

MICROPLASTICS: FORMATION, DISPOSITION, AND ASSOCIATED DANGERS. AN OVERVIEW

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ABSTRACT

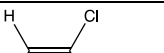
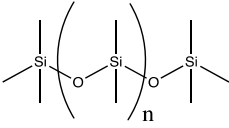
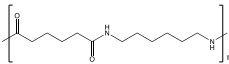
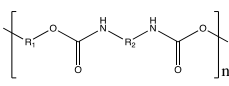

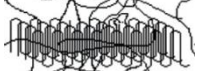
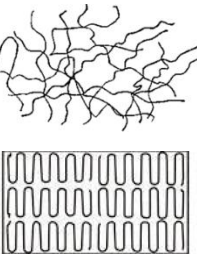
In recent decades the increase in the use of plastics has been exponential around the world, reaching a presence in places such as rivers, oceans and lakes, as well as in terrestrial environments such as agricultural soils. Associated with the great use of plastics in all areas of work, plastic particles smaller than 5 mm, called microplastics, have been found in all environmental matrices: aquatic environment, dispersed throughout the water column, terrestrial environment, infiltrating the soil sedimenting, and in the air, being transported by the wind. In each of these matrices, microplastic serves as transport for highly polluting compounds such as heavy metals, polycyclic aromatic hydrocarbons and organochlorine pesticides. In addition to environmental matrices, microplastics have been found in animals and humans in alarming numbers. In this way, this review addresses issues related to the formation and distribution of microplastics throughout the ecosystem and different organisms.

Keywords: Microplastic, pollution, cross-pollution, plastic in humans.

INTRODUCTION

To understand microplastics we must first understand what a plastic is, where they come from, how they are formed, what they are for, etc. If we go to the generality, a plastic is a material of compounds that can be organic or synthetic, these plastic materials have the main characteristic of being malleable, which allows them to have an infinity of forms with ample utilities. For this reason, it is that plastics have a wide classification according to how they are made, according to the behavior against heat, by synthesis reaction, molecular structure, biodegradable, etc. (see Table 1). Thus, how all these plastics are made up of very small molecular units (monomers) they are technically known as polymers.

Table 1. Brief classification of some types of plastics.

Classification	Types	Examples	Structure	Ref.
Reaction of synthesis	Addition Polymers	Vinyl chloride		[1-4]
	Condensation polymers	Silicone		
Behaviour to the heat	Thermoplastics (TP)	Nylon 6,6		[5-7]
	Thermostable (TS)	Polyurethane		
Molecular structure	Amorphous	Poly(styrene) atactic		[8-13]
	Semicrystallines	Poly(ethylene)		
	Crystallines*	Polyamides*		

* Although there is no 100% crystalline material, polyamides are materials that have a very high crystallinity.

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Since the 1950s, these materials have become very useful products in all known areas, from household products, agriculture, engineering, medicine, among many other areas. They are of great help due to their wide versatility, low production cost and stability, however, high production also generates a very high amount of waste that ends up in the environment, generating severe global pollution problems [14, 15], accumulating in the oceans and thereby generating ecological risks [16], as well as effects on human health [17]. More than 6300 million tons of plastic waste have been reported and 79% of it is associated with different landfills and natural environments [18], where only 10% is recycled properly [19]. This is why the (mis)excessive and extensive use of plastic products results in small plastic particles beginning to be detected in aquatic and terrestrial environments, including rivers, oceans, lakes and estuaries [20-26]. In addition, as of 2010 more than 275 million tons of plastic have been reported in the oceans and emissions are estimated at 8 million tons of macroplastic and 1.5 million tons of microplastic annually [27]. In addition to the above, there are projections in which it is estimated that there were 710 million tons in the ocean by 2040 [28] so that this large amount of plastic waste is being a very high contribution to the generation of both microplastic, nanoplastic and their leachate due to the different aging processes [29]. The different destinations of plastic on the surface of the sea are still a mystery due to the wide diversity in vertical and spatial transport mechanisms, considering also that small waste derived from primary and secondary sources is almost omnipresent in nature, generating severe impacts on nature [30], synthetic polymers found in the environment, drinking water, and food [31, 32]. These small plastic particles do not have a strict definition, however it has become widespread that 5 mm is the upper limit for a microplastic [33-36], so concerns have been increasing due to their presence in different environmental matrices [37] so the effects need to be addressed further. However, the plastic problem is considered to be below (and very close) to problems such as global warming and ocean acidification [38] as the properties of plastics begin to change immediately through weathering processes after they enter the environment [39].

Plastic and its fragmentation:

Although, in a year only 1% of the microplastic is the one that is floating in the ocean, we must understand how the transformation, fragmentation and fate of the rest is possible, since plastic particles have been reported in the water column around the world [40, 41]. Now, as we already mentioned, once plastics enter the environment they begin to decompose physically and chemically, although the degradation time will depend on factors such as the environment, temperature, relationship with chemical additives to the plastic, etc. For example, areas such as the coasts of the high Arctic have high UV temperatures and freezing [42], so plastics will be more fragile and more susceptible to breakage, while those found in the deep sea can be preserved for decades [16, 43]. Chemical additives serve to modify properties and meet the desired yields, however, many of these have sensitivity to environmental stress such as UV rays, heat, cold, mechanical damage, etc. In addition to being released if natural exposure is prolonged. 5 major additives [44] have been reported to "leak" due to exposures. While inorganic additives such as calcium carbonate (CaCO₃), widely used, generate cracks due to physical effects [45].

These cracks lead to what is known as weathering of plastic litter in the marine environment. This currently meets 2 of the 3 criteria that imply being a threat to the planet in terms of chemical pollution and release of new entities. These criteria correspond to:

1. Exposure on a planetary scale
2. It is not easily reversible
3. It causes disruptive impact on the vital processes of the earth system.

At 2017, which is where weathering of plastic trash was described, it was unclear whether plastic waste was meeting the third criterion. However, over the years it has been shown that there is indeed a significant impact on Earth systems. It has been established that these microplastics can leach into terrestrial systems through landfills and various human activities due to uncontrolled discharges [46, 47].

Microplastic in the aquatic environment:

In 2010, more than 275 million tons of plastic were recorded and 31.9 million of the poorly managed plastics ended up in the environment, where about 8 million tons ended up in the ocean through rivers, surface runoff and other processes [27, 48], and it must be considered that about 80% of plastics present in the oceans originate in terrestrial environments to make their way to different bodies of water [49]. Studies of concentration, abundance and distribution of microplastics have been reported in freshwater bodies such as lakes [50-53], rivers [53-55], and estuaries [56-58], and especially in the ocean [59-63], where synthetic textiles should be considered the most important sources of microplastics (see Figure 1).

All this waste affects the marine ecosystem, where there have been more than 100 thousand deaths of marine animals per year and more than 700 marine species threatened by different types of plastics. In general, we can see the distribution of plastic waste as regular plastics and microplastic (in addition to nanoplastics) according to their origin (see Figure 2).

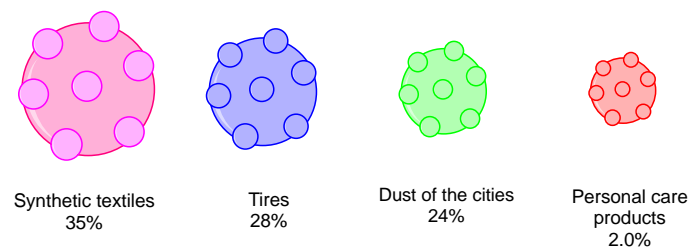


Figure 1. Important agents in terms of the generation of ocean microplastics

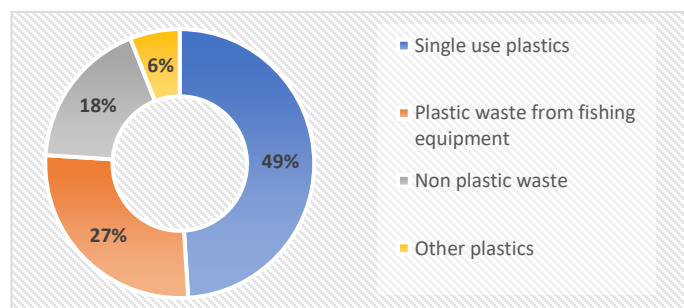


Figure 2. Distribution of microplastics in the ocean by type.

The problem is such that these fragments of plastics, microplastics, have been found in the open oceans [64] including the polar waters of the Arctic [65]. This great concern is due to the fact that microplastics may be agents of transport of chemical pollutants in the marine ecosystem due to the absorption of potentially hazardous substances on their surfaces [66]. For example, phenanthrene, a toxic substance belonging to the group of PHAs that is included in the list of priority toxic compounds, reaches the different bodies of water where it can be transported by microplastics where it will later accumulate in marine sediments (see Figure 3).

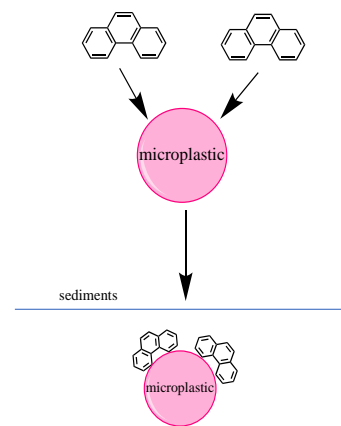


Figure 3. Transport of toxic compounds into sediments by microplastic particles.

At the same time, plastic waste found in aquatic environments carries chemicals of small sizes (1000 Mw) that can enter cells and interact with important biological molecules generating alterations in the endocrine system. These chemical compounds have two classifications: i. Hydrophobic chemicals that are absorbed from seawater given by the existing affinity of chemical compounds for the hydrophobic surface of plastics. ii. Additives. Monomers and oligomers of the molecules that make up plastics. A well-known example is the constitutional monomer bisphenol A (BPA) (see Figure 4.a) and alkylphenol additives (see Figure 4.b) that generate estrogenic effects, as well as phthalate plasticizers (see Figure 4.c) that have effects on testosterone production. At the same time, when plastic sizes are reduced, the chemical properties of plastics remain unchanged [67], e.g. adipato-coterephthalate polybutyrate (PBAT) (see Figure 4.e) and low-density polyethylene (see Figure 4.d).

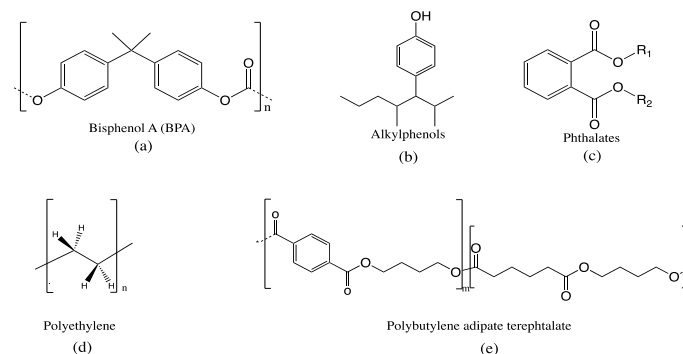


Figure 4. Structures of some microplastics present in the environment. a. Bisphenol A. b. Alkylphenol. c. Phthalates. d. Polyethylene. E. Polybutylene adipate terephthalate.

It has been estimated that between 15 and 51 trillion microplastic fragments, equivalent to 93,000 and 236,000 tons are already found in the oceans worldwide [68]. The complexity of this is that, unlike larger plastics that are easier to remove either by natural or human-assisted processes, microplastics are more difficult to detect and thus be eliminated [48], which means that over time they can remain in sediments and enter the food chain.

Microplastics are important carriers of compounds such as PAHs, which are readily adsorbed by organisms causing biotoxic effects other than when adsorbed alone [69, 70]. The interactions between microplastics and PAHs correspond to hydrogen interactions, binding of halogenated compounds and π - π interactions [71] (see Figure 5), where it has been shown that polystyrene microplastics can interact with different aromatic compounds through π - π bonds [72]. Other studies have reported that the amide group of a polyamide microplastic forms interactions by hydrogen bonds with the benzene ring [73] and at the same time, studies of five bisphenol compounds have been recorded in polyvinyl chloride microplastics where, in addition to exhibiting interactions by hydrogen bonds, the chloride ion in this type of microplastics can form halogenated bonds with the electron donor benzene ring [34] (see Figure 6).

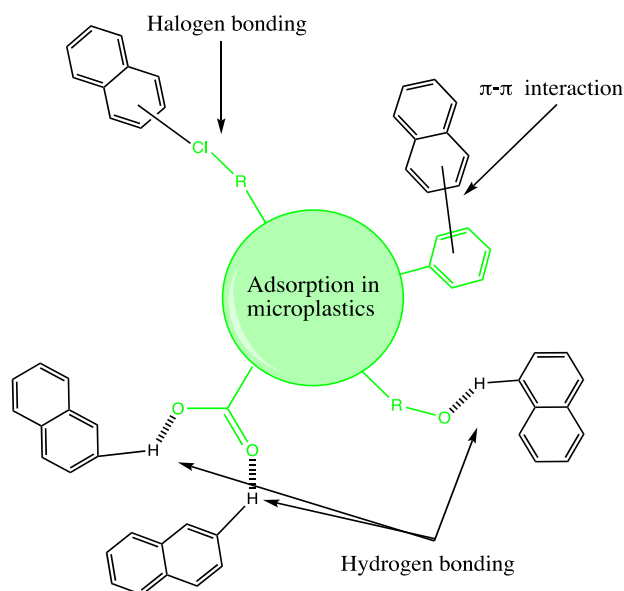


Figure 5. Adsorption of contaminants by microplastics by hydrogen bonding interactions, halogenated bonds and interactions (Image adapted from Wu, et al., 2019 [34]).

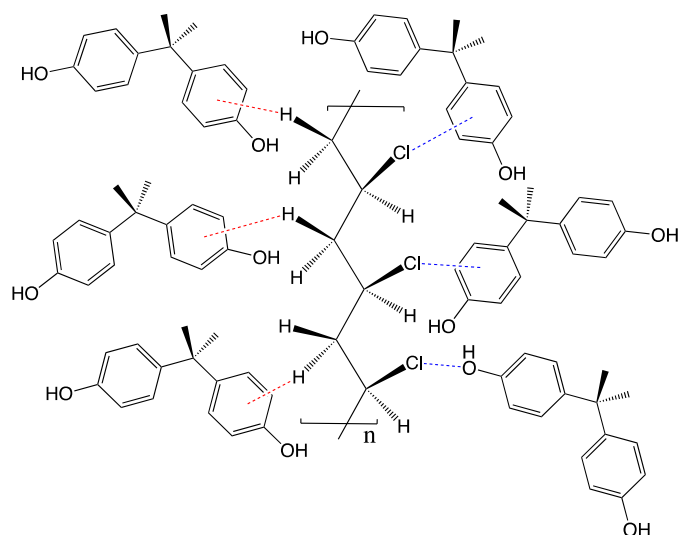


Figure 6. Interaction by hydrogen bond and halogenated bonds of polyvinyl chloride with the π benzene ring bond.

Thus, absorption and transport of antibiotics by microplastics has also been recorded. In this way, the microplastics of polyethylene, polystyrene, polypropylene, and polyamide are agents of absorption and transport of different antibiotics, although polyamide microplastics have the highest adsorption capacity for antibiotics such as sulfadiazine, amoxicillin, tetracycline, ciprofloxacin, and trimethoprim, due to the high presence of hydrogen bridge interactions [73].

Microplastics in the terrestrial environment:

This section will review the aspects that generate impacts on biogeochemical or nutrient cycles in the terrestrial environment [74]. Microplastics have now been found in soil due to additives in agricultural soils, the application of compost derived from municipal solid waste, compost derived from waste recovered from landfills and at the same time the disposal of plastics in landfills [75]. Without going any further, there are reports in which it has been shown that the content of microplastics in terrestrial ecosystems can be between 4 to 23 times higher than in the ocean [76], for this reason is that microplastics in agricultural soils can cause unknown effects and for this reason be a danger to global food health [77].

Currently, mulch films are one of the most important sources of microplastics entering agricultural soils [75, 76] where they end up accumulating in crops [78, 79]. In addition to the commonly used plastics, polypropylene, polystyrene and polyvinyl chloride, additives are added to different plastic products such as flame retardants [76].

In soil, there are 3 types of transformation, including fragmentation and degradation, which are physical and biological chemicals. Among these, chemical degradation influenced by UV radiation is important, generally dominating over the initial degradation processes of the vast majority of plastic waste. This process, phototransformation, is what begins to degrade soil plastics [80, 81]. In this way, as plastics become smaller and smaller, they accumulate and interact with soil compounds through electrostatic forces promoted by root exudates or by the feeding and excretion of different animals [79]. Thus, the incomplete process of microplastic degradation can result in the accumulation of these compounds at microbial and submicrobial scales, posing hitherto unknown dangers to the environment [76], in addition to the fact that in addition to animals in the terrestrial environment, the expansion and decomposition of plant matter can help the formation of macropores in the soil, being a transport agent for microplastic [82]. Among the most common contaminants in soils, we have organochlorine pesticides (OPs) [22, 83-86], polycyclic aromatic hydrocarbons (PHAs) [87-89] and heavy metals [90-93] that migrate vertically aided by the adsorption on the surfaces of microplastics in the soil through bioturbation, runoff [94, 95], water infiltration [96, 97], irrigation channels [98], among others. While plastic particles can spread both through the air, allowing settlement anywhere (by atmospheric transport), including agricultural soils, sedimentation (see Figure 7) [99]. At the same time, landfills are a very important source of microplastics as there is a higher likelihood of photodegradation, oxidation and biodegradation of plastics [75, 100].

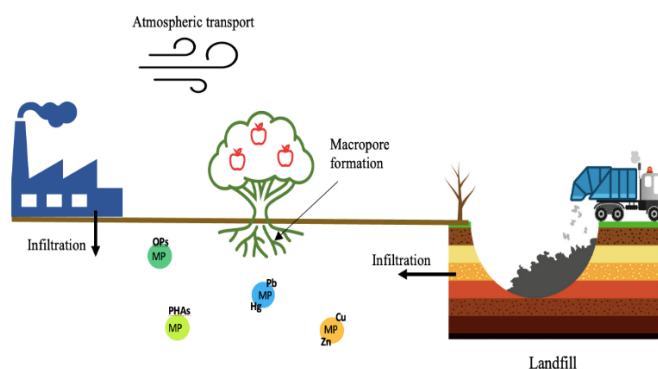


Figure 7. Transport of polluting compounds by microplastics transported by water infiltration by industries, landfills and atmospheric transport.

Microplastic in animals:

Microplastics have been detected in the tissues of different animals, such as in the gastrointestinal tracts of worms, fish, and crustaceans [48, 101, 102]. The fact that microplastics are reported in different aquatic environments, including pelagic zones and sedimentary habitats, makes them highly accessible to aquatic animals [103]. In East Asian seas alone, hundreds of thousands of km² of microplastic parts have been estimated.

The most common routes of exposure have been reported to be dermal contact, inhalation, and ingestion [104, 105], the latter of which has been estimated to be only for aquatic organisms [106], specifically, microplastics are located in the gut and interact with different physiological processes from there [107, 108]. Studies with green mussels (*Perna viridis*) have revealed that although no mortality was observed in the control and exposed groups, diet decreased in the groups with higher exposure to worn-out polyethylene microplastic and increased the number of microplastic particles [42] in the intestines of organisms. Thus, the microplastic present not only affects food, but also growth and reproduction [109]. Other studies have reported decreases in respiration with increased concentration of PVC particles during exposure [110].

Like the intestine, the lymph nodes, liver and spleen are greatly affected by microplastic particles (see Figure 8), however, the intestine is the most affected to affect nutritional absorption, metabolism and defense [111].

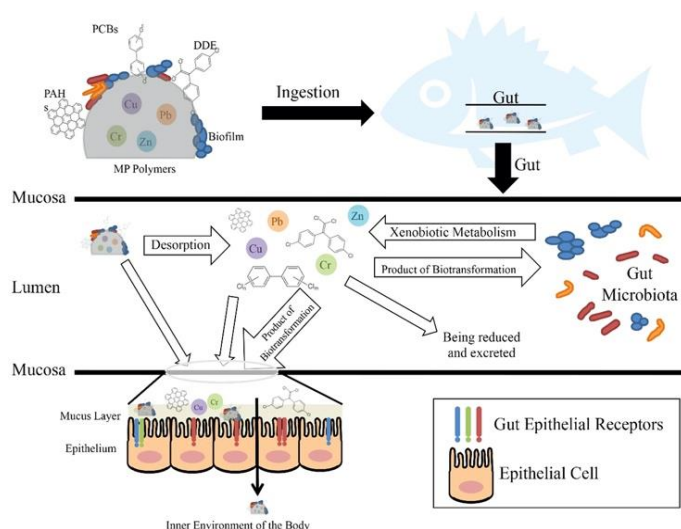


Figure 8. Adsorption of persistent organic pollutants (POPs) by microplastics and their storage and accumulation in animal tissues. Image taken from Weixin et al., 2022 [69]

For marine mammals, the effect of plastics and microplastics is no different, as they are affected through entanglement, ingestion, and habitat degradation [105, 112, 113]. An example is the misticetis or baleen whales that feed by megafilter that wrap large amounts of water next to the prey and it is this megafiltration that makes it prone to exposure to microplastics, in addition to contaminated prey [114, 115]. Without leaving behind land animals, there are post-mortem studies in tissues of dogs and cats in which plastics were found in 35 of 49 animals ranging in size from 1 to 10 μm [116].

However, not only have microplastics been found in animals, but it is also estimated that each human being consumes annually more than 100,000 microplastics either by ingestion or inhalation [117], among these microplastics we find poly(vinyl chloride) (PVC), poly(ethylene) (PE), poly(propylene) (PP) [118], poly(styrene) (PS) [119] and polyethylene terephthalate (PET) [120]. Without going any further, it is estimated that people ingest between 37,000 and 90,000 microplastic particles per year just when using a plastic cup or cup [121], however, depending on the type of plastic, the intake of the particles can be higher or lower (see Figure 9).

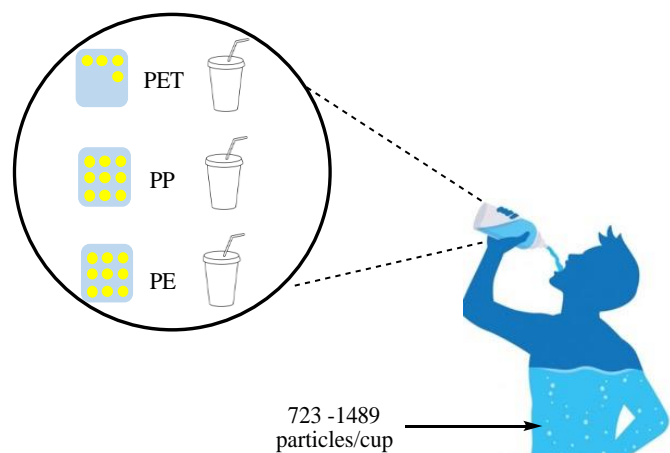


Figure 9. Estimation of plastic consumption per cup used. Image adapted from Zhou et al., 2023. [121]

On a day-to-day basis, humans ingest large amounts of microplastic unconsciously:

- Electric plastic kettle: 4 to 29 million microplastics per liter during use.
- Plastic bottle: 1 to 16 million microplastic per liter, equivalent to 1.5 million microplastic particles per baby per day.

At the same time, microplastics released from cosmetic and personal care products come into contact with the skin and those plastic particles smaller than 100nm can enter the skin barrier. Studies have verified that a large amount of microplastic can enter the human body and even the placenta, fetal liver, lungs [122], heart [123], kidneys [124], and even the brain [125, 126]. These and more actions that we carry out every day lead us to consider that microplastics are a great challenge for human health (see Figure 10).

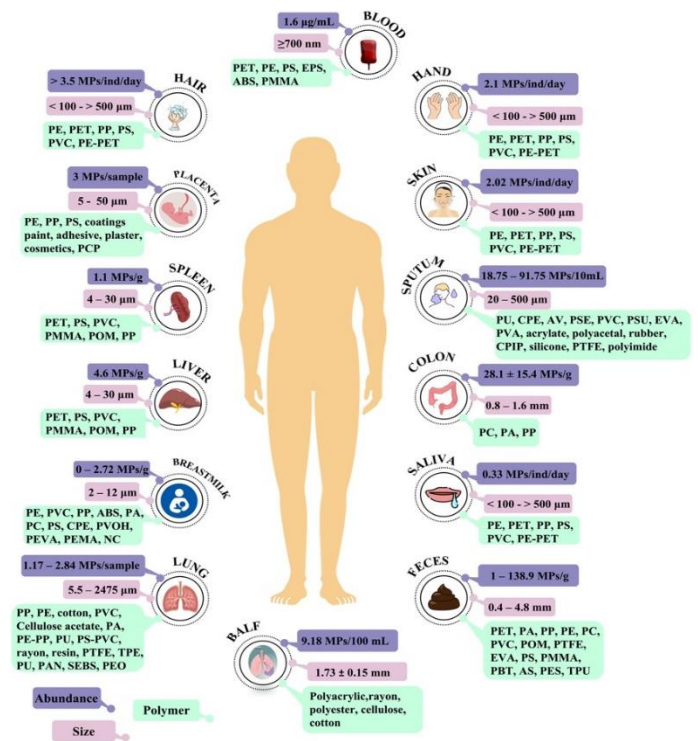


Figure 10. Illustration with the main characteristics of microplastic and its original compound present in different parts of the body. Corresponding acronyms: PET: Polyethylene terephthalate, PS: polystyrene, PP: polypropylene, PVC: polyvinyl chloride, PA: polyamide, PC: polycarbonate, PTFE: polytetrafluoroethylene, NC: nitrocellulose, EVA: vinyl alcohol, PEVA: polyethylene acetate, POM: polyoxymethylene, TPE: thermoplastic elastomer, PAN: polyacrylonitrile, SEBS: styrene-ethylene-butylene copolymer, PEO: polyethylene oxide, PCP: personal care products. Image taken from Kutralam-Muniasamy et al., 2023. [127]

CONCLUSIONS AND PERSPECTIVES:

Each finding of microplastics in the different environmental matrices and in organisms (animals and humans) has meant a concern that grows over time, which is why every year studies related to microplastics and their effects on the ecosystem increase since so far only the origin is known, transport and accumulation, but the certain effects on different organisms and how it may affect the food chain are not known. Although plastics are one of the most important materials for almost all areas of work, it is important that their correct use and, as far as possible, their reduction, added to the good management of waste to avoid the dangers that plastic can mean and in our lives.

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