Organisms	Type of sample	Site description	TCS ($\mu\text{g kg}^{-1}$)	Reference
<i>Algae and invertebrates</i>				
Filamentous algae (<i>Cladophora</i> spp.)	Whole organism	Receiving stream for the city of Denton (TX, USA) WWTP	100–150	Coogan <i>et al.</i> (2007)
	Whole organism		50–400	Coogan and La Point (2008)
Freshwater snails (<i>Helisoma trivolvis</i>)	Muscle		50–300	Coogan and La Point (2008)
<i>Vertebrates</i>				
Rainbow trout (<i>Oncorhynchus mykiss</i>)	Bile	Upstream from WWTP, Sweden (caged);	710	Adolfsson-Erici <i>et al.</i> (2002)
		downstream 2 km from WWTP (caged)	17 000	
Breams, male (<i>Abramis brama</i>)	Bile	River sites (Netherlands)	14 000–80 000	Houtman <i>et al.</i> (2004)
	Muscle	River sites (Germany)	0.25–3.4	Boehmer <i>et al.</i> (2004)
Pelagic fish	Plasma	Detroit River (USA)	0.75–10	Valters <i>et al.</i> (2005)
Atlantic bottlenose dolphins (<i>Tursiops truncatus</i>)	Plasma	Estuary, South Carolina	0.12–0.27	Fair <i>et al.</i> (2009)
		Estuary, Florida	0.025–0.11	
Killer whale (<i>Orcinus orca</i>)	Plasma	Vancouver Aquarium Marine Science Centre	9.0	Bennett <i>et al.</i> (2009)

The characteristics of the aquatic ecosystem can affect the concentrations and the characteristics of chemicals present in the water. The pH, sediment density, and water flow

have been shown to affect the amount of triclosan present in the water. Both the sediment density and the water flow change the amount of sediment present in the aquatic ecosystem, which in turn determines the amount of contamination in the sediment. The contamination level in the sediment is related to the physical amount of sediment present in the ecosystem and where contaminated wastewater effluent will flow towards and deposit pollutant chemicals. Even the seasonality and intensity of the sunlight can have an effect on the amount of contamination. The hours of sunlight and the intensity of that sunlight are dependent on the seasons, with higher amounts of sunlight also corresponding to warmer months. The amount of sunlight, its ability to penetrate into a water body (related to the intensity), and the temperature of the water body increase the amount of photo-degradation of any chemical in water. Therefore, more triclosan can be removed from the environment during the warmer, sunnier months than in winter months, allowing the concentration of the antimicrobial to fluctuate throughout the year. This trend is seen for all environmental contaminants.

In fact, some compounds like those found in sunscreens are generally seasonal contaminants, or even if present throughout the year, are only present in high concentrations for part of the year. In the spring snowmelt can also play a huge role in affecting the concentrations of contaminants in water bodies, resulting in a spike in contaminant concentrations. In geographical areas with lots of snow, pollutants are able to settle into the snow through atmospheric deposition. The longer the winter season, the more chemicals are able to build up in the snow piles and accumulate. When these snow piles begin to melt in the spring nearby water bodies can be flooded with high concentrations of these chemicals at once, creating a spike in the concentrations of multiple contaminants.

In addition to affecting the concentrations of water pollutants over time, the characteristics of the water can affect how the pollutants behave. The pH levels of aquatic systems have also been linked to determining the toxicity of triclosan. The un-ionized form of the antibacterial is the most toxic form, however in most aquatic ecosystems, triclosan exists in its ionized hydrophilic form, reducing its toxicity. Despite its reduced toxicity, triclosan is still harmful to aquatic life, and has also been shown to be more toxic for younger organisms. Triclosan has even been found to alter swimming ability in fish. Even more concerning is that triclosan is more toxic to amphibians than it is to fish, meaning that amphibians are subject to potentially worse adverse effects than altered swimming ability. Algae are even more vulnerable to triclosan's toxicity than amphibians from acute exposure. Tables 7 & 8 show some potential health effects associated with different concentrations of triclosan found across a variety of fish species. When compared to the values found in Tables 5 & 6, some of the same concentrations of triclosan that are found in aquatic systems or in fish tissue are associated with the health effects seen in Tables 7 & 8.

Table 7: The effects of triclosan (TCS) exposures for both freshwater (FW) and marine, or saltwater (SW), aquatic organisms (Dann and Hontela 285-311).

Test species	Life stage	System type	Route of exposure	Test duration	TCS exposure	Endpoint	Reference
<i>Algae</i>							
Phytoplankton (<i>Dunaliella tertiolecta</i>)		SW	Water (static)	Acute (96 h)	3.5 $\mu\text{g l}^{-1}$	EC ₅₀ (population density)	DeLorenzo and Fleming (2008)
Green alga (<i>Selenastrum capricornutum</i>)		FW	Water (static)	Acute (72 h)	4.7 $\mu\text{g l}^{-1}$	EC ₅₀ (growth)	Tatarazako et al. (2004)
Green alga (<i>Scenedesmus subspicatus</i>)		FW	Water (static)	Acute (96 h)	1.4 $\mu\text{g l}^{-1}$	EC ₅₀ (biomass)	Orvos et al. (2002)
Alga (<i>Closterium ehrenbergii</i>)		FW	Water (static)	Acute (48 h)	620 $\mu\text{g l}^{-1}$; 250 $\mu\text{g l}^{-1}$	EC ₅₀ genotoxicity	Ciniglia et al. (2005)
Blue-green alga (<i>Anabaena flos-aquae</i>)		FW	Water (static)	Acute (96 h)	1.6 $\mu\text{g l}^{-1}$	EC ₅₀ (biomass)	Orvos et al. (2002)
<i>Invertebrates</i>							
<i>Daphnia magna</i>		FW	Water (renewal)	Acute (48 h)	390 $\mu\text{g l}^{-1}$	EC ₅₀ NOEC reproduction	Orvos et al. (2002)
				21 days	40 $\mu\text{g l}^{-1}$		
<i>Ceriodaphnia dubia</i>		FW	Water (renewal)	Acute (48 h)	240 $\mu\text{g l}^{-1}$	EC ₅₀ NOEC reproduction	Orvos et al. (2002)
				7 days	182 $\mu\text{g l}^{-1}$		
<i>Chironomus tentans</i>		FW	Water (renewal)	6–7 days	220 $\mu\text{g l}^{-1}$	IC ₅₀ (growth)	Tatarazako et al. (2004)
<i>Hyalella azteca</i>		FW	Water (renewal)	10 days	400 $\mu\text{g l}^{-1}$	LC ₅₀	Dussau et al. (2008)
Grass shrimp (<i>Palaemonetes pugio</i>)	Embryo	SW	Water (renewal)	Acute (96 h)	651 $\mu\text{g l}^{-1}$	LC ₅₀	DeLorenzo et al. (2008)
	Larvae				154 $\mu\text{g l}^{-1}$	LC ₅₀	
	Adult				305 $\mu\text{g l}^{-1}$	LC ₅₀	
Crustacean (<i>Thamnocephalus platyurus</i>)		FW	Water (static)	Acute (24 h)	470 $\mu\text{g l}^{-1}$	LC ₅₀	Kim et al. (2009)
Bivalve (<i>Mytilus galloprovincialis</i>)	Hemocytes	SW	<i>In vitro</i>	Acute (30 min)	1 μM	↓ lysosomal membrane stability	Canesi et al. (2007)
	Whole animal	SW	Injection	Acute (24 h)	2.9 ng g ⁻¹	Altered hemocyte and digestive gland function	Canesi et al. (2007)
Zebra mussel (<i>Dreissena polymorpha</i>)	Hemocytes	FW	<i>In vitro</i>	Acute (60 min)	0.1 μM	Genotoxicity	Binelli et al. (2009a, 2009b)
			<i>In vivo</i>	Acute (96 h)	1 M	Genotoxicity	
Fish	Adult	FW	Water	Acute (96 h)	390 $\mu\text{g l}^{-1}$	LC ₅₀	CIBA (1998)
Rainbow trout (<i>Oncorhynchus mykiss</i>)	Embryo	FW	(flow-through)	61 days	71.3 $\mu\text{g l}^{-1}$	Delayed swim-up ;	Orvos et al. (2002)
				35 days		↓ 35 dph survival;	
						erratic swimming, locked jaw	
Medaka (<i>Oryzias latipes</i>)	Fertilized eggs	FW	Water (renewal)	14 days	313 $\mu\text{g l}^{-1}$	↓ hatching; delayed hatching	Ishibashi et al. (2004)
	Larvae (24 h old)			Acute (96 h)	602 $\mu\text{g l}^{-1}$	LC ₅₀	
	Male fish			21 days	20 $\mu\text{g l}^{-1}$	↑ liver Vtg	
	Fry	FW		Acute (48 h)	350 $\mu\text{g l}^{-1}$	LC ₅₀	Foran et al. (2000)
	Eggs	FW		14 days	400 $\mu\text{g l}^{-1}$	IC ₅₀ (hatching)	Tatarazako et al. (2004)
		SW	<i>In ovo</i> injection	1 day post-fertilization	4.2 ng egg ⁻¹	EC ₅₀ (survival)	Nassef et al. (2010)

Table 8: The endocrine-disrupting effects from triclosan exposure observed in a variety of organisms(Dann and Hontela 285-311).

Test species/system	Life stage	Aquatic system	Route of exposure	Test duration	TCS exposure	Effects	Reference
Fish Medaka (<i>Oryzias latipes</i>)	Embryos	FW	Water	14 days	100 µg l ⁻¹	Weak androgenic (or anti-estrogenic) effect (↑male fin size, slight male bias sex ratio)	Foran <i>et al.</i> (2000)
	Male fish	FW	Water	14 days	20 µg l ⁻¹	Weak estrogenic activity; ↑Vtg in male fish; activity in yeast assay	Ishibashi <i>et al.</i> (2004)
Mosquitofish (<i>Gambusia affinis</i>)	Male fish	FW	Water	35 days	101.3 µg l ⁻¹	↑vitellogenin, ↓sperm count	Raut and Angus (2010)
Bream (<i>Abramis brama</i>)	Bile of male fish	FW	Field sites, Netherlands		No activity up to 0.1 mM	No estrogenic activity detected in ER-CALUX assay	Houtman <i>et al.</i> (2004)
Amphibians North American bullfrog (<i>Rana catesbeiana</i>)	Tadpoles	FW	<i>In vivo</i>	18 days	0.15 µg l ⁻¹	Disruption of T ₃ -dependent developmental metamorphosis processes	Veldhoen <i>et al.</i> (2006)
South African clawed frog (<i>Xenopus laevis</i>)	Tadpoles	FW	<i>In vivo</i>	21 days	1.5 µg l ⁻¹ 0.6–32.4 µg l ⁻¹	↓larval growth; no effect on metamorphosis	Fort <i>et al.</i> (2010)
	Males	FW	Water; i.p. injection	14 days	20–200 µg l ⁻¹ ; inject 4-400 µg g ⁻¹ body weight	No effect on Vtg in males; no effects on CYP1A and EROD; ↓Vtg in i.p. injected males	Matsumura <i>et al.</i> (2005)
Mammals Sheep	Placenta		<i>In vitro</i>		0.6 nM	↓Estrogen sulfonation (IC ₅₀)	James <i>et al.</i> (2010)
Rats (Wistar)	Pre-pubescent males		Oral (gavage)	31 days	200 mg kg ⁻¹ 30 mg kg ⁻¹	No effect on timing of puberty; ↓levels of plasma testosterone and T ₄	Zorrilla <i>et al.</i> (2009)
	Males; isolated Leydig cells		<i>In vivo</i> (daily intubation) <i>In vitro</i>	60 days 2 h	5–20 mg kg ⁻¹ 0.01–10 µM	Disruption of LH, FSH, pregnenolone and testosterone synthesis; ↓mRNA expression of StAR and steroidogenic enzymes	Kumar <i>et al.</i> (2008, 2009)
Rats (Long–Evans)	Adult female		Oral (gavage)	4 days	100 mg kg ⁻¹ day ⁻¹	↓Plasma T ₄	Crofton <i>et al.</i> (2007)
	Female weanlings		Oral (gavage)	4 days	300 mg kg ⁻¹ day ⁻¹	↓Plasma T ₄ and T ₃	Paul <i>et al.</i> (2010)
Human	Adults		brush 2/day with TCS toothpaste	14 days	0.3% w/w TCS	No effect on thyroid status	Allmyr <i>et al.</i> (2009)

Amphibians and fish are exposed to triclosan and its transformation products in part through their primary food source, algae, which accumulate these chemicals. Another large exposure route to triclosan, especially to foraging fish, is its presence in the sediment. Due to its low solubility in water and high lipophilicity, about 50% of the triclosan in the water treatment process sorbs onto sediments in the water, and ends up in biosolids. This allows the triclosan to settle into sediments in aquatic systems, where it is able to persist. Triclosan has

even been found to still be present in 30-year-old sediments. This persistence is most likely due to the anaerobic and dark conditions of the sediment, preventing further degradation of the chemical. In addition to the fact that once hydrophobic chemicals enter sediments, they rarely leave without a disturbance.

Additional Concerns:

In Sweden 25% of toothpaste brands contain triclosan, meaning 2 tons of the chemical are used per year for toothpaste alone in only one country. The use of triclosan in other personal care products in Sweden amounts to 300 kg of triclosan produced annually (Dann and Hontela 285-311). Worldwide triclosan is produced in quantities greater than 15,000 tons per year. Such large quantities explain why triclosan is so prevalent in the environment. Due to its presence in personal care products that get washed down the drain, and the large quantities of the chemical produced for use each year, methyl-triclosan, a transformation product present in virtually all domestic wastewater treatment effluent, and other triclosan transformations are continuously introduced into aquatic systems.

Another concern, beyond the environmental and health effects, of the frequent use of triclosan has recently been raised. Triclosan is predominately used as an anti-microbial in personal care products like soaps and hand sanitizers. The high usage of these products has lead to high levels of bacteria exposed to triclosan. As with all anti-bacterials, the more frequent the use, the greater the chance of resistant bacterial strains developing. With the large quantities of triclosan introduced into the environment, where it is able to persist, the likelihood of bacteria developing a resistance to triclosan is high. Some studies have already

detected triclosan resistant bacteria in the lab. Though these studies differ in their opinion of whether resistant bacteria, which has only been observed in a laboratory setting, will be able to develop in real world settings. Other studies have shown that soaps containing triclosan do not have any improvement in reducing the amount of bacteria on the body (in the case of body cleansing products), or in preventing disease (in the case of hand sanitizer like products). This suggests that triclosan's largest usage, and the usage that is expected to increase over time, is not effective at reducing bacteria. Which begs the question, if triclosan is unable to significantly reduce bacteria in personal care products or on the body, are its environmental and health effects worth its use in such products? These personal care products do not include oral care products, in which triclosan has been shown to be able to reduce plaque and gingivitis, but rather other cleansing products such as soaps and hand sanitizers. The high usage of these ineffective products have all the health and environmental risks, as well as the risk of developing triclosan-resistant bacteria, but none of the health benefits for humans. In light of the risks associated with, and the ineffectiveness of, these products, perhaps it is best if the use of triclosan is restricted to use in oral care products only.

Another concern with triclosan's use in non-oral care personal care products is it can undergo a reaction with free chlorine present in tap water, a normal chemical used to clean and disinfect domestic water, to form chloroform. Chloroform can be formed from the daily use of household products containing triclosan when mixed with treated tap water. This conversion into chloroform increases with higher water temperatures. This small exposure to chloroform is generally considered not to be a significant risk to human health. However when chloroform exposure occurs, in combination with exposures of other chlorinated products, it suspected to become problematic.

Fragrances:

What are Fragrances and Why are They Used:

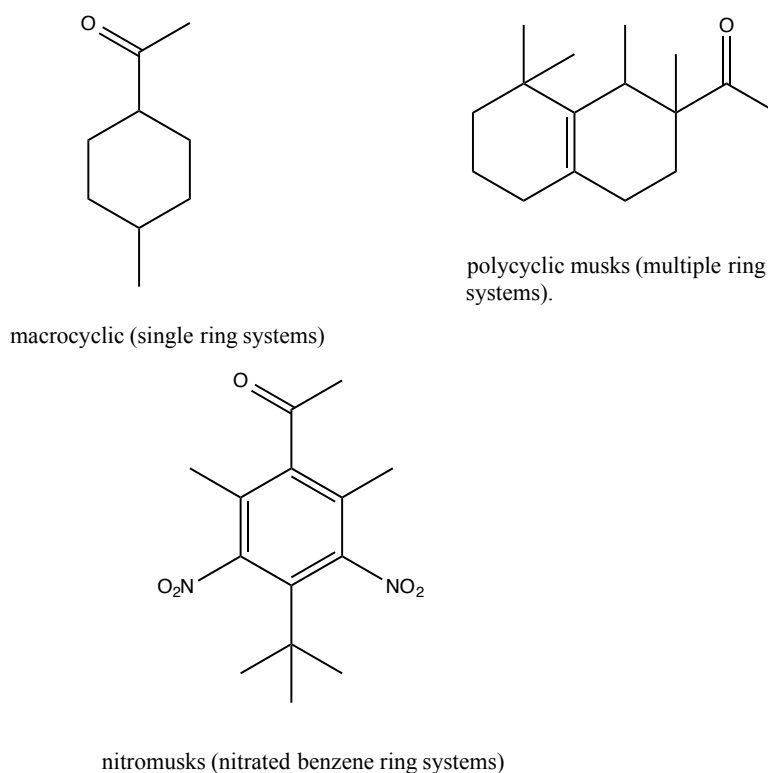


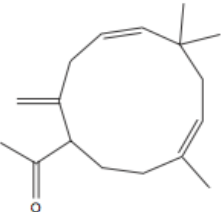
Figure 10: Structures of known fragrance chemicals for the three main types of fragrance compounds.

Fragrances are a mixture of chemicals, specifically semi-volatile organic compounds that are used to deliver a pleasant odor to cosmetic products. The chemicals in fragrances can be natural plant-based essential oils or man-made materials made from petroleum compounds. Recently, the man-made chemicals have become more widely used due to greater variety and lower costs. In fact, 95% of fragrance chemicals used in personal care products are petroleum based, meaning they are also synthetically made compounds. These synthetic fragrances are

made up of macrocyclic (single ring systems), nitromusks (nitrated benzene ring systems), and polycyclic musks (multiple ring systems) (Figure 10) (Taylor, Weisskopf, and Shine 14-069X-13-14). All of these chemicals are known to be harmful to both human health and the environment (Zhang et al. 857-869).

Table 9: Examples of a few fragrance chemicals, and a summary of their material identification, volume use and dermal exposure (Belsito et al. S1-44).

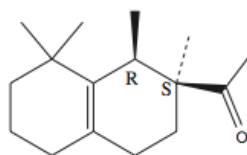
Alkyl cyclic ketones

Material	Synonyms	Structure	Worldwide metric tons (annual) ^a	Dermal systemic exposure (mg/kg/day) ^b	Maximum skin level (%) ^{c,d}
1-(6,6,9-Trimethyl-2-methylene-4,8-cycloundecadien-1-yl)-ethanone^f C ₁₇ H ₂₆ O CAS#: 55987-49-0 Log <i>K_{ow}</i> (calculated): 5.89 Molecular weight: 246.40 Vapor pressure: 0.000337 mm Hg @ 25 °C Water solubility: 0.2314 mg/l @ 25 °C	1-(6,6,9-Trimethyl-2-methylenecycloundeca-4,8-dien-1-yl)ethanone; 1-(6,6,9-trimethyl-2-methylenecycloundeca- 4,8-dien-1-yl)ethan-1-one		0	0	0

Unsaturated bicyclic ring

Ethanone, 1-[(1R,2S)-1,2,3,4,5,6,7,8-octahydro-1,2,8,8-tetramethyl-2-naphthalenyl]-,rel-C₁₆H₂₆O
 CAS#: 185429-83-8
 Log *K_{ow}*(calculated): N/A
 Molecular weight: 234.38
 Vapor pressure: N/A
 Water solubility: N/A

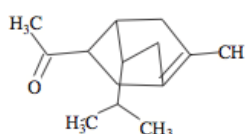
Georgywood



Captive^l – Givaudan

1-[5(Or 6)-Methyl-7(or 8)-(1-methylethyl)bicyclo[2.2.2]oct-5-en-2-yl]ethan-1-one C₁₄H₂₂O
 CAS#: 68259-33-6
 Log *K_{ow}*(calculated): 4.20
 Molecular weight: 206.29
 Vapor pressure: 0.00929 mm Hg @ 25 °C
 Water solubility: 10.44 mg/l @ 25 °C

Ethanone, 1-[5(or 6)-methyl-7(or 8)-(1-methylethyl)bicyclo[2.2.2]oct-5-en-2-yl]-; Felvione



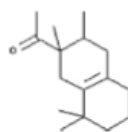
0.1–1

0.0025

0.12

1-(1,2,3,4,5,6,7,8-Octahydro-2,3,8,8-tetramethyl-2-naphthalenyl)ethanone^g C₁₆H₂₆O
 CAS#: 54464-57-2
 Log *K_{ow}*(measured): 5.6–5.7^h
 Molecular weight: 234.38
 Vapor pressure: 0.0011 mm Hg @ 25 °C
 Water solubility: 1.077 mg/l @ 25 °C

Ethanone, 1-(1,2,3,4,5,6,7,8-octahydro-2,3,8,8-tetramethyl-2-naphthalenyl)-; 1-(1,2,3,4,5,6,7,8-Octahydro-2,3,8,8-tetramethyl-2-naphthyl)ethan-1-one; 1-(2,3,8,8-Tetramethyl-1,2,3,4,5,6,7,8-octahydronaphthalen-2-yl)ethanone; OTNE; Amberonne; Boisvelone; Isocyclemone E; Iso E super



>1000

0.4604

8.17

Fragrances, in addition to being made up of multiple types of chemicals, are organized into two categories for use in personal care products. One category of fragrances is used for masking the bad odors of the chemicals present in the formulation of the product. Some of these fragrances can also serve a functional purpose in the product by acting as a cleaning or moisturizing agent in the products (Belsito et al. S1-44). This group of fragrances is not always labeled on the ingredients list. The other category of fragrance used is the type most people will think of in regards to fragrances. This type of fragrance chemicals are used to make the product have a nice aroma, or the smell the consumer will experience while using the product. These aromatic fragrances are listed as “fragrance,” or “parfum” in Europe, on the ingredients list. However, the ingredients label is only required to report that this type of fragrance was used in the product, not which individual chemicals make up the fragrance used. The aromatic fragrance chemicals used for the smell of the product are considered trade secrets because these formulations are unique per product and brand ("Ingredients > Fragrances in Cosmetics."). In fact, the one term “fragrance” on the ingredients list typically includes anywhere from 50 to several hundred individual chemicals, with some sources stating up to 500 individual chemicals are able to be used under the one term, “fragrance.” In fact, over 3,000 chemicals considered as fragrance chemicals have been found to be used in manufacturing, (Zhang et al. 857-869; Dodson et al. 935-943) meaning that combinations of over 3,000 chemicals are used under the label fragrance without the public’s knowledge of the individual chemical identities. Some of these confidential fragrances have been found to use phthalates, which have known health and environmental affects, to make the aroma of the products last longer. As part of the fragrance formulation phthalates in this situation are not

required to be labeled either. Thus a known chemical with health effects may be used in a variety of products without the public's knowledge.

Labeling Issues:

Fragrances in personal care products can be comprised of both natural plant based chemicals and man-made chemicals synthesized from petroleum based chemicals (Belsito et al. S1-44; Zhang et al. 857-869). These man-made chemicals can be labeled as natural products if they are based on natural plant products, even if these synthetic chemicals differ slightly from the natural chemicals they are based on. In fact the terms, “natural,” “nontoxic,” and “green” are all terms that are unregulated and have no standard definition in personal care products (Dodson et al. 935-943). Fragrance chemicals have been linked to many health sensitivities. The naturally based synthetic fragrance chemicals that have different stereoisomers, or spatial orientations of the molecule, can have different health effects than the natural products they are based on (Dodson et al. 935-943). Many of these health effects cause skin irritations or allergies, since the mechanisms in our bodies to metabolize and remove these chemicals, cannot quite handle these altered natural products.

There is a difference between the labeling phrases “unscented” and “fragrance-free” on personal care products. The term “unscented” includes fragrance chemicals, but not strong aromatic fragrances. The functional fragrances, which are present in most products, can still be included in the term unscented. Only the aromatic fragrances, used for pleasant product smell, are excluded from this term on the label. The term “fragrance-free” can mean that all fragrance chemicals including the functional chemicals are absent from the product. However,

these terms have no legal definition, and are regulated by the fragrance and cosmetic companies alone, so functional fragrances can be still be present in the product even in “fragrance-free” labeled products. These issues are extremely important because many people have skin sensitivities or allergies to these fragrance chemicals. The ability to know whether these chemicals are present in their products is an important issue for many people. However, people with these sensitivities have to instead learn through trial and error which products they are able to use without developing a skin irritation or allergic reaction to the product.

Table 10: The concentrations of total fragrances found through a variety of personal care products (Zhang et al. 857-869).

Products	Fragrance fraction (% v/v)
Perfume extract	15–40
Esprit de Parfum	15–30
Eau de parfum	10–20
Eau de toilette	5–15
Eau de cologne	3–8
Perfume mist	3–8
Splash and aftershave	1–3
Candle (g g^{-1})	4–6
Shower gel	0.5–1
Soaps (g g^{-1})	0.5–3
Detergent	0.03–0.15
Maintenance and cleaning products	0.07–0.1
Hair-care products	Less than 1
Shampoos	Less than 1
Bodywash	Less than 1
Nail polish	Less than 0.1
Makeup	Less than 0.1
Cosmetics	Less than 0.1
Air fresher	0.5–1
Deodorants	Less than 0.5
Body lotions	Less than 0.1
Dishwash	0.1–0.5

The data are from the product fact sheet of each of the products.

Health Effects:

Humans widely use and absorb unknown quantities of fragrance chemicals, and even unknown numbers of fragrance chemicals, into their bodies through the use of multiple products, repeated use, and even exposure from air containing these compounds (Shen et al. 164-176). Due to the undisclosed formulations of fragrances, the pK_{ow} 's of many of these chemicals are unknown, so the likelihood of these chemicals accumulating in the body is unknown. There is little government regulation and safety monitoring on these chemicals (Zhang et al. 857-869). The fragrance industry regulates and tests the safety of these chemicals itself ("Laws & Regulations > FDA Authority Over Cosmetics."). However, fragrance chemicals, though generally considered safe by the fragrance industry, have been linked to neurological disorders such as anxiety, depression, obsessive-compulsive disorder, phobias, panic attacks, migraines, and hormone disruption, as well as the development and triggering of allergies, asthma attacks, sinus problems, and other chronic respiratory diseases (Zhang et al. 857-869; Belsito et al. S1-44). Each of these health effects has been found to have dramatically increased over the last decade or so, which corresponds to increased usage of fragrances and fragrance products (Zhang et al. 857-869). In addition to these health effects, fragranced products are considered a source of indoor air pollution. Due to this recent link to indoor air pollution, the EPA has stated that the amount of fragrances used should be minimal, yet the fragrance industry has yet to be regulated (Belsito et al. S1-44). This is critically important because, the petroleum based fragrance compounds which account for about 95% of all fragrance compounds used, have been reported to cause skin diseases, birth

defects, cancer, and include a handful of chemicals that have been shown to actively increase the growth of human breast cancer cells (Zhang et al. 857-869).

In addition to the above health effects, fragrance products can affect the skin immediately through irritation, inflammation, eczema, or allergy developments (Table 11). It has been observed that women are more sensitive to fragrances than men, and older people (> 60 years) are more likely to be allergic to fragrances than younger people. Even if no immediately noticeable irritations occur, the fragrances can still affect the skin. Once these fragrances are adsorbed they can cause the collagen below the skins surface to breakdown, which reduces the skin's ability to heal itself. In fact, environmentally relevant concentrations of fragrances in the water at extremely low concentrations (parts per million), has been shown to block the ability of human cells to fight toxic substances (Zhang et al. 857-869). All the health effects mentioned in this paragraph are related to fragrance compounds on or absorbing into the skin. Studies have found that not only do these substances actually absorb into the skin, but that many of these fragrance compounds can bioaccumulate in the skin. One study showed that up to 68% of the applied fragrances were able to absorb into the skin continuously throughout the study period (Belsito et al. S1-44). Another study found that between 2-3% of the fragrances absorbed into the human skin remained there and were able to bioaccumulate. Due to this bioaccumulation, and continuous use of such products, the health effects of fragrances should be considered chronic, rather than acute, which is the primary exposure scenario considered in most safety studies (Zhang et al. 857-869).

Table 11: Some observed human health effects caused by fragrance chemicals (Zhang et al. 857-869).

Fragrances	Dose	Application method	Exposure time	Results	References
Cinnamaldehyde	10 μ L of 100% the fragrance in every day	Applied on human skin	3 d	Leading to allergy	Smith et al. (2000)
Cinnamic alcohol	10 μ L of 100% the fragrance in every day	Applied on human skin	3 d	Leading to allergy	Smith et al. (2000)
Ethylene brassylate	50 μ L of 10% the fragrance in ethanol/diethylphthalate (1:1, v:v) in every other day	Applied on human skin	3 weeks	10 irritation out of 36 subjects	RIFM (1989)
Ethylene dodecanedioate	20% the fragrance in petrolatum in 3 d a week	Applied on human skin	3 weeks	2 irritation out of 25 subjects	RIFM (1978)
<i>Juniperus occidentalis</i>	25 μ L of 50% the fragrance in petrolatum in every day	Applied on rat skin	3 d	5 irritation out of 5 subjects	Craig et al. (2004)
<i>Chamaecyparis lawsoniana</i>	25 μ L of 100% the fragrance in every day	Applied on rat skin	3 d	5 irritation out of 5 subjects	Craig et al. (2004)
Lylal	10 μ M the fragrance in agar plates	Applied on human non-tumoral keratinocyte cells	24 h	85 cells death out of 100	Usta et al. (2013)
Lilial	10 μ M the fragrance in agar plates	Applied on human non-tumoral keratinocyte cells	24 h	65 cells death out of 100	Usta et al. (2013)
Methyl dihydrojasmonate	1000 mg the fragrance kg body weight ⁻¹ d ⁻¹	Fed to Rat	7–20 d	Dehydration	RIFM (2007)
Methyl dihydrojasmonate	120 mg the fragrance kg body weight ⁻¹ d ⁻¹	Fed to rat	7–20 d	Found tan areas in the liver and a pale spleen of 2 subjects out of 25	Politano et al. (2008)
Methyl jasmonate	3 g kg body weight ⁻¹ d ⁻¹	Fed to rat	7 d	Central nervous system depression	Scala and Burtis (1973)
Oxotridecyl alcohol (Isotridecan-1-ol)	4.75 g kg body weight ⁻¹ d ⁻¹	Fed to rat	7 d	Central nervous system depression	Scala and Burtis (1973)
Cervolide (12-oxahexadecanolide)	0.025 ml 3% the fragrance	Guinea pig	Once	10 irritations out of 10 subjects	RIFM (1977)
Octyl alcohol (2-ethyl-1-hexanol)	5 g kg body weight ⁻¹ d ⁻¹	Fed to rat	7–20 d	Central nervous system depression	RIFM (1980)
Rose ester (2-phenoxyethanol)	1 g kg body weight ⁻¹ d ⁻¹	Fed to rat	15 d	Central nervous system depression	Scognamiglio et al. (2012)
Rose ester	2 g kg body weight d ⁻¹	Fed to rat	15 d	Death	Scognamiglio et al. (2012)

People can be exposed to fragrances through inhalation. These chemicals are semi-volatile compounds, so that the aroma fragrances give products can be smelled, or inhaled, by the user. Upon inhalation the chemicals can enter the brain directly through the nasal passage way. Upon entry into the brain, the fragrance compounds can modify blood flow and pressure in the brain, which has an effect on hormone regulation (including disorders related to endocrine disruption) and nervous system problems (Sun et al. 339-344). Such effects in the brain is why fragrance chemicals have been linked to neurological problems such as anxiety, phobias, obsessive behavior, migraines, and asthma (Zhang et al. 857-869). However, the primary route of exposure to fragrances is considered dermal exposure (Zhang et al. 857-869;

Belsito et al. S1-44), like most other personal care products. This is particularly relevant for the personal care products such as lotions, which contain fragrances that are then applied to and left on the skin. Once on the skin, the fragrances, like all compounds, have the potential to enter the body's fatty tissue, or blood stream where they are then able to travel throughout the body.

Overall the fragrance industry has claimed fragrances are safe for dermal exposure (Zhang et al. 857-869). One study performed on rats and rabbits showed that all the fragrance compounds tested showed low acute toxicity via the dermal route (Belsito et al. S1-44). This study does not take into account the chronic exposure of these chemicals or the inhalation route of exposure, which has been the exposure route linked to many of the disorders associated with fragrance chemicals and their associated indoor air pollutants. Fragrances are considered indoor air pollutants. Fragrances can undergo secondary reactions with other compounds present in indoor air to make other harmful indoor air compounds such as formaldehyde, glycol ethers, ultrafine particles, and secondary organic aerosols (Dodson et al. 935-943). In addition to making these secondary indoor air pollutants, fragrances are considered indoor air pollutants on their own, due to the fact that they contain many of the same chemicals that are present in cigarette smoke (Zhang et al. 857-869).

In the Environment:

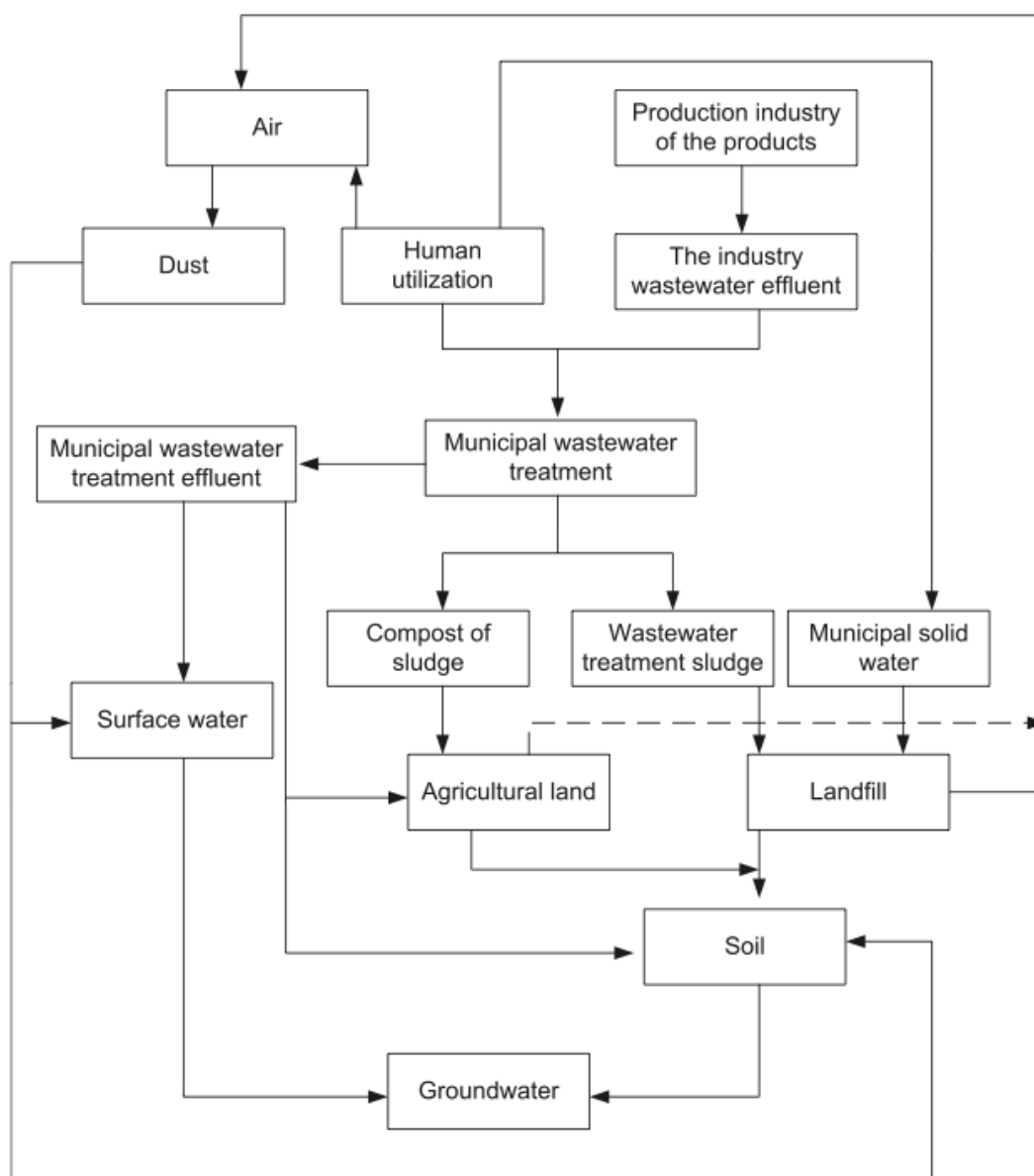


Figure 11: A schematic depicting the many areas of the environment, and routes into the environment, fragrances, as well as other chemicals, can have (Zhang et al. 857-869).

Fragrances have been found throughout the environment (Figure 11), and recently have caused concern due to their ability to bioaccumulate in fatty tissue and persist in the environment, the recent characterization of fragrances as “indoor air pollutants,” and the fact

that environmentally relevant concentrations of fragrances in water has been shown to cause adverse health effects in humans. Fragrances are released into the environment through human use, as well as disposal of the product containers. The chemicals may enter the environment either from being washed down the drain, or through leaching that can occur in landfills from the product containers that may still hold some product. In addition, fragrances have been found as water contaminants due to the release of industrial wastewater from factories that produce fragrances. The main source of fragrances in the environment from personal care products are perfume, cologne, body wash, cosmetics, shampoos, hair-care products, and deodorants. Most of which can travel down the drain and into wastewater treatment facilities. There are currently no standards for the amount of fragrances that are allowed in drinking water, so the testing and targeted removal processes of fragrances in water are limited. However, one study has found that ~50% of the fragrance chemicals that enter a wastewater facility are removed (Zhang et al. 857-869), although what proportion of this removal is due to the treatment of the wastewater compared to the volatilization of the compounds out of the water is unknown.

Table 12: The concentrations of some commonly used fragrances in both surface water and wastewater (Zhang et al. 857-869).

Commercial trade name	Chemical name	Acronyms	Conc. in surface water	Conc. in wastewater
Cashmeran	1,2,3,5,6,7-Hexahydro-1,1,2,3,3-pentamethyl-4H-inden-4-one	DPMI	NA	<1.6 $\mu\text{g L}^{-1}$
Celestolide	1-[6-(1,1-Dimethylethyl)-2,3-dihydro-1, 1-dimethyl-1H-inden-4-yl]-ethanone	ADBI	<50 ng L^{-1}	<30 $\mu\text{g L}^{-1}$
Galaxolide	7-Acetyl-1,1,3,4,4,6-hexahydro-4,6,6,7,8,8-hexamethylcyclopenta(g)-2-benzopyrane	HHCB	<300 ng L^{-1}	<25 $\mu\text{g L}^{-1}$
Habanolide	(12E)-1-oxacyclohexadec-12-en-2-one	-	NA	<1.6 $\mu\text{g L}^{-1}$
Methyl dihydrojasmonate	Methyl 2-(3-oxo-2-pentylcyclopentyl)acetate	MDJ	NA	<5.4 $\mu\text{g L}^{-1}$
Muscone	(R)-3-methylcyclopentadecanone	-	NA	NA
Musk ambrette	4-tert-Butyl-2,6-dinitro-3-methoxytoluene	MA	ND	ND
Musk ketone	1-(4-Tert-butyl-2,6-dimethyl-3,5-dinitrophenyl)ethanone	MK	<30 ng L^{-1}	<420 ng L^{-1}
Musk moskene	1,1,3,3,5-Pentamethyl- 4,6-dinitroindane	MM	ND	ND
Musk tibetene	1-Tert-butyl-2,6-dinitro-3,4,5-trimethylbenzene	MT	ND	ND
Musk xylene	1-Tert-butyl-3,5-dimethyl-2,4,6-trinitrobenzene	MX	<7 ng L^{-1}	<260 ng L^{-1}
Patchouli ethanone	1-(2,3,8,8-Tetramethyl-1,3,4,5,6,7-hexahydronaphthalen-2-yl)ethanone	OTNE	<30 ng L^{-1}	<1.9 $\mu\text{g L}^{-1}$
Phantolide	6-Acetyl-1,1,2,3,3,5-hexamethylindane	AHMI	<5.5 ng L^{-1}	<50 ng L^{-1}
Tonalide	7-Acetyl-1,1,3,4,4,6-hexamethyltetrahydronaphthalene	AHTN	<60 ng L^{-1}	<1.9 $\mu\text{g L}^{-1}$
Traseolide	5-Acetyl-3-isopropyl-1,1,2,6-tetramethylindane	ATII	<2.5 ng L^{-1}	<32 ng L^{-1}

NA: not available; ND: not detected.

Since fragrance chemicals are semi-volatile they can easily be removed from wastewater through volatilization. Volatilization of these compounds occurs predominately in the aeration step of the wastewater treatment process. Aeration involves agitating the wastewater and bubbling air through the water, both of which increase the fragrances' interactions with air, allowing them to change phase and volatilize out of the water as the resulting air bubbles rise. Once volatilized the fragrances can become air pollutants, or settle onto the ground or water as contaminants upon contact with dust and other suspended air particles. As an air pollutant, fragrances have the possibility of reacting with other air

contaminants to form toxic by-products. In addition to being volatile, fragrance chemicals are specifically designed to be hydrophobic so as to increase the time the fragrance-containing product has a noticeable aroma. The fragrances that do not volatilize out of the wastewater during the aeration phase, like all other hydrophobic substances, adsorb onto the suspended lipophilic particles in the wastewater and settle into the sludge. Fragrance materials have also been shown to absorb into the cells of bacteria and other microbes that are added to the wastewater to biodegrade other chemicals present in the water. However, due to the anti-microbial properties of some fragrances, they are resistant to bacterial biodegradation, and reduce the bacteria's ability to degrade other organic compounds in the water. The fragrances that were unaffected by the bacteria can then enter surface waters where they can persist, bioaccumulate in aquatic life, volatilize, or seep into groundwater. The fragrances that were adsorbed onto the wastewater sludge can re-enter the environment as a land contaminant directly from the sludge, or as a water contaminant from leachate from the sludge whether it is used as a fertilizer or placed in a landfill.

Fragrances are also able to contaminate the soil from landfill leachate of the discarded product containers, or from the application of wastewater sludge for fertilization on agricultural fields. Once in the soil these compounds can be removed by leaching into nearby water bodies, taken up by plants or soil organisms, or possibly degraded by sunlight or microorganisms. However, the photo-degradation of compounds in the soil can only occur on the top layer of soil. Lower soil layers or soil shaded by plants do not allow enough sunlight penetration through to degrade any chemicals.

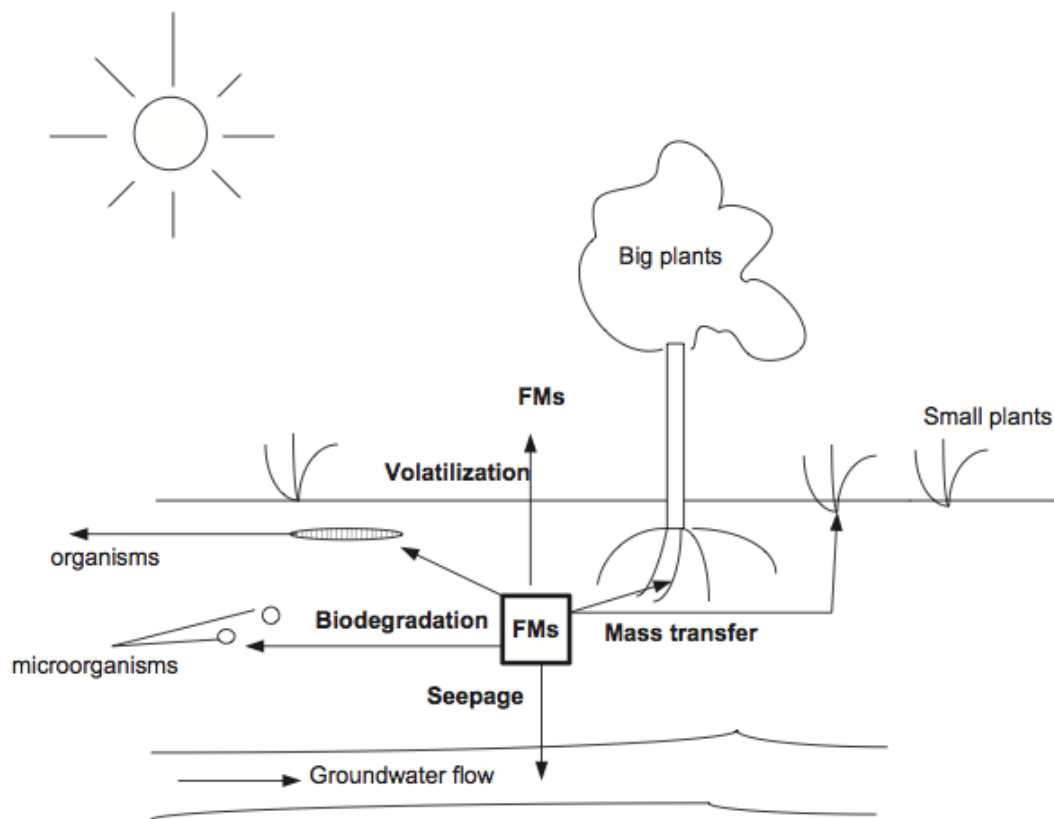


Figure 12: A schematic of how fragrance chemicals (FM) can enter water, volatilize, be taken up by plants or organisms, by bio- or photo-degraded in the environment (Zhang et al. 857-869).

Conclusion:

As has been demonstrated in this paper many of the chemicals used in personal care products carry tremendous environmental and health risks, including certain diseases that have been on the rise in the US such as autism, ADHD, obesity, diabetes, numerous sexual development and fertility disorders, as well as multiple cancers. Due to these risks, and in comparison to the banning or partial restriction of these chemicals in the European Union for use in personal care products, the use of these chemicals in the same products in the US is called into question. The regulations surrounding personal care products in general, need to be

seriously redesigned. To begin with, the term personal care products should be defined so that the law is clear which personal care products are subject to the regulations currently in place. The safety tests, pre-market safety requirements, government authority, and both the labeling terms and requirements need to be seriously re-considered and made more stringent. However, the likelihood of these changes being enacted in reality is rather limited. The most likely actions that will force these companies to change the formulations of, and the regulations surrounding personal care products will be consumer action.

Consumers choosing to buy only safe personal care products, and demanding information about the products they are using, will force the companies to change their current business practices. Some online sources for consumers looking for more information about their products, or to get involved in demanding stricter government regulations, are currently available. The Environmental Working Group's Skin Deep database, analyzes personal care products to give consumers a more complete ingredient list of their products, and rates the overall safety of these products. The Campaign for Safe Cosmetics is a resource for any consumer looking for more information regarding the issues surrounding personal care products and for how to get involved in making a difference. However, the main problem is the lack of information regarding these chemicals. More research into the health effects, the health effects of combinations of these chemicals, and the fate of these chemicals in the environment needs to be completed in order for both consumers and regulators to make informed decisions regarding their personal care products.

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