Chapter 12

Microworld

12.1 Microworld Length

1 – 1000 micrometers (μm) 1.0 x 10^{-6} m

The dimensions of bacteria are on the order of one micrometer.

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A red blood cell is a biconcave disk about seven micrometers in diameter and about 2.5 μm thick at its edge. The thickness of the cell decreases to less than a single micrometer at the center. The arteries through which these blood cells flow are over 10 000 μm (10 mm) in diameter at their largest extent, but inside the brain they can be as small as 2 μm in diameter. The 7 μm red blood cells pass through these capillaries by deforming themselves into a bullet-like shape. They then spring back into their original form when they exit into a larger diameter vessel.

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The silk produced by the mulberry silkworm has a maximum width of about 13 micrometers. This silk fiber has a triangular cross-section with rounded corners. The shimmering colors of silk are created because of this triangular prism shape. Light is refracted by these threads, causing different colors to appear at different angles, which produces a multitude of shimmering colors.

Micrometer Sized Objects

Example	Dimension
Scarlett Fever Bacteria Diameter	2 μm
Typhoid Fever Bacteria Length	3 μm
Spider Web Silk	3-8 μm
Red Blood Cell	7 μm
Snowflake	10 μm
Silkworm (Bombyx mori) Silk	13 μm
Fog Droplet Mean Diameter	10-15 μm
Diameter of a Fine Human Hair	17 μm
Score Line Thickness of Pull-Top Soda Can	25 μm
Micrometeorites	50 - 2000 μm
Paper Thickness	90 μm
Smallest Dimension Resolvable by Unaided Eye	100 μm
Airborne Disease Droplet Diameter	100 μm
Coat of Paint	100 μm
Human Egg Cell (diameter)	130 μm
Diameter of a Thick Human Hair	181 μm
Tardigrade (water bear) length	500 μm
Great Pyramid Joint Openings (mean)	500 μm
Thickness of Credit Card	760 μm
Phytoliths	1 - 1000 μm
Microspheres	1 - 1000 μm

Table 12.1

Silk is traditionally measured with a unit called a *denier* by the textile industry. The original denier was defined as a silk thread 9600 aunes in length, and equal to the weight of a coin called the denier. Four hundred aunes has a length of 476 meters. The denier coin has a mass of 24 paris grains. It was noted this relationship, when scaled to 9000 meters, produces a single silk strand with a mass of 1.004 grams. This metric coincidence allowed people in the textile trade to continue using the denier by defining it as a thread which has a mass of one gram, and is 9000 meters in length.

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If a fog is optically dense enough that it's hard for a human to see through it, the individual droplets of fog have a mean diameter of about 10-15 micrometers.

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The design of a pull-top opening on a soda can requires incredible precision. The score line, which becomes the oval boundary of the drinking aperture created when a person pulls on the lever-arm of the pull-top, is only 25 micrometers thick. This is four times thinner than an average human hair. In order for young children and the elderly to readily open a pull-top can, the thickness of the score-line must be within a tolerance of 5-7 micrometers. If the score thickness is larger than 35 micrometers, the can will not open. The sides of a modern soda can are only around 125 μm thick.[1] Similar in thickness to a coat of paint.

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The average thickness of paper is about 90 μm, or over twelve times as thick as the diameter of red blood cell.

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Understanding physics at the micrometer level can be a matter of life and death.[2] When the COVID-19 pandemic appeared in 2020 there was a consensus about how diseases spread by airborn means. It was thought that the SARS-Cov-2 virus was not spread by airborne droplets. Linsey Marr, an engineering professor at Virginia Tech was not convinced. The evidence she saw indicated that the COVID-19 corona virus could hang in the in the air, and infect people who breathed in enough of the contagion.

At the beginning of April 2020, the World Heath Organization (WHO) tweeted that it was a fact that COVID-19 is NOT airborne. A considerable number of aerosol scientists thought this was a mistake, and tried to warn the WHO. Superspreading events were proliferating. They were occurring in restaurants, call centers, cruise ships, and in situations where people were across the room from a contagious person. The distance was larger than the one to two meter safety guildlines the WHO quoted along with

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frequent hand washing.

The WHO claimed the SARS-Cov-2 only traveled in large droplets. These droplets were so large they would immediately fall to the ground, therefore 1-2 meters was a safe distance. If this was true, then why the large outbreaks? The WHO's experts demurred, and demanded more proof of airborne transmission. During a video call, Lidia Morawska, a well respected atmospheric physicist, attempted to forward her view, but was immediately silenced, and told she was wrong by a WHO expert. His abruptness startled Morawska.

For over 20 years, Morawska had been advising a separate section of the WHO about the effects of air pollution. It was accepted that small particles of soot and ash could hang in the air, travel widely over great distances, and be inhaled. The WHO's advisors seemed to be asserting that the same physics which applied to particulates, did not apply to particles saturated with virus that were expelled by the lungs. These WHO advisors claimed that airborne particles were 5 micrometers or smaller. Larger sizes would make their way to the ground, and become harmless.

The stakes were too large for Linsey Marr to ignore. It wasn't an academic argument, the pandemic would put a multitude of lives in danger if the currently accepted science was wrong. Marr was concerned that outdated science was determinining public health policy. Marr obtained a number of medical textbooks, and according to them, almost all respiratory infections are transmitted by coughs or sneezes. The idea is that when a person sneezes or coughs, bacteria and viruses are ejected like projectiles from a gun. Like firearm projectiles, they are thought to immediately drop toward the ground after they have been discharged. Their range is thought to be from one to two meters, and when they hit the floor, they adhere. Only those that make it to another person's nose or mouth have the potential to produce infection.

There are diseases, such as measles and tuberculousis, that are known to violate this scientific model. They are called "airborne" transmitters. These contagions travel within aerosols. Aerosols

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are thought to be particles so small they can remain suspended for hours, and travel long distances. The simple act of breathing can distribute them.

Whether a droplet produces airborne transmission, or is a droplet which immediately begins a journey to the ground, is of paramount importance. Droplets can be dealt with though frequent hand washing with soap and water. Aerosols are more like gas warfare, one needs an N95 mask to act as a barrier.

Textbooks defined an aerosol as having a 5 μm diameter, so anything smaller remains airborne, anything bigger is termed a droplet, and immediately begins to drop to the floor. Marr was sure the physics was wrong, but the number appeared over and over. In 2011, she installed air sampling equipment in day care centers, and airplanes—in locations where textbooks said no flu virus should be found. There was enough discovered to make people sick.

Marr wrote up the work, but the major medical journals rejected her paper. She continued to experiment and strengthen her case that aerosols were infecting people with the flu virus. Finally, a specialized publisher, *The Journal of the Royal Society Interface* began accepting her work for publication.

But where did the 5 μm diameter definition come from? Medical textbooks simply repeated it without citation. The trail went cold until December of 2019. It was then, that Marr encountered a paper published by a group headed by Yuguo Li, an indoor-air researcher at the University of Hong Kong. During the 2003 SARS outbreak, he investigated an outbreak at an apartment complex. It strongly indicated that coronavirus could be transmitted by airborne particles. Li encountered the same intellectual resistance that Marr had, when trying to get his findings accepted by the medical community.

Li simulated coughs and sneezes mathematically. What he found was that few heavy droplets were generated, and too few destinations: nostrils, eyes, or an open mouth existed, that could produce much infection. Li's research group came to the conclusion the medical establishment had it reversed. Most colds and flu, and other respiratory illnesses, were spread by aerosols. The group argued the 5 micrometer aerosol boundary was spurious, and was only extant in a decades old CDC document published for hospitals.

Jose-Luis Jimenez, an atmospheric chemist at the University of Colorado at Boulder, was deeply curious how the 1 to 2 meter WHO recommendation for social distancing originated. It appeared to him the guideline was based on a small number of studies from 1930s and 1940s. The authors of those experiments thought it was very possible that airborne transmission past 2 meters was likely. The literature was contradictory.

Jimenez emailed Marr with his findings, she shared her concerns about the apocryphal origin of the 5 micrometer aerosol boundary, and suggested the two issues might be associated. Was the 1-2 meter distance based on the assumption of a 5 μm droplet. Finding the original source of this assumption became paramount. They enlisted a historian, graduate student Katie Randall for help. She had the understanding of how to trace historical documents the team needed, but the trail went cold. As tuberculosis was one of the earliest airborne diseases studied, she began searching for the oldest documents which referred to 5 μm sized droplets, and involved tuberculosis. The oldest document she found cited a long out-of-print 1955 book, authored by Harvard engineer William Firth Wells, titled *Airborne Contagion and Air Hygiene*. This was the break she needed.

The book was an epitome of his 23 years of research on the subject. Wells and his wife Mildred, a physician, characterized air samples. They generated a curve that related how gravitational and evaporative forces opposed one another when acting respiratory particles. Their computations predicted the time it would take for a particle of a given size to travel from a person's mouth to the ground. Their work indicated that particles larger than 100 micrometers plunged to the ground within seconds. Particles smaller than this remained airborne. Their boundary for airborne

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particles was 100 μm, not 5 μm.

Wells performed experiments in the 1940s. He used ultraviolet lights to disinfect the air inside schools. The classrooms with UV lamps installed significantly decreased the number of kids who came down with measles. This indicated the measles virus must be airborne. Measles was not established as an airborne disease until decades after Well's research.

Randall discovered a schism had occured in medicine. Alexander Langmuir was the influential chief epidemiologist of the recently created CDC. He was convinced that personal cleanliness and hand washing were the key to controlling infectious diseases. He saw Well's views as reactionary, a return to the idea of "bad air" transmitting disease that had dominated medicine in previous centuries.

Langmuir was caught-up in this schism. He was concerned about the threat of biological warfare. Could enemies deploy airborne pathogens across US cities? Langmuir published a paper that embraced a sort of cognitive dissonance. It dismissed the idea of airborne infection at the same time as it accepted his work as seminal to the understanding of the physics of airborne infection.

Langmuir noted that humans were good at filtering out particles larger than 5 micrometers in extent. Particles smaller than this, could penetrate deep into the lungs. In the case of miners, and factory workers, this caused irreversible damage. The key to engineering the lethal transmission of a pathogen to a large population, would be to introduce it into a liquid that would then be atomized into particles smaller than 5 μm. These would be small enough to subvert the bodies defenses.

By the 1980s Langmuir had begun to soften his stance on airborne infection. He now saw it as a possibility. What had changed his mind? It was one of Well's last studies that were conducted at a VA hospital. Wells and his fellow researchers transfered exaust air from a tuberculosis ward into cages containing around 150 guinea pigs. A small number of guinea pigs came down with tuberculosis. Another 150 guinea pigs were added to the exper-

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iment, but UV light was used to disinfect the air channeled to them. All the guinea pigs with treated air remained healthy, and the controls continued to contract tuberculosis. This was the first clear evidence that a disease that infected humans, tuberculosis, could be transmitted through the air.

These revolutionary results were published in 1962. Wells died the next year. Shortly after, Langmuir gave a speech to a group of public health workers. He credited Wells with enlightening them on how to make their response to a burgeoning epidemic of tuberculosis effective. Langmuir emphasized that the particles, which transmitted the dangerous tuberculosis pathogen, were smaller than 5 micrometers.

Within the CDC there was an apparent conflation of Well's observations following his death. The particle size which was thought to transmit tuberculosis, 5 μm, was generalized as a definition for all airborne pathogens. Well's 100 micrometer airborne threshold languished, and was forgotten. The five micrometer size was incorporated into textbooks, and as one textbook copied another, became textbook folklore.

Linsey Marr was floored that Randall solved the mystery of the incorrect 5 micrometer definition. The definition had ossified into scientific dogma, and it would take considerable effort to over come this entrenched belief. It permeated leading medical bureaucracies. In light of the COVID-19 pandemic, this information was of paramount importance to public health.

An open letter was penned in July of 2020. It was addressed to the medical community, and the WHO, and signed by Marr, Jimenez, and 237 other scientists and physicians. The letter generated headlines, and a strong backlash. The WHO recognized the possibility of aerosol spread, but renewed its guideline of 1-2 meters for effective social distancing. People only needed to wear masks in poorly ventilated areas, or in enclosed areas where they could not maintain the 1-2 meter guideline. Jimenez saw this recommendation as irresponsible. People were using it to argue against using HEPA units in schools and offices based on the new

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recommendation. Marr and a number of scientists and physicians persevered by writing a letter that was published in *Science*. The CDC finally acknowledged that SARS-CoV-2 can spread through aerosols which can linger for a long period of time.

Airborne transmission is complex, and depends on how contagious SARS-CoV-2 is compared with other pathogens. Measles will infect 90 percent of people who are vulnerable to infection in the presence of someone with the virus. The SARS-CoV-2 virus appears to be far less contagious, and does not appear to infect people over considerable distances, or when a space is well-ventelated. It infects people who are in the immediate proximity of another infected person. It coincidentally looks like a pathogen as mis-described in current textbooks.

Understanding the physics of how droplets propagate between people, will help us contain future pandemics, and guide research. On Friday April 30th of 2021 the WHO tacitly updated it's website, and acknowledged that coronavirus can spread via aerosols, as well as larger droplets. By early May, the CDC revised its COVID-19 advise. The inhaling of aerosols is now at the top of the list as the mechanism of transmission.

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100 μm is the diameter of a splattered ink droplet produced by a 2-4 picoliter drop of inkjet ink when it impacts on a page.

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Animals so small they can only be seen with the aid of a microscope are called Micro-animals. A plethora of these animals exist, but the one which probably receives the greatest attention is called the tardigrade or water bear. The first person to observe a water bear under a microscope was German zoologist Johann August Ephraim Goeze (1731-1793) in 1773. Over one thousand species of tardigrades have since been identified. A typical water bear has a length of around 500 micrometers when fully grown. Different species of adult water bears range from 100 μm to 1500 μm in length and are clearly denizens of Microworld. Tardigrade fossils establish they have existed on Earth for at least 530 million years, and survived the last five large mass extinctions.

Water bears are found on every continent on Earth, and range from 6000 meters above sea level in the Himalayas to 4000 meters below the surface of the ocean, and also exist 5 meters below solid ice in Antarctica.

Tardigrades are the most indestructible organism known to science. This Micro-animal can survive temperatures from near absolute zero (1 K or -272° C) to well above the boiling point of water (420 K or 150° C). Water bears can withstand six times the maximum pressure found in the deepest regions of the ocean. They survive exposure to ionizing radiation at values hundreds of times the lethal level for humans. Tardigrades are also the first animal known to survive exposure to outer space, and its accompanying solar radiation, for at least ten days.

Water bears can enter a reversible biological state in which their metabolism becomes essentially suspended, with a metabolic rate 0.01% of normal. They can dehydrate themselves to 1% of their ordinary water content. Tardigrades can survive in this suspended state for over ten years, and then revive. Some research indicates they may be able to remain dormant for up to 100 years. Water bears are born with a finite number of cells which do not increase in number as it matures. The Tardigrade becomes larger because each of its individual cells increases in size.

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The white outer casing stones on the The Great Pyramid at Giza were used to produce a smooth striking surface. These two meter limestone blocks have joints with mean openings of 500 micrometers. The thickness of a credit card is about 760 micrometers, so one could not fit a credit card into the average joint between these casing stones.

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In 1977, Walter Alvarez (1940 –) was studying geological strata in Italy. He was working with Italian geologist Isabella Premoli Silva, who is an expert on *foraminifera.* Foraminifera are often called forams for short. In general, forams are Microworld-

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sized marine creatures, less than 1000 μm, which produce an external shell called a test. These tests exist in a large variety of shapes and configurations. (See Figure 12.1)

When forams die, their shells sink and become part of the marine sediment. The species of forams found in a sedimentary layer provide a timeline, which allows Silva to determine its age.

Silva brought a puzzling anomaly to Alvarez's attention. The limestone layer belonging to the final stage of the Cretaceous period, about 66 million years ago, teamed with forams of all manner. Immediately above this abundantly-populated layer, is a layer of clay, which is about 10 millimeters thick, and devoid of forams. Above this empty layer, the forams reappear, but the number of species has diminished to a tiny fraction of those found below the clay layer. Walter Alvarez noted the appearance of this lifeless layer of clay was coincident with the time period in which dinosaurs had perished. Alvarez doubted it was a coincidence and collected samples for later study.

Alvarez wondered how much time the 10 millimeter layer of clay had taken to form. This would be equal to the amount of time it took the forams to restore themselves into the ecosystem. Walter had taken a position at Berkeley where his Nobel Prize winning father, Luis Walter Alvarez (1911–1988), still worked. Walter discussed this anomaly with his father, who became enthralled.

Walter's father knew meteorites have a much larger concentration of the element iridium than is found on the surface of the Earth. The constant micrometeorite rain we experience could possibly act as a way to determine the amount of time the clay layer had taken to form. The longer the layer took to form, the more iridium would be present. What was needed were measurements to calibrate time versus the amount of iridium present.

Samples from the clay layer, as well as those found above and below, were tested. The clay layer contained an astonishing amount of iridium, it was over 25 times that of the surrounding strata! Was there a problem with the sample? Walter obtained new samples from a location in Denmark called Stevns Klint,

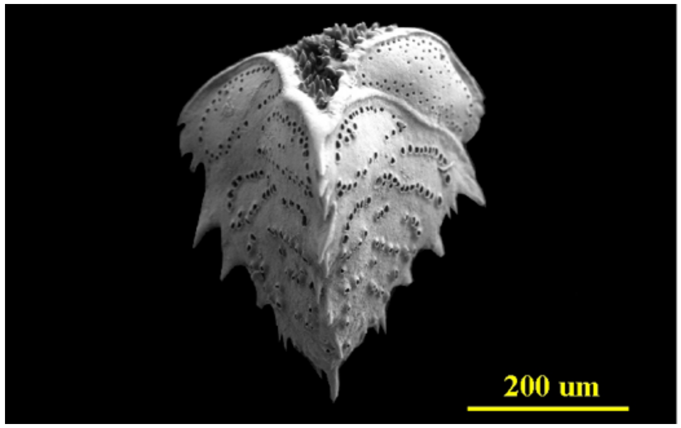

Figure 12.1: Foram (Photo Credit: Heidi Crevison Souder Used by Permission)

where the clay layer is exposed, and samples above and below are readily obtained. The new samples also contained enormous amounts of iridium. A third set of samples from the Southern Hemisphere also had an anomalous amount of iridium.

After considerable debate and conjecture, Walter and his father Luis developed the asteroid impact hypothesis. There is very little iridium on the surface of planet Earth because this heavy element sank into the interior during the formation of the planet.* Meteors contain large amounts of iridium by comparison. They posited that 65 million years ago, an asteroid about 10 meters across struck the Earth. Upon impact, it exploded, releasing an estimated 400 Zettajoules of energy. The atomic bomb dropped on Nagasaki released an energy of 84 Terajoules (0.000 000 4 Zettajoules). This means the hypothesized asteroid was equal to about 5 000 000 000 Nagasaki bombs.

*Iridium is the second densest element, after osmium, which is the most dense. Iridium is the most corrosion-resistant element known. Iridium is so rare in the Earth's crust, only three Megagrams of it are produced worldwide each year.

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In 1980, the Alvarezes submitted a paper to *Science* entitled *Extraterrestrial cause for the Cretaceous-Tertiary extinction.* The reaction was swift and negative. The singular absence of life had been noted since the time of Darwin, but was thought to be attributable to a gap in the fossil record. But as more fossils were gathered, the problem did not go away. A period of tens of millions of years was missing, but the explanation was thought to involve a mass extinction, not a quick catastrophe. The belief in gradual change was so entrenched, the idea of an asteroid snuffing out the dinosaurs within a geological instant, was met with contempt. The location of this clay layer is known as the Cretaceous–Paleogene boundary or K–Pg boundary.† The K–Pg geological signature is now dated to about 66 million years ago.

Gradually, scientific evidence began to accumulate, and favored the asteroid impact hypothesis. Shocked quartz, of the type found at nuclear test sites, was found within a layer of K–Pg boundary clay in Montana. Evidence of an enormous tsunami was discovered in south Texas, and dated to the end of the Cretaceous. Gravity surveys, undertaken in the 1950s while searching for oil, revealed what was thought to be the remains of an underwater volcano below the Yucatan Peninsula in Mexico. In 1991, the Alvarezes located core samples which had been taken contemporaneously with the oil survey. Right at the K–Pg boundary, the samples contained a layer of impact melt-rock. The underwater depression was not a caldera; it was a meteorite impact crater. The feature was dubbed the "Crater of Doom" by Walter Alvarez, but it is generally called the Chicxulub crater after a nearby town.

The discovery of the Chicxulub meteor began with the absence of Microworld-sized marine creatures in a layer of clay. The desire to determine the amount of time it took for the clay layer to ac-

†This layer was known as the K-T boundary for Cretaceous-Tertiary boundary. K was used because C had already been taken for Carboniferous. The K-T boundary is now called the K-Pg boundary by many researchers. The K-Pg stands for the Cretaceous–Paleogene boundary. The date for this boundary had been revised to be 66.24 million years ago.

cumulate, lead to the hypothesis a timeline could be determined from the *number of micrometeorites* which were deposited within the layer. The attempt to indirectly measure the concentration of micrometeorites in the sterile clay layer, by determining the amount of iridium present, in turn led to the discovery of a single Kiloworld sized macro-meteorite which impacted the Earth and took out the dinosaurs. That hypothesis also explained the loss of the Microworld-sized *foraminifera* which inspired the original scientific investigation.

In 1832, Charles Darwin (1809-1882) collected dust which had collected in his ship's sails. He sent this dust, and a sample provided to him from another ship around six hundred Kilometers to the north, to scientist and microscopist Christian Ehrenberg (1795–1876).[3] Ehrenberg noted the dust sample contained "siliceous shields" and "siliceous tissues of plants," which are today known as *phytoliths*, from Greek roots meaning "plant stone." Phytoliths are inorganic silica, which forms a conformal layer on the insides of plant cells, and preserves their geometric structure.

Phytoliths have been categorized and studied and can act as identifiers for many plants. Because they are made of silica, they are very rugged and resist weathering; they can resist heat of up to 1000 degrees Celsius. After a plant dies, they remain identifiable for tens of millions of years. Phytoliths range in size from 1 to 100 micrometers. Phytoliths are often combined with other material. It turns out the plaque (dental calculus) found on teeth can be rich in phytoliths. This has allowed researchers to reconstruct the diet of the giant ape *Gigantopithecus blacki.* This tallest known ape is discussed in Uniworld. It is thought to have been over three meters tall, with a mass of well over 500 Kilograms. The phytoliths attached to its teeth reveal *Gigantopithecus* ate a disparate diet of grasses, including bamboo, along with fruit such as jackfruit and durian.

Prior to the use of phytoliths for determining the varieties of plants a humanoid ate, it was inferred from artifacts and surround-

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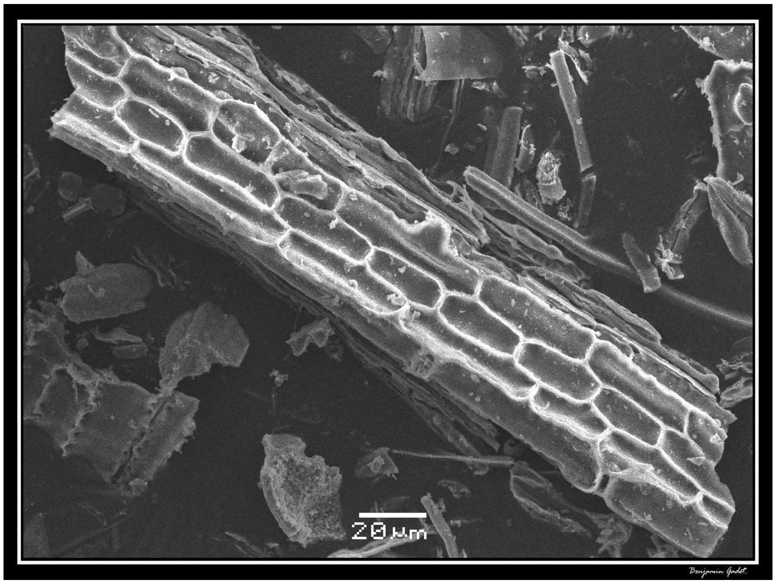

Figure 12.2: Elephant Grass Phytolith – Creative Commons – Benjamin Gadet

ing fauna. Neanderthals were long thought to have existed mostly with a diet of meat, but phytolith analysis of their dental calculus reveals they ate available date palms. The phytoliths found in different sections of caves indicate woody plants may well have been used to secure the entrance and grasses were used to sleep upon.

Phytoliths have allowed scientists to trace the domestication of maize to a region of Southwest Mexico, and, in combination with other evidence, determine it occurred about 8000 to 9000 years ago. Phytoliths have allowed researchers to identify unknown pastures and agricultural plots around a 17th century farmhouse, and enlarged the extent to which it was thought these activities took place.

Some phytoliths have captured ancient carbon, which makes carbon dating possible for a large number of samples found in a dig. The silica acts as a preservation vehicle to protect the encased carbon. This method is particularly useful when no wood or suitable organic material is available. Once again the Microworld sheds light on the worlds above Uniworld.

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Where Microworld definitely expands into larger metric worlds, is when one assesses the amount of single celled organisms on Earth, known as prokaryotes. There are an estimated 5 x 10^{30} prokaryotes on our planet.[4]. Assuming each single celled bacteria is about 2 μm long, and were stacked end to end, their length would be 10 Yottameters! Recall the observable universe is only 880 Ym in diameter. The length of the Milky Way Galaxy is about 1 Zettameter. We would have to lay 10 000 Milky Way Galaxies end-to-end to equal the length of unicellular bacterial on Earth.

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Small spheres made from glass, ceramics, plastics, and other materials with diameters from 1 to 1000 micrometers are called microspheres. These small spheres have a large number of industrial applications. They are used for drug release in medicine, and in the manufacturing of ceramic filters and reflective signs. Microspheres are in cosmetics, and used to create electronic paper. Colored microspheres are utilized as fluid flow indicators. Hollow glass microspheres are often added to solid materials to lower their densities.

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A colloid is created when small particles with dimensions in the micrometer range, or smaller, are dispersed in a liquid medium. Paints, inks, and food products like mayonnaise and milk are examples of familiar colloids commonly found around the house. Glue is another example of a colloidal suspension. The Greek word for glue is “kolla”, which is where “colloid” comes from.

Italian chemist Francesco Selmi (1817–1887) wrote about the preparation of “pseudosolutions” in 1847. Small particles held in suspension by the actions of matter in another phase were understood not to be solutions. Michael Faraday (1791–1867) was able

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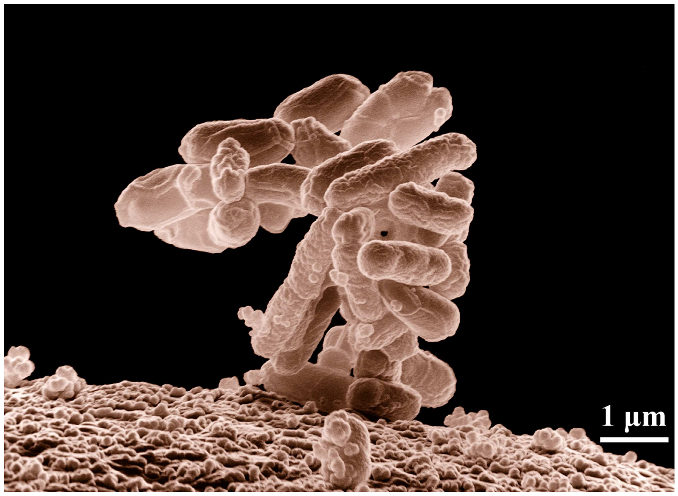

Figure 12.3: E coli at 10 000x magnification – USDA

to suspend gold particles in water. A suspension of a solid (gold) within a liquid (water) is called a *sol*.

12.2 Microworld Area

1 – 1 000 000 square micrometers (μm^2) 1 x 10^{-12} m^2

Square Micrometer Area Objects

Example	Dimension
Microsphere (1 μm diameter)	3.14 μm^2
E. coli Bacterium	6 μm^2
Red Blood Cell	100 μm^2
Human Hair Cross-section Area (100 μm diameter)	7 854 μm^2
Microsphere (564 μm diameter)	1 000 000 μm^2

Table 12.2

The surface area of a microsphere with a diameter of 1 μm is 3.14 μm^2. A microsphere with a surface area of 1 000 000 square

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micrometers has a diameter of 565 μm.

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An E. coli bacterium and human red blood cell have surface areas of six and one hundred square micrometers respectively. E. coli bacteria is acultative anaerobic organism. What this means is that if oxygen is present, it metabolizes oxygen to live, if no oxygen is present, it can use fermentation to exist. Antonie van Leeuwenhoek, around 1680, half-filled two identical glass tubes with crushed pepper powder, into which he introduced clean rain water. Leeuwenhoek left one of the glass tubes open to the environment, the other he sealed with a flame. After a number of days, he investigated the open ended tube and found "a great many very little animalcules, of divers sort having its own particular motion." It was expected that the sealed tube would be devoid of animalcules, but to his surprise "a kind of living animalcules that were round and bigger than the biggest sort that I have said were in the other water." The oxygen had been consumed by the aerobic bacteria, which produced an environment suited for anaerobic ones. In the case of E. coli, it can exist in both.

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The cross-section of a common human hair of 100 micrometer diameter is 7854 square micrometers.

12.3 Microworld Volume

1 – 1000 Microliters (μL) 1 x 10^{-6} L

A large spherical raindrop has a mean diameter of about two millimeters, and a volume of 4.9 microliters. A sphere of water with a 10 millimeter diameter contains 524 microliters. A 1000 microliter drop of water has a diameter of 12.41 millimeters.

Wilson Bentley (1865–1931) is best known for his pioneering work photographing snowflakes, but he was also the first American to measure the diameter of raindrops. He measured them by allowing raindrops from a storm to fall into a pan which contained a 25 mm layer of finely sifted flour. This thickness kept

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the raindrops from hitting the bottom of the metal pan. What he discovered was each drop would produce a small pellet of dough. He allowed them to dry and then measured their diameters.

Microliter Objects

Example	**Volume**
Raindrop (2 mm diameter)	5 μL
Drop of Water	60 μL
Sphere of Water (10 mm diameter)	524 μL
Sphere of Water (12.41 mm diameter)	1000 μL

Table 12.3

It could not be assumed the diameters of the dried flour balls were the same size as the original drops. Bentley determined the size of the original rain drops by producing artificial "raindrops" of known diameter with a dropper. He was able to measure the dimension of the drops just before they necked away from the dropper.

The calibration drops were allowed to fall from 3-9 meters into the pan with flour. He repeated this process with a number of different sized drops. This in turn allowed him to determine the approximate size of the original raindrops from the size of flour pellets they left behind. Smaller raindrops, about 2 mm in diameter, left flour pellets almost exactly the same size as the original drops. The largest drops, six millimeters in diameter, would flatten slightly on impact. The original raindrop diameter was seen to be about 30% smaller than the maximum extent of the flour pellets.

Bentley discovered most rain consists of drops which have a range of sizes, but the vast majority of raindrops are of the smaller variety. In a small percentage of rainstorms, raindrops are found to be of an almost uniform size, which are called *monodisperse*. The flour pellets Bentley measured ranged in diameter from 850 μm to 5100 μm, which is a range of volume from 0.32 μL to 7 μL

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(320-7000 nL)

12.4 Microworld Mass

1 – 1000 micrograms (μg) 1 x 10^{-6} g

Microgram Objects

Example	Volume
Uncertainty of Prototype Kilogram	50 μg
Poppy Seed	300 μg

Table 12.4

The gram was adopted by France as the mass equal to a cube with one-hundredth of a meter (10 mm) sides, filled with water at the temperature of melting ice. To produce as accurate a standard for this mass as was technically possible, it was decided to increase the volume of the defining cube. The sides of the cube were increased to one-tenth of a meter (100 mm). This cubical volume is equal to a liter, and has a mass of 1000 grams, which is a Kilogram. It was further decided to use the temperature at which water is most dense (4 °C) as the standard. This mass would be rendered as a metal artifact to produce a standard. It was fabricated from platinum, adopted as the Kilogram in 1799, and remained the definition of the Kilogram for the next 90 years.

An international agreement called The Metre Convention was signed in 1875 by seventeen nations, and a new artifact for the Kilogram was commissioned. In 1883, the new Kilogram artifact was found to be indistinguishable from the previous standard. The new artifact is called The International Prototype Kilogram (IPK). The IPK is a cylinder constructed from an alloy of 90% platinum and 10% iridium. The iridium was added to make the standard more durable. In 1889, a new standard Kilogram artifact was adopted. It remains the standard of mass to this day. Official copies of the IPK were distributed to nations around the world

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to serve as their primary standards. About every 40 years, these standards are compared with the IPK to maintain their traceability back to the IPK.

Modern measurements of a one-tenth-of-a-meter cube of water, with a controlled isotope content, indicate the scientists who measured the original Kilogram value over 215 years ago were correct to within 25 milligrams.

The Kilogram is the last metric standard based on an artifact, and not a scientific phenomenon which can be independently reproduced in multiple laboratories around the world. It is also the only base unit in the metric system with a prefix.

The mass of the Kilogram *is* the IPK. Three times, in 1889, 1948, and 1989, the IPK was compared with its clones. The clones were not exact, and each was given an offset value with respect to the mass of the IPK for calibration. Before the replicas are compared, they are cleaned. This removes about 5 to 60 micrograms of contamination, and a second cleaning has been seen to remove up to 10 more micrograms. The most recent standards verification revealed the masses of the replicas are diverging from each other. Analysis indicates the IPK has lost somewhere on the order of 50 micrograms over the last 100 years with respect to its replicas. The reasons for this are still not understood. It is not possible to establish if the artifact copies are changing with respect to the IPK or vice versa.

Uncertainty in the International Prototype Kilogram cascades its way through metric units, which are defined in terms of the IPK. This uncertainty has prompted metrologists to investigate new candidate definitions for the Kilogram, which would be in terms of natural phenomena, not an artifact. The uncertainty of the IPK is in the microgram range and estimated to be around 50 μg. A poppy seed has a mass of about 300 micrograms.

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