LAYER 1

Non-woven polypropylene with large, randomly oriented fibers that are thermally bonded together, as visible in Fig. 1.1.

The large pores make this layer hydrophobic and effective at repelling liquid droplets, while the thick fibers (~150-200 microns) provide durability and structure to the mask exterior.

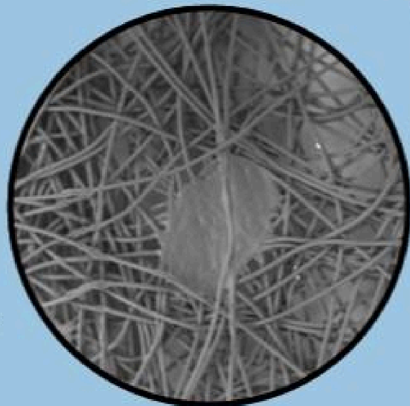


Fig 1.1: x42 magnification of the first layer of a 4-ply disposable mask. Taken using SEM.

LAYER 2

Melt-blown polypropylene with densely packed, fine fibers. The fibers form a tight web that acts as the primary filtration layer, trapping small particles through mechanical and electrostatic interactions.

This layer is the only small particulate filter, with fibers around 50 microns thick.

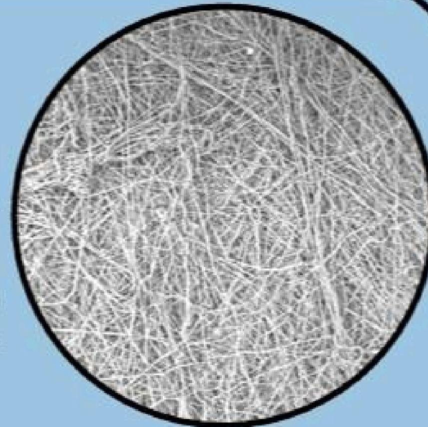


Fig 1.2: x42 magnification of the second layer of a 4-ply disposable mask. Taken using SEM.

DISPOSABLE 4-PLY

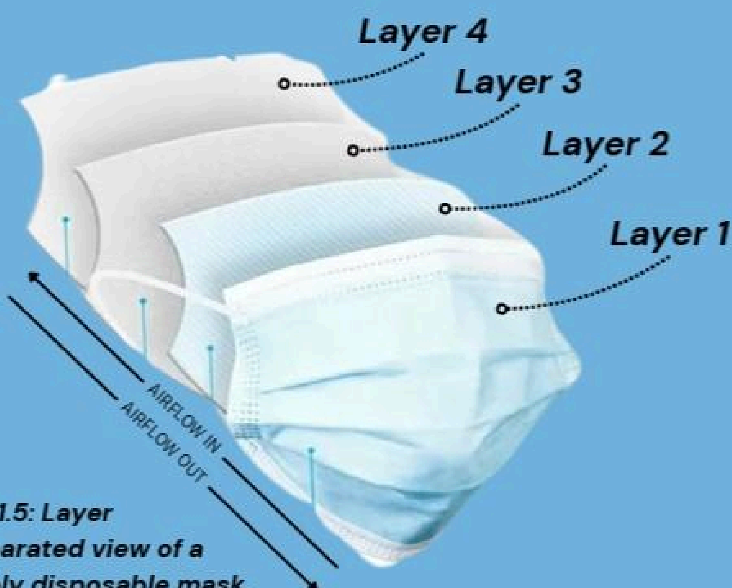


Fig 1.5: Layer separated view of a 4-ply disposable mask.

Manufacturing Process:

Disposable masks are produced through an automated process that converts polypropylene pellets into non-woven fabric. The pellets are melted, extruded into fine fibers, and bonded into continuous sheets, which are then layered, ultrasonically welded, and cut into mask shapes. Finally, nose wires and ear loops are attached before sterilization and packaging, completing a fast, high-volume manufacturing cycle.

LAYER 3

Non-woven polypropylene visually similar to the outermost layer, composed of large, thermally bonded fibers.

It adds structural integrity and supports the adjacent melt-blown layer, but will likely not filter out any particles that already made it through the melt blown layer.

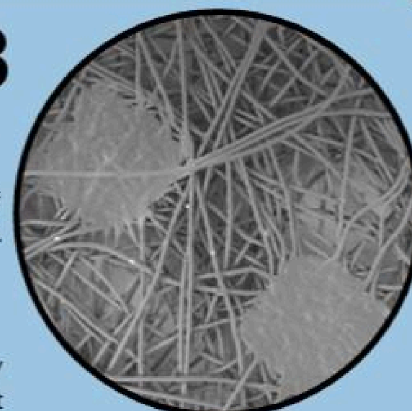


Fig 1.3: x42 magnification of the third layer of a 4-ply disposable mask. Taken using SEM.

LAYER 4

Non-woven polypropylene with the same fibrous morphology seen in Layers 1 and 3. This layer need to be held together since it is directly against the mouth. Although we can see it is thermally bonded (figure 1.4), it could still potentially shed fibers.

Again, this layer will likely not do any meaningful filtering.

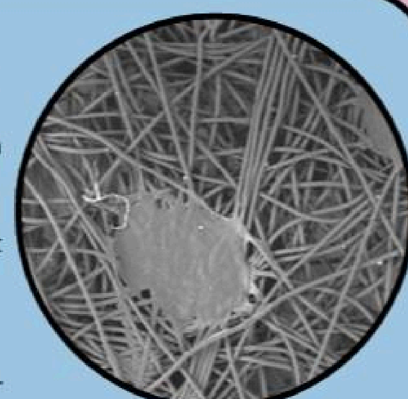
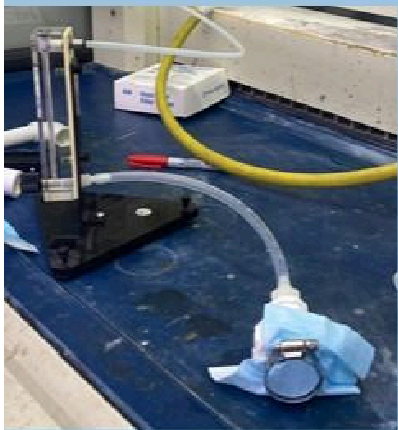


Fig 1.4: x42 magnification of the fourth layer of a 4-ply disposable mask. Taken using SEM.

Breathing Mask Fibers Experiment



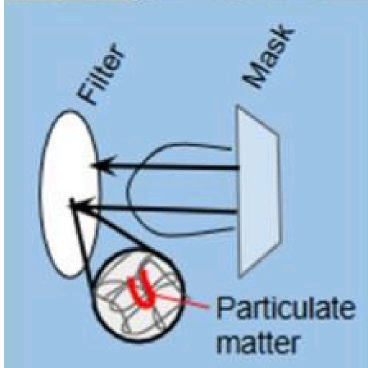
Flowmeter: Measures "breath" rate

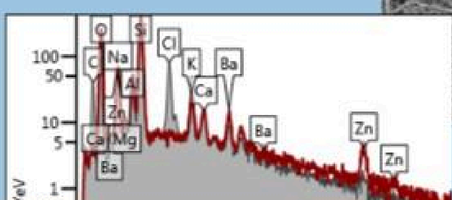
Tubing: connects to vacuum and PVC mouth fitting

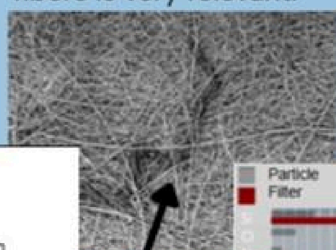
Metal Clamp: Secures mask to "mouth"

Glass Filter: catches particles that may come off of the mask

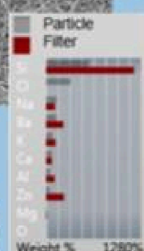
On the black mask filter, particles found were composed of carbon and chlorine, suggesting it may have come off of the polyvinyl chloride pieces holding the mask. A 2002 study done in Italy shows that longer exposure to working with PVC increases the odds ratio of developing lung cancer, if this material had come off of the mask. On the blue mask, calcium carbonate particles were found on the SEM, which are not hazardous to human health. Other particles with atomic weights lower than silicon were identified on the blue mask filter, but too fine to analyze with the EDS. If these fibers are the same material as the mask, polypropylene, the health effects of ingestion are not well understood. One study monitored mice that had ingested polypropylene, and found elevated protein levels in toll-like receptors (microbe detectors in the immune system) in the lung tissue. 49% of microplastics found in the human respiratory system are fibers, meaning the study of mask fibers is very relevant.



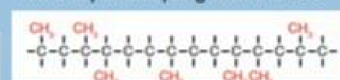




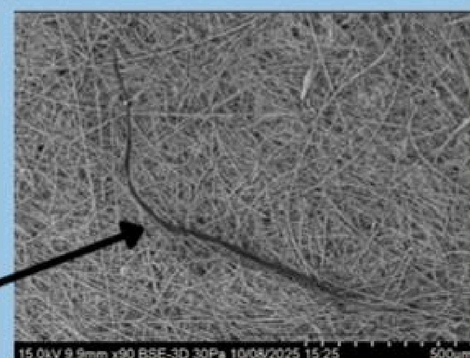
Particle with chlorine in it



Atactic polyethylene, shown below, has less crystallinity and is therefore less stiff, making it ideal for being woven in mask layers. This property may also lead to its difficulty in analyzing with the EDS.



Fine fiber on blue mask filter. Elements with lighter atomic weights than silicon, such as carbon and oxygen, show up darker than the background on the SEM.



PARTICLES FOUND WITH SEM AND EDS: CALCIUM CARBONATE, CHLORINE, CARBON

Research Questions

For our single-use plastic (SUP) project, our team researched surgical face masks from two perspectives: material science/composition, and world impact.

Is it a good idea to wear plastic over your air intake for many hours in the day? What kind(s) of plastics are masks made of? How do "low" and "high" quality masks have differing compositions? How did masks effect the SUP system during covid?

Material Composition

We examined two types of surgical masks: a 4-ply disposable mask (Blue Mask) and a KN95 mask (Black Mask). The Blue Mask consists of 4 layers of melt-blown plastic, while the Black Mask has 5. Fourier Transform Infrared Spectroscopy (FTIR) analysis revealed that most layers are made of polypropylene, except for Layer 4 of the Black Mask, which contains polyethylene and polyester.

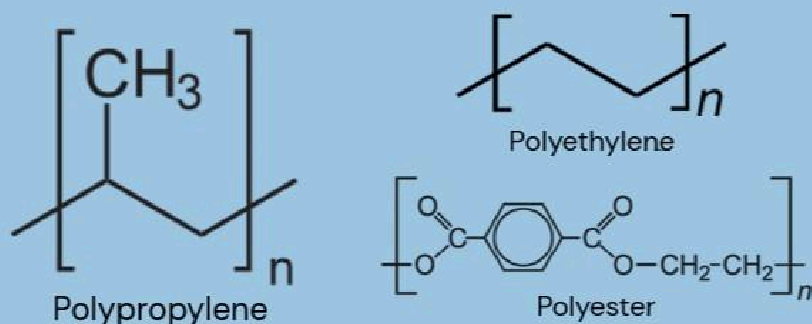


Fig 3.1: Mer units of polypropylene, polyethylene, and polyester

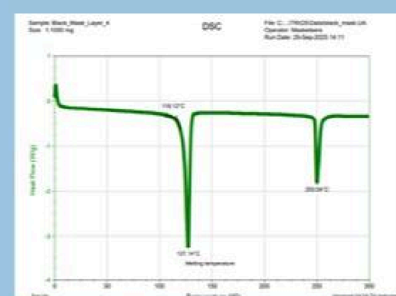


Fig 3.2: DSC scan of layer four of the KN95 mask

This was confirmed by Differential Scanning Calorimetry (figure 3.2), showing two peaks where the sample melted. A microscopic image of Layer 4 (figure 2.4) shows the two materials intertwined, supporting our hypothesis.

Comparison: Blue vs. KN95 Mask

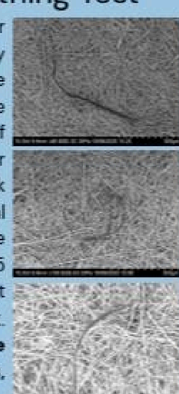
Filters/Layers

Filters rely on Van der Waals bonds so that particles stick to the fibers. Particles greater than a micron have enough inertia to travel in a straight path toward a fiber, particles less than 0.1 micron move chaotically and will eventually bump into a fiber, and particles in between travel around fibers with the air.

The KN95 has an electrically charged layer to catch these "in between" particles, but the KN95 also has layers with much denser fabric, allowing more particles to be filtered out mechanically.

Shedding/Breathing Test

We can use the results of our breathing tests to directly compare the shedding of the masks when simulating airflow. We collected multiple samples of polypropylene fibers that after filtering the disposable 4-ply mask that matched exact with the final polypropylene layer. While we found some residue on the KN95 filter as well, we found nothing that could tie it directly to the mask. **We ultimately conclude that the 4-ply mask DOES shed fibers, while the KN95 mask does not.**



Disclaimer: the results of this test are not conclusive. More research will need to be done in order to make true, more accurate comparisons.

Final Analysis

The main differences between masks is the fiber size and inclusion of an electrically charged layer in the KN95 mask. **These properties affect the mask's ability to filter out particles, as more layers and smaller, denser fibers on the KN95 are more likely to interact with particles.** The electrically charged layer on the KN95 is also more effective in capturing particles that travel with the air than the neutral filter on the blue mask. **The KN95 is therefore more effective in filtering particles out of the air.** Additionally, the breath experiment showed particles on the 4-ply disposable mask filter that matched the final layer of the mask exactly.

KN95 masks require more materials but prove to be more effective due to the fiber size, fiber density, and the inclusion of the charged layer.

LAYER 2

Spun-bound polypropylene layer with smaller fibers, ~100 microns, than the outer layer, serving as a pre-filter for medium-sized particles. The fibers are randomly oriented and we found no evidence of bonding.

This layer provides additional structural stability and helps distribute airflow evenly before it reaches the finer melt-blown layers.

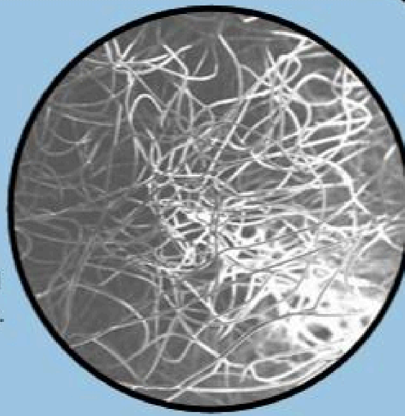


Fig 2.2: x42 magnification of the second layer of a KN95 mask. Taken using SEM.

LAYER 1

Non-woven polypropylene with large pores, designed to catch large particles and be **hydrophobic**. We can visibly see the areas where the fibers are **thermally bonded** to hold the layer together in figure 2.1.

The exterior fibers are larger for a filter, **~200 microns**, but they allow the exterior of the mask to be more durable.

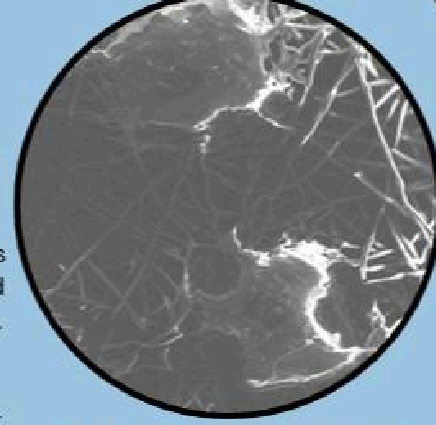


Fig 2.1: x42 magnification of the first layer of a KN95 mask. Taken using SEM.

LAYER 3

Melt-blown polypropylene with ultrafine fibers (~10-20 microns) forming a dense, electrostatically charged web for filtering the smallest particles.

This layer captures fine particles through both mechanical and electrostatic filtration.

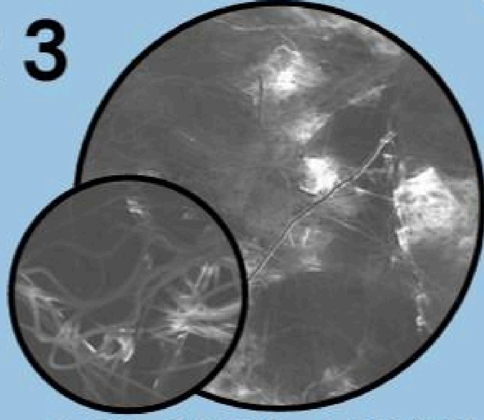


Fig 2.3: x42 (right) and x650 (left) magnifications of the fourth layer of a KN95 mask. Taken using SEM.

KN95

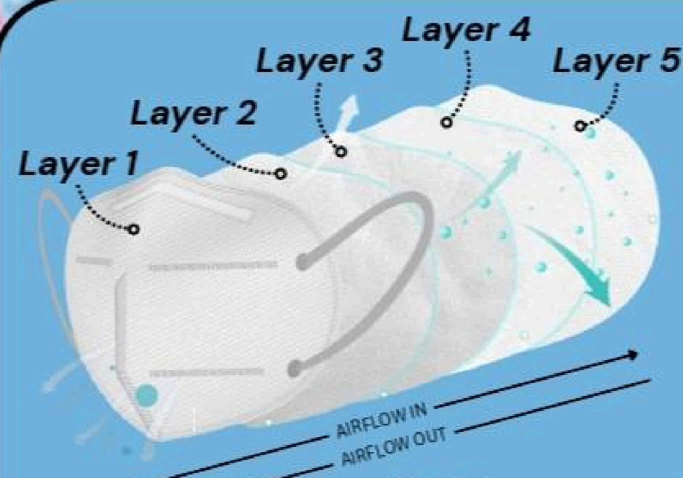


Fig 2.6: Layer separated view of a KN95 mask with airflow

LAYER 4

A second **melt blown layer, with interwoven polyester and polyethylene** (~5-50 microns). We can visibly see the differing strands in figure 2.4.

Provides mechanical strength and captures fine particles through a tightly packed fiber network.

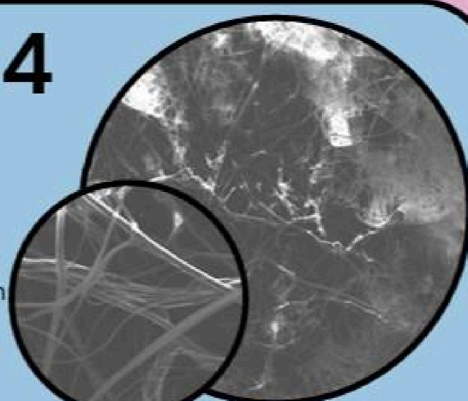


Fig 2.4: x42 (right) and x450 (left) magnifications of the fourth layer of a KN95 mask. Taken using SEM.

LAYER 5

Non-woven polypropylene with a soft texture and larger pores than the melt-blown layers (fibers ~200 microns).

Designed for skin contact: breathable, hydrophilic enough to absorb moisture, and thermally bonded to prevent fiber shedding.

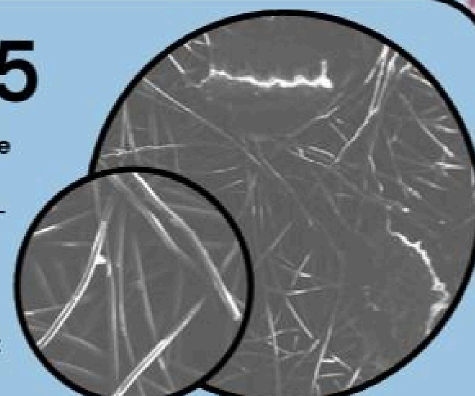


Fig 2.5: x42 (right) and x140 (left) magnifications of the fourth layer of a KN95 mask. Taken using SEM.

Environmental Impact of Masks

About **1.6 billion** masks went into the ocean in 2020[1].

If masks end up in landfills, they leach toxic chemicals into the groundwater. If they are improperly disposed of, some animals mistakenly feed on them or masks can entangle animals' limbs. Additionally, a single face mask can release over 1000 microplastics when immersed in water[2]. Masks have major environmental impacts.

Fig 4.1: Images of masks being discarded in landfills, being incinerated, and becoming lost in the ocean. The pictures do not accurately represent the end-of-life processes of masks but serve rather as a visual representation.

There's no good way to dispose of masks! Landfilling is the most common strategy. When they are buried in landfills, they degrade into microplastics[2]. When face masks are incinerated with other mixed wastes they release greenhouse gases along with hazardous compounds like heavy metals, dioxins, PCBs. Because face masks are lightweight, cheap, and simple, they are difficult to recycle large-scale[2].

52 billion face masks were produced in 2020 **—2.6 million tons of CO_2 equivalent**[2].