SEEING WITH ELECTRONS:
THE SCANNING ELECTRON MICROSCOPE

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Intro to Visual and Critical Studies

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Humans, as sighted creatures, rely on light to see. Without light, the eyes do not work properly. For centuries, people have been trying to see beyond what the unaided eye can perceive. In the 1600s, when lenses were first being created, they brought a whole new world into view, the microscopic world[1]. These magnifying lenses were ultimately developed into the light microscopes. Eventually, technological advances made a way to see with something other than light. Researchers discovered that light has a limit and to see the smallest of the micro world, an electron beam must be used. This electron beam was eventually developed into the scanning electron microscope (SEM). Microscopes have brought about numerous discoveries in science, medicine, inspired artists, and even questioned our perception of the known world. Seeing microscopic objects and organisms has changed the way the world is visually perceived now that microscopic objects and organisms can be better understood and manipulated. With the aid of the electron, the SEM brings many new things that would otherwise be too small to see, into detailed view.

Sighted creatures use their vision to better understand the world around them. Humans have an advantage over other sighted creatures due to technological advances that can be used to help us see with greater detail. The human eye has a limited ability to resolve small objects. To resolve, that is, be able to see an object clearly and in detail. There is a physical limitation to how much detail humans can pick up. Even with 20/20 vision, the human eye can only see objects clearly to a certain resolution before everything gets blurry. The unaided eye can see up to about 75 μm, which means things like fruit flies and strands of hair are visible, but there is a vast world that humans cannot perceive on their own[2].

[1] Egerton, Ray F., *Physical Principles of Electron Microscopy*. New York: Springer Science+Business, Inc., 2005. 4

[2] Ibid., 6.

The Advent of the Microscope

When microscopes were first being invented in the 1600s, people used lenses to magnify the objects they were observing. As the technology for lenses developed, so too did the microscope. Eventually, researchers learned that if light is shined through an object and magnified with lenses, it can be seen in fine detail. This technology is what is now known as the modern light microscope[3]. To observe a specimen through a light microscope, it must be prepared in a way that the light can shine through it or it must already be translucent enough to see through. If the specimen is too opaque, light microscopes would not be able to resolve the image very well. With the SEM, a specimen can be viewed as a whole and does not need to be translucent, unlike the light microscope[4].

With the aid of a light microscope, a human's resolving power becomes about 1000x greater than what is resolvable with the naked eye[5]. The resolving power limitation of a light microscope is directly related to the diffraction of light waves themselves[6]. This limit to light's resolving abilities makes a light microscope only able to resolve up to about 0.3μm because light waves themselves are too big to see any smaller. So, things like viruses and DNA are not resolvable by a light microscope[7]. Electrons naturally have a shorter wavelength than light, therefore making the resolution power much greater[8]. An illustrator named Malcolm Douglas Chaplin, who will be discussed later, eloquently describes light waves as being "too fat" so they

[3] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscopy*. Sudbury: Jones and Bartlett Publishers, 2009. 3.

[4] Egerton, Ray F., *Physical Principles of Electron Microscopy*. 16.

[5] Ibid., 6.

[6] Ibid., 2-3.

[7] Burgess, Jeremy, Michael Marten, Rosemary Taylor. *Under the Microscope: A Hidden World Revealed*. New York: The Press Syndicate of the University of Cambridge, 1990. 7.

[8] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscopy*.

cannot pick up as much detail as electron beams[9]. Electron beams, rather than light beams, enable tiny cells and their moving parts to be resolvable so humans are able to see a much clearer image. SEMs have drastically changed the blurry, out of focus world of the naked eye and the light microscope into a crisp and clear image that can easily be understood.

It is important to know the history and development of an SEM in order to better understand how it is possible to "see" electrons. SEMs have a very recent history as compared to the light microscope. In the late 1800's, scientists began searching for something with a shorter wavelength than light in order to get a higher resolution of objects that are too small for light waves. Later on in the 1920s, the electron was discovered and scientists learned that it is possible to bend the trajectory of electrons with electron lenses. There lenses work in a similar way as a conventional light microscope lens. The first electron microscope was built by Ernst Ruska and Max Knoll in 1933. The image that the researches captured was of silicon steel. It was a very crude image and left the specimen almost unrecognizable because the powerful electron beam charred the object it was focused on[10]. The electron microscope was eventually developed into two distinct types of microscopes, the Scanning Electron Microscope (SEM), which is discussed in this paper, as well as the Transmission Electron Microscope (TEM) will be briefly discussed[11]. A few years later in 1937, commercial prototypes that could resolve up to 5-10nm were in circulation. Companies such as Philips and Hitachi continued to develop the SEM. Not until the 70's did more breakthroughs happen with the electron microscopes ability to resolve images. Researchers began using lanthanum hexoboride crystals as the cathode in the electron beam, rather than the tungsten used in the past. This led to a more focused beam and therefore a

[9] Caula, Rodrigo. "World's Smallest Book Measures 70 Micrometers". DesignBoom. http://www.designboom.com/technology/worlds-smallest-book-measures-70-micrometers/ (accessed October 26, 2015).

[10] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscopy*. 4.

[11] Burgess, Jeremy, et al. *Under the Microscope: A Hidden World Revealed*. 7.

better image. The next evolution in SEMs came with the computer. Getting a specimen prepared for an SEM image, taking the image, and developing it was a lengthy and arduous processes. Being able to hook up SEMs to a computer in order to control the beam and convert the images into something visible, greatly sped up the process[12].

Working an SEM is a complicated procedure. First, there is the long process of preparing the specimen for view. If the object being viewed is already something like a heavy, solid metal it is fairly easy to prepare[13]. The researcher simply places the object in the vacuum sealed chamber that the SEM is housed in and begins the imaging process (Figure 1). For most other specimens, especially biological material, it is not so easy. The most vital factor in imaging biological material is that it cannot be alive at the time of imaging. Living material would not survive the preparation process, let alone being shot with an electron beam[14]. When biological material is placed in a vacuum chamber for view, the conditions of the vacuum will evaporate any water and the harsh environment will begin to break down the specimen. Also, additional issues that may arise are that when a specimen is "scanned" with the electron beam, it will either char the specimen or sometimes electrons can build up on the surface of the object and cause artifacts in the image. Artifacts are anomalies in an image that are not part of the object being viewed[15]. These artifacts are similar to a washed out image or lens glare in a conventional digital camera. In order to remedy these issues, many objects are "sputter coated" in a metal that does not easily absorb electrons and can also contour to the surface of the object, such as gold or platinum. Sputter coating is the process of leaving an extremely thin coating of metal particles on

[12] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscopy*. 6.

[13] Lodish, H., A. Berk, C.A. Kaiser, M. Krieger, M.P. Scott, A. Bretscher, H. Ploegh, P. Matsudaira. *Molecular Cell Biology Sixth Edition*. New York: W.H. Freeman and Company, 2008. 388.

[14] Ibid., 389.

[15] Kamaladasa, R.J., and Picard, Y.N. "Principles and Application of Electron Channeling in a Scanning Electron Microscope for Dislocation Analysis." *Microscopy: Science, Technology, Applications and Educations* Vol. 3 (2010): 1586-1588.

a specimen[16]. Many objects, for example, human tissue, after or even during the process of sputter coating are frozen so they can keep their integrity when they are placed in the vacuum chamber for imaging[17]. Another issue with getting SEM micrographs of biological material is that the electron beam can actually destroy the specimen. Therefore the beam has to be set to a lower intensity in order to preserve the sample, even after the rigorous prepping that was done beforehand[18]. Once again, seeing with electrons is a very long process. People cannot perceive electrons with the naked eye so great care must be given to prepare a specimen in order for it to be easily translate into something humans can see.

After the specimen is prepared and placed in the vacuum, the electron microscope can do what it was made to do, get an image. Unlike with light microscopes, where you can look directly through the eye piece and see everything in front of you in real time, the SEM needs an interface. People need the help of a computer to see electrons. Because of advances in technology, SEM images can be fairly quickly viewed on a computer monitor[19]. SEM image capture can take a few seconds because the SEM beam has to scan across the object to get an accurate image[20]. It is possible, though, to see SEM micrographs as a video of about 60 frames per second. This allows the one operating the microscope to locate a specimen and also helps the SEM operator focus on the specimen. Although the video setting is helpful, a good, clear image is never possible if the SEM's video option is utilized. Nearly all images that are published or used for research are not captured using a SEM's video capabilities[21].

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[16] Burgess, Jeremy, Michael Marten, Rosemary Taylor. *Under the Microscope: A Hidden World Revealed*. 9.

[17] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscopy*. 30.

[18] Echlin, P. "The Application of Scanning Electron Microscopy to Biological Research." *Philosophical Transaction B* Vol. 261 (1971): 51.

[19] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscopy*. 4.

[20] Egerton, Ray F., *Physical Principles of Electron Microscopy*. 17.

[21] Ibid., 28.

Figure 1. Pictured here is a modern Scanning Electron Microscope located in a lab [22]

The SEM generally has two concentrated electron beams that focus on the object of interest in an x and y axis[23]. These beams, after going through a series of electron lenses, excite the electrons of the material being imaged. The excited electrons are referred to as "secondary electrons". Secondary electrons bounce off the surface of the specimen and are picked up by the detector, much like a human eye picks up visible light[24]. Secondary and primary electrons are picked up by the electron detector located near the bottom of the vacuum chamber the specimen is housed in which generates a signal[25]. This signal is then processed and the image is displayed on the computer screen. Although SEMs cannot resolve as small a detail as TEMs, they are useful because an entire object and its surface can be viewed. TEMs work much differently than

[22] Electron Microscopy Online Training. "Hitachi S-4700 FE-SEM". ACMALeTraining. http://mcff.mtu.edu/acmal/electronmicroscopy/FE_Form_Function.htm (accesessed November 18, 2015).

[23] Peng, L.-M., S.L Dudarev, M.J. Whelan. *High-Energy Electron Diffraction and Microscopy*. New York: Oxford University Press, 2004.

[24] Kamaladasa, R.J., and Picard, Y.N. "Principles and Application of Electron Channeling in a Scanning Electron Microscope for Dislocation Analysis." *Microscopy: Science, Technology, Applications and Educations* Vol. 3 (2010): 1585.

[25] Lodish, H., et al. *Molecular Cell Biology Sixth Edition*. 388.

SEMS. TEMs require a small, thin section of an object and can only view the interior of the object because of the intensity of the beam. This makes it difficult to understand an object as whole or to view the exterior of a specimen. Whereas SEMs can view entire objects or sections of a larger object. SEMs are significantly more versatile than a TEM[26].

Viewing things at a higher resolution can bring about a greater understanding of an object. With more understanding comes more knowledge. The Scanning Electron Microscope has brought about a brand new way of perceiving the world beyond the limits of light. As well as giving a greater knowledge of how the tiny parts of the universe work.

People used to perceive the world entirely differently before microscopes and especially before electron microscopes. With the help of microscopy, scientists began analyzing what they were seeing and started making hypotheses about the new microbiological world they were perceiving. Sometimes though, the way they interpreted the tiny structures under a light microscope was not an accurate interpretation. A good example of this misinterpretation were some scientist's explanation of what the interior of a human sperm cell looked like (Figure 2). When an educated person today looks at a sperm cell under a microscope, they understand what it is they are looking at. This person is aware that there is not a tiny, already formed human inside a sperm cell, like the depiction form the late 1600's by Nicolas Hartsoeker [27] [28].

Instead, the viewer is aware that sperm is a cell that can fertilize an egg. This is just a small example of what was not easily understood with primitive light microscopes but is now understood with the help of more powerful microscopes[29]. Furthermore, not until meticulous study of muscle tissue in 1950 did scientists begin to understand things such as how the human

[26] Burgess, Jeremy, et al. *Under the Microscope: A Hidden World Revealed*. 12.

[27] Alberts, Bruce, et al. *Essential Cell Biology Third Edition*. 664

[28] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscope.* 13.

[29] Alberts, Bruce, et al. *Essential Cell Biology Third Edition*. 664.

muscle contracts. Its complicated mechanism is not easily understood and an electron microscope's close up view helped researchers begin to understand how the muscle fibers work[30]. The way mankind perceived the microscopic world completely changed after the SEM's invention. There are still tiny mechanisms in nature that, even with the help of electron microscopes, cannot be visually perceived. Which puts scientists in a similar place to the researchers in the late 1600s who had a glimpse of the microscopic world but still did not have the appropriate tool to see all that they wanted to see. An example of this comes from a Biochemist by the name of Martin Solano who is a doctoral candidate at Georgia Institute of Technology. He mentions that humans cannot visually perceive the composition of atoms, there are only methods by which we can infer their properties and components. Similar to the way scientists in the 1600s inferred about the parts of the microscopic world that they could not yet see [31]

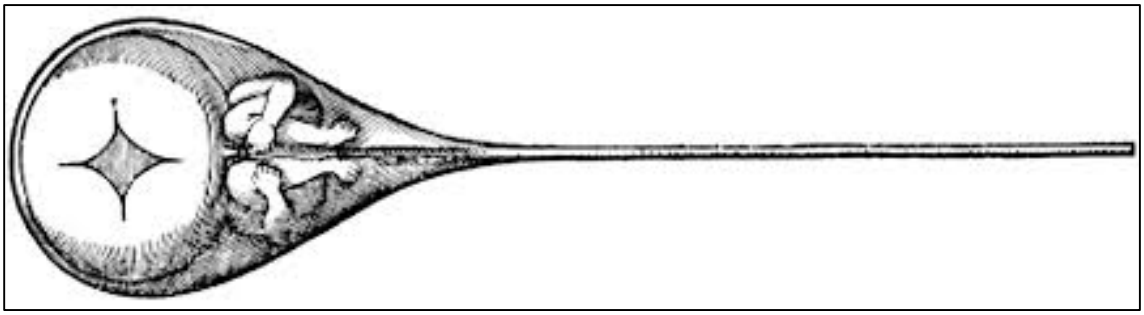

Figure 2. Nicolas Hartsoeker's illustration of a sperm cell under a light microscope from the late 1600's [32].

[30] Burgess, Jeremy, et al. *Under the Microscope: A Hidden World Revealed*. 12.

[31] Solano, Martin. Interview by Jennifer Cantley. Personal Interview. Atlanta, November 27, 2015.

[32] Chandler, Douglas E. and Roberson, Robert W. *Bioimaging: Current Concepts in Light and Electron Microscope*. 13.

SEMs allow us to expand our sense of sight. Burgess et al put it eloquently by saying "Though there is far more to perception than the sense organs, they are clearly fundamental; and in humans the eyes are most fundamental of them all." while talking about vision in their book, *Under the Microscope* [33]. In a way, we are not even seeing the tiny objects imaged by an SEM, but a representation of the object translated to visible light.

SEMs have also given a face or even a personality to those things that would have otherwise been invisible to the unaided eye. There are many mechanisms, objects, and organisms that would not be understood well if it was not for SEMs. For example, Ebola (Figure 3). Ebola was first pictured using an SEM in 1976 by Dr. Frederick A. Murphy. No one knew what the virus was or what it looked like until that moment[34]. Ever since then, the image of the twisted strand of an Ebola virus has inspired interest and fear in many, especially in the wake of the recent outbreak in Africa in 2014-2015. This SEM gives the disease a face. A very large portion of the population sees that iconic micrograph of Ebola and inherently has some idea of what it is[35]. A similar emotional reaction happens with another well-known microscopic killer, cancerous fibroblasts[36] (Figure 4). This monstrous form with tendrils reaching across the surface, imbedding in tissue, is eerie to look at. People have always struggled with many deadly diseases. Not until electron microscopes were invented were many of those diseases able to be physically viewed and better understood[37]. Other parts of the microbiological world are not always as deadly. Things like the DNA-containing chromosomes and the tiny organelles of cells can be viewed. Another interesting microscopic inhabitant that can be that can be resolved by an SEM is

[33] Burgess, Jeremy, et al. *Under the Microscope: A Hidden World Revealed*. 18.

[34] Sifferlin, Alexandra. "Ebola: The First Glimpse of a Virus." *Time Magazine*. October 13, 2014. http://time.com/3502740/ebola-virus-1976/

[35] Ibid.

[36] Solano, Martin. Interview by Jennifer Cantley. Personal Interview. Atlanta, November 27, 2015.

[37] Alberts, Bruce, et al. *Essential Cell Biology Third Edition*. 695.

the Tardigrade (Figure 5). The Tardigrade is a bear-like microscopic animal that only feeds off of plant cells[38]. There are whole zoos of tiny animals and organism, some disturbing, like the cancer cells, some adorable, like the tardigrade, that are visible with help from an electron beam. Things that were invisible to the human eye are now understood because of SEMs.

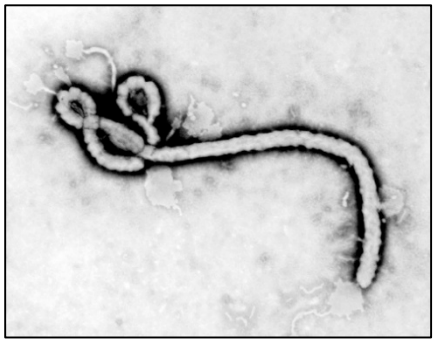

Figure 3: The first image ever taken of the Ebola virus. Taken in 1976 by Dr. Frederick A. Murphy [39]

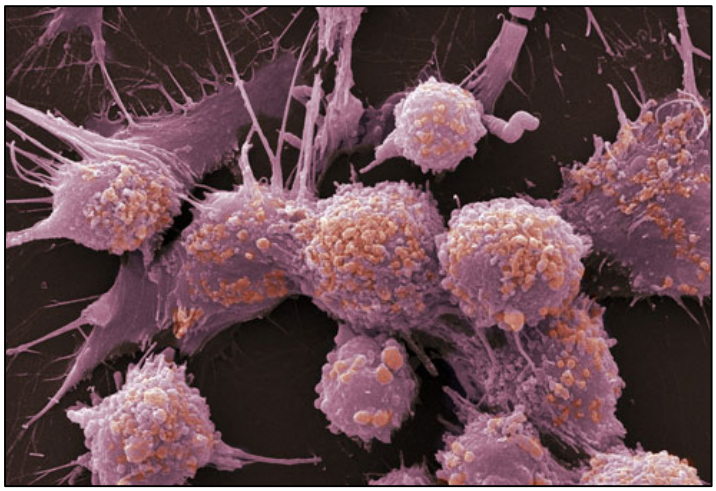

Figure 4: Pictured here is an SEM micrograph of cancer cells[40].

[38] Miller, Williams R. "Tardigrades". *American Scientist*. October, 2011. http://www.americanscientist.org/issues/feature/tardigrades/1

[39] Sifferlin, Alexandra. "Ebola: The First Glimpse of a Virus." *Time Magazine*. October 13, 2014. http://time.com/3502740/ebola-virus-1976/

[40] Alberts, Bruce, et al. *Essential Cell Biology Third Edition*.

Figure 5: The microscopic organism, the Tardigrade, is thought by many to be as cute as a teddy bear[41].

SEM micrographs are generally manipulated before being presented. Artifacts must be removed and color must be added. This is because electron beams do not pick up color, since wavelengths of electrons do not fall in any color spectrum[42]. All original SEM micrographs do not have color without being influenced by human hands. Many researchers will color images based on what they want to highlight in their research. For example, if a scientist was imaging mice neurons and needed to differentiate the neurons from the rest of the tissue, a color would be chosen and the scientist would fill the area of interest using imaging programs or Photoshop[43]. Others use electron dispersive x-ray spectroscopy (EDX) to pinpoint certain elements in a specimen and then use a computer program that colors the specific elements depending on the spectroscopy data received[44]. Some even color their images to make them look aesthetically pleasing. For example, images of diatoms, which are tiny organisms that live in aquatic

[41] Miller, Williams R. "Tardigrades". *American Scientist*.

[42] Egerton, Ray F., *Physical Principles of Electron Microscopy*. 3.

[43] Hood, Zachary D. Interview by Jennifer Cantley. E-mail. November 18, 2015.

[44] Hood, Zachary D., Hui Wang, Yunchao Li, Amaresh Samuthira Pandian, M. Parans Paranthaman, Chengdu Liang. "The 'Filler Effect': A Study of Solid Oxide Fillers with β-Li_3PS_4 for Lithium Conduction Electrolytes." *Solid State Ionics* (2015): 1-6, accessed November 18, 2015, doi:10.1016/j.ssi2015.10.014.

environments and take up a large portion of the upper part of the ocean (Figure 6). Some diatoms are generally visible under a light microscopes but are often imaged by SEMs to show greater detail and three-dimensionality[45]. In order to get the vibrant rainbow hues of the aquatic diatoms, color must be artificially added. These added colors are almost solely done by researchers and scientists. It is, at times, surprising how beautifully and creatively these images are colored[46].

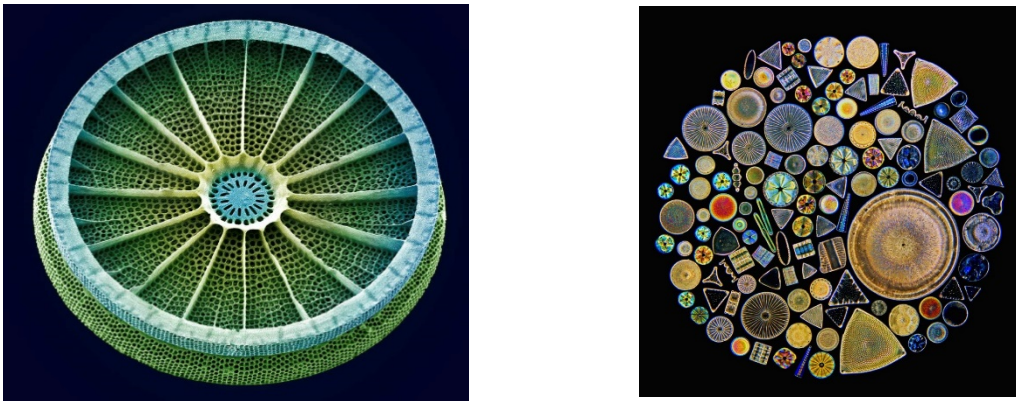

Figure 6: On the left is an artificially colored SEM micrograph of a diatom. On the right is a vibrant assortment of diatoms under a light microscope[47].

Science and Art

Scientific research is very structured and data driven. Much of science relies on vision and being able to see the object of study in some way. In that way, science does have similarities to the visual arts. Art and science have been compared by many scholars over many years. When detailing SEM micrographs, it is difficult not to compare the images to art, especially since micrographs have inspired so many artists and scientists alike. In an article by James Elkins, he states, "…not much is gained by comparing the scientists' criteria of elegance, clarity, and simplicity with artistic criteria, and that the two senses of images are worlds apart—but in terms

[45] Burgess, Jeremy, et al. *Under the Microscope: A Hidden World Revealed*. 102-103.

[46] Hood, Zachary D. Interview by Jennifer Cantley.

[47] Burgess, Jeremy, et al. *Under the Microscope: A Hidden World Revealed*. 102-103.

of the attention scientists lavish on creating, manipulating, and presenting images, the 'two cultures' are virtually indistinguishable."[48]

Images of the actual specimen of study can give a researcher and scientist a greater understanding of what they are researching. Scientists and researchers take great pride in their images, similarly to the way artists do. Sometimes, the images they are publishing are being seen for the first time ever, much like when a painter creates a new piece of art on a canvas[49]. SEM imaging is also a long and meticulous process, much like many works of art that take a very long time to create. It is not surprising that there is an organization for scientists that holds contests each year called "Science as Art" to see who has the best, most artistic microscopic image. This organization is called the Materials Research Society (MRS) and scientists from all over the world submit micrographs to be judged and chosen as pieces of art[50]. These images consist of a broad range of objects and specimens and utilize many types of microscopes. Some are pictures of chemical reactions that are then colored to resemble a forest of trees or rose petals. Some are even stunning abstract forms created from everyday objects, such as salt crystals[51] (Figure 7) (Figure 8). These images also fall under the category of coloring micrographs to make them aesthetically pleasing, similar to the diatoms mentioned earlier. Electron micrographs can simultaneously be art as well as illustrative figures for results that scientists produce. Zach Hood, a researcher and doctoral candidate in Biochemistry at Georgia Institute of Technology, commented, "I think that there is an art to collecting SEM images and choosing what part of the sample to image. Some of the SEM images reported in literature are truly remarkable, and personally, I regard them both as research and as art. I can attest that many scientists at different

[48] Elkins, James. "Art History and Images That Are Not Art". *The Art Bulletin* Vol. 77 No. 4 (1995): 559.

[49] Hood, Zachary D. Interview by Jennifer Cantley.

[50] Materials Science Research. "Science as Art". MRS. http://www.mrs.org/science-as-art/ (accessed November 18, 2015).

[51] Ibid.

institutions regard such images in the same way."[52] Hood works with nanomaterials for biomedical and energy-related applications and uses SEMs extensively in his studies.

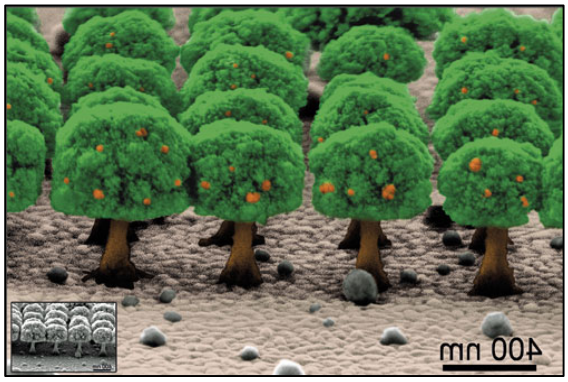

Figure 7: The chemical reaction of, caused these tree-like forms to grow. After the scientist colored them in to look like an enchanted forest[53].

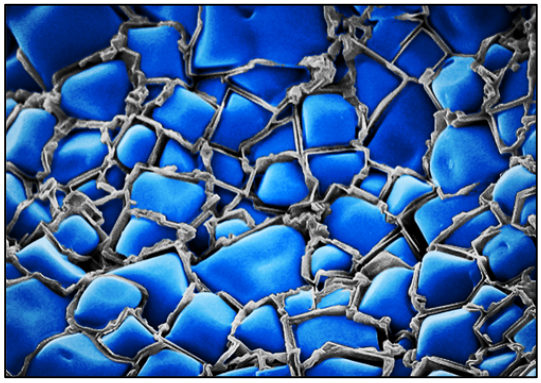

Figure 8: This micrograph shows how abstracted salt crystals can become when viewed with an SEM[54].

Many artists throughout history have been influenced by microscopic images such as Odilon Redon and Wassily Kandinksky to name a few[55]. With the advent of the SEM comes many more microscopic things to see and more inspiration for contemporary artists. An example of a contemporary artist who uses the micro world to inspire her is Mara G. Haseltine. Her work titled *Nano to Geo* creates large installations and even entire parks mimicking the microscopic

[52] Hood, Zachary D. Interview by Jennifer Cantley.

[53] Materials Science Research. "Science as Art". MRS.

[54] Ibid

[55] Elkins, James. "Art History and Images That Are Not Art". *The Art Bulletin* Vol. 77 No. 4 (1995): 555.

worlds. Cell walls, DNA and Peptides dance across ocean views and through gardens in her colorfully whimsical installations [56] (Figure 9). Sebastian Zagarella, another artist inspired by micrographs, used and appropriated SEM images of the HIV virus to create an installation titled *Inside/Out*. He displays patterns of the HIV virus on things like chairs, wallpaper, and candle sticks in a modern looking living space. The micrograph he chose of the HIV virus is supposed to represent the way HIV, though invisible to the naked eye, is still seen because of the physical toll the disease takes on the body (Figure 10)[57].

Figure 9: One of Mara G. Haseltine's large installations of microbiological structures taking up most of the landscape of this park[58].

[56] MedinArt. "Mara G. Haseltine." MedinArt.eu. http://www.medinart.eu/works/mara-g-haseltine/ (accessed November 11, 2015).

[57] MedinArt. "Sebastian Zagarella." MedinArt.eu. http://www.medinart.eu/works/sebastian-zagarella/ (accessed November 10, 2015).

[58] MedinArt. "Mara G. Haseltine." MedinArt.eu.

Figure 10: A serene dining room installations created by Sabastain Zagarella which illustrating a person's interior and exterior battle with the HIV virus[59].

It is interesting that some individuals take objects that cannot be seen by the unaided eye and make them bigger, while others take objects that are visible and make them too small to see. Two people of interest changed the scale of a regular size objects and made them so small that they could only be viewed under an electron microscope. Many artists play with the concept of scale. Malcolm Douglas Chaplin, an artist and illustrator who is in the Guinness Book of World Records for creating the smallest book known to man[60]. This book is titled Teeny Ted from Turnip Town and was made using a focused gallium ion beam (FIB) and measures in at 70 µm by 100µm (Figure 11). This book can only be viewed and read using an SEM, which means only a select few actually get the pleasure of reading this book in person. After spending a lot of money to create the tiniest book, Chaplin decided to raise money to get his book printed in a size readable by light waves and the human eye since the average person does not have access to an SEM[61]. Another artist, Jonty Hurwitz, went through great length to create tiny sculptures of the human figure measuring in at 80x20x100µ in size, which is smaller than a human hair (Figure

[59] MedinArt. "Sebastian Zagarella." MedinArt.eu.

[60] Guinness World Records. "Smallest Reproduction of a Printer Book." Guinness World Records. http://www.guinnessworldrecords.com/world-records/smallest-reproduction-of-a-printed-book/ (accessed November 2, 2015).

[61] Caula, Rodrigo. "World's Smallest Book Measures 70 Micrometers."

12). These sculptures were created using an incredible 3D printing technology called multiphoton lithography. This beautiful figurine is, of course, too small to be viewed without the aid of an SEM62. These artists show that inspiration can come in all shapes, sizes and wavelengths.

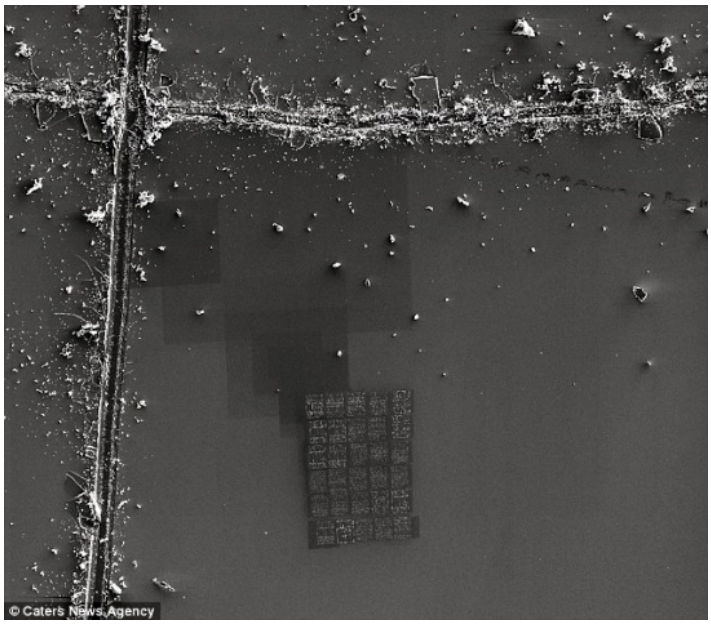

Figure 11: The tiny rectangles toward the lower middle of this micrograph contain each panel of the small book known to man[63].

[62] McDonald, Glenn. "Amazing Nano Sculptures Only Visible by Electron Microscope." *Discovery*. November 19, 2014. http://news.discovery.com/tech/amazing-nano-sculptures-only-visible-by-electron-microscope-141119.htm (accessed November 11, 2015).

[63] Caula, Rodrigo. "World's Smallest Book Measures 70 Micrometers."

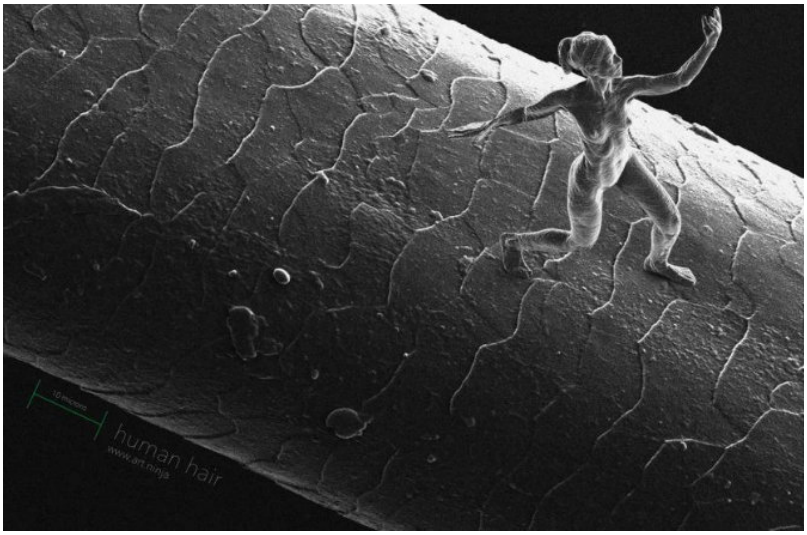

Figure 12: A sculpture of female human figure is shown here standing on a single strand of human hair[64]

Technology inspires artists and scientists alike to create and understand a completely novel world. Microscopy has brought light to a miniature world that previously was all but occluded by darkness. Electron microscopy's limit of resolutions, however, leaves an even smaller story to be unraveled. Where the limitations of technology leave scientists searching for answers, art is able to press forward only limited by the artist's creativity.

[64] McDonald, Glenn. "Amazing Nano Sculptures Only Visible by Electron Microscope."

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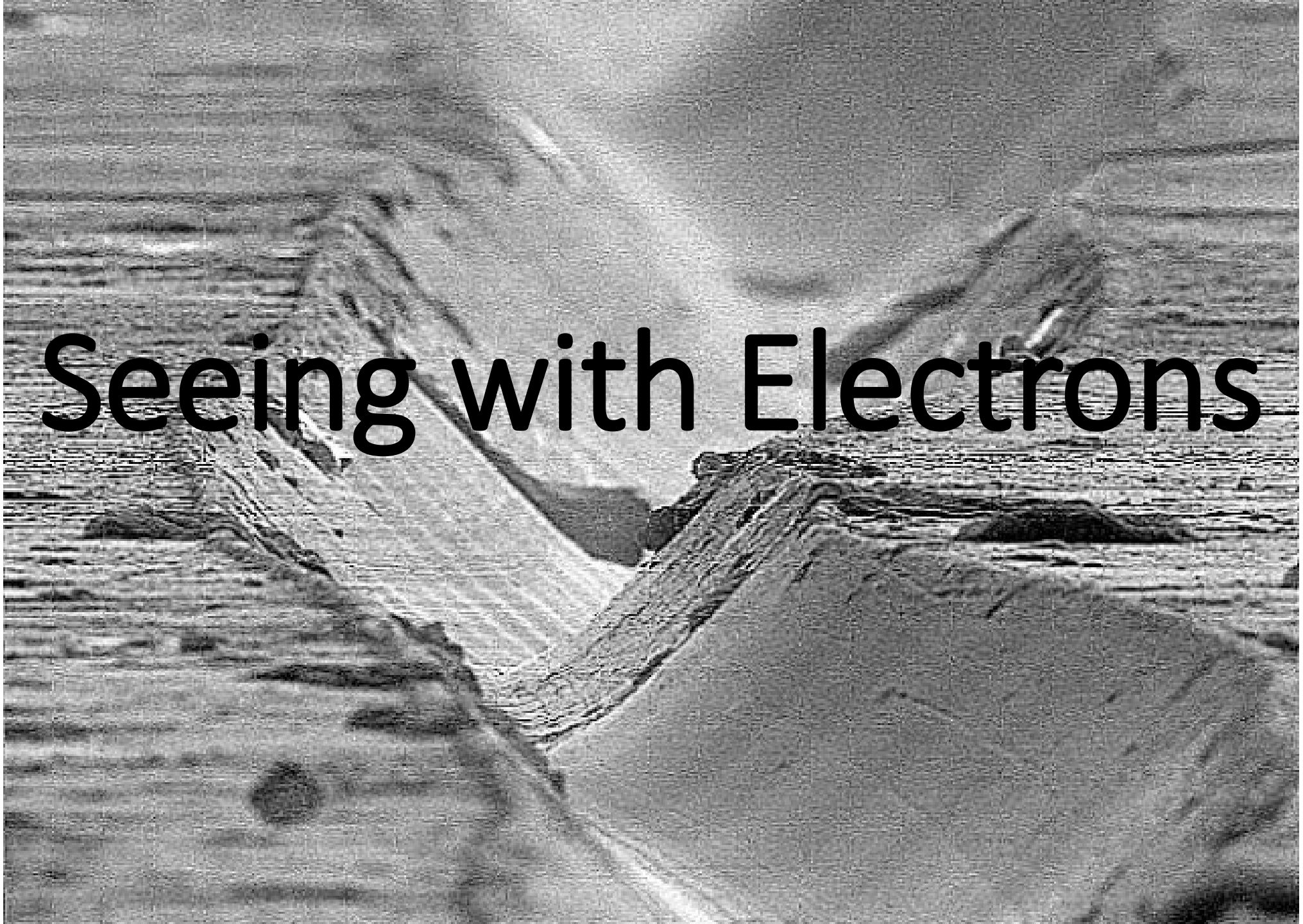
Seeing with Electrons

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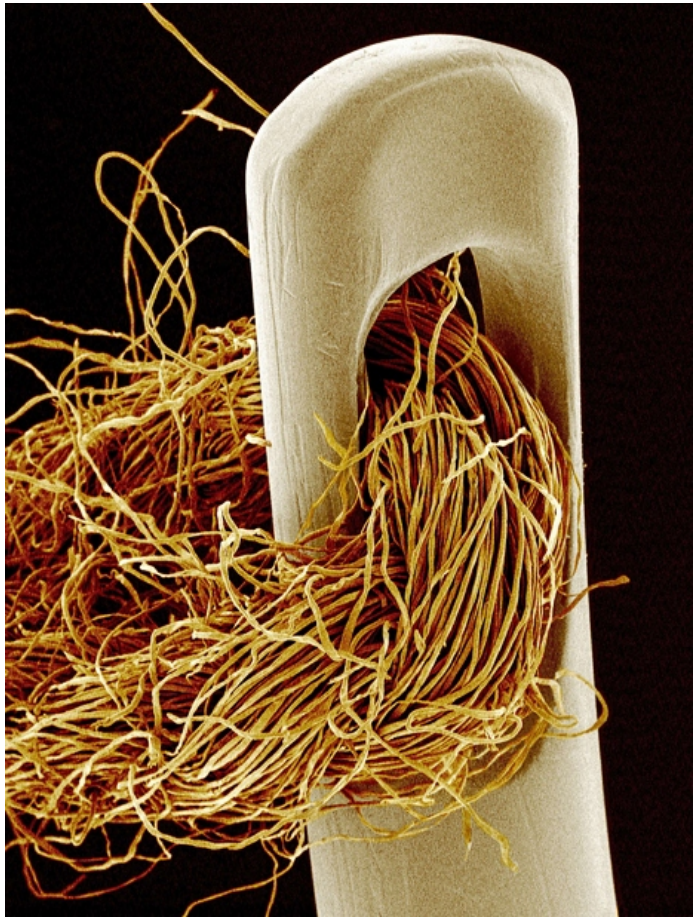

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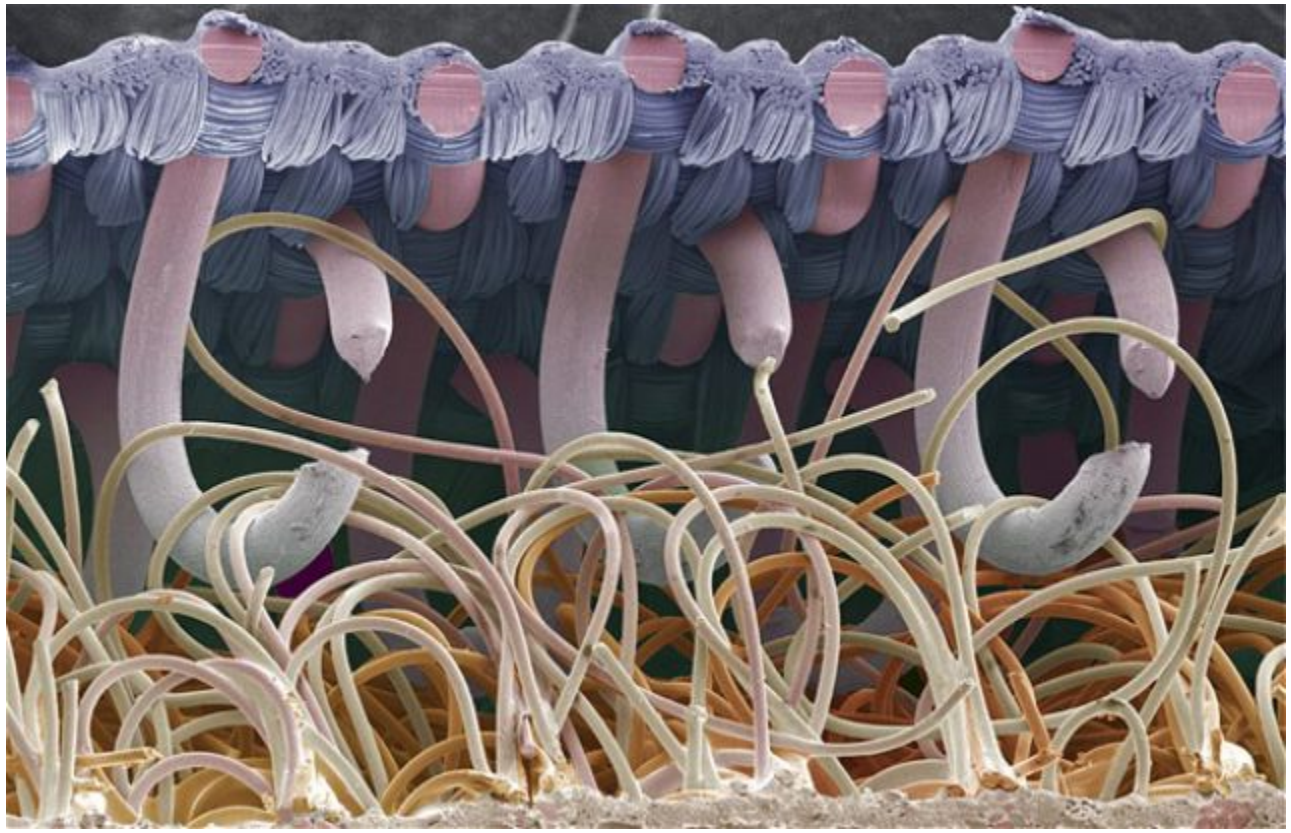

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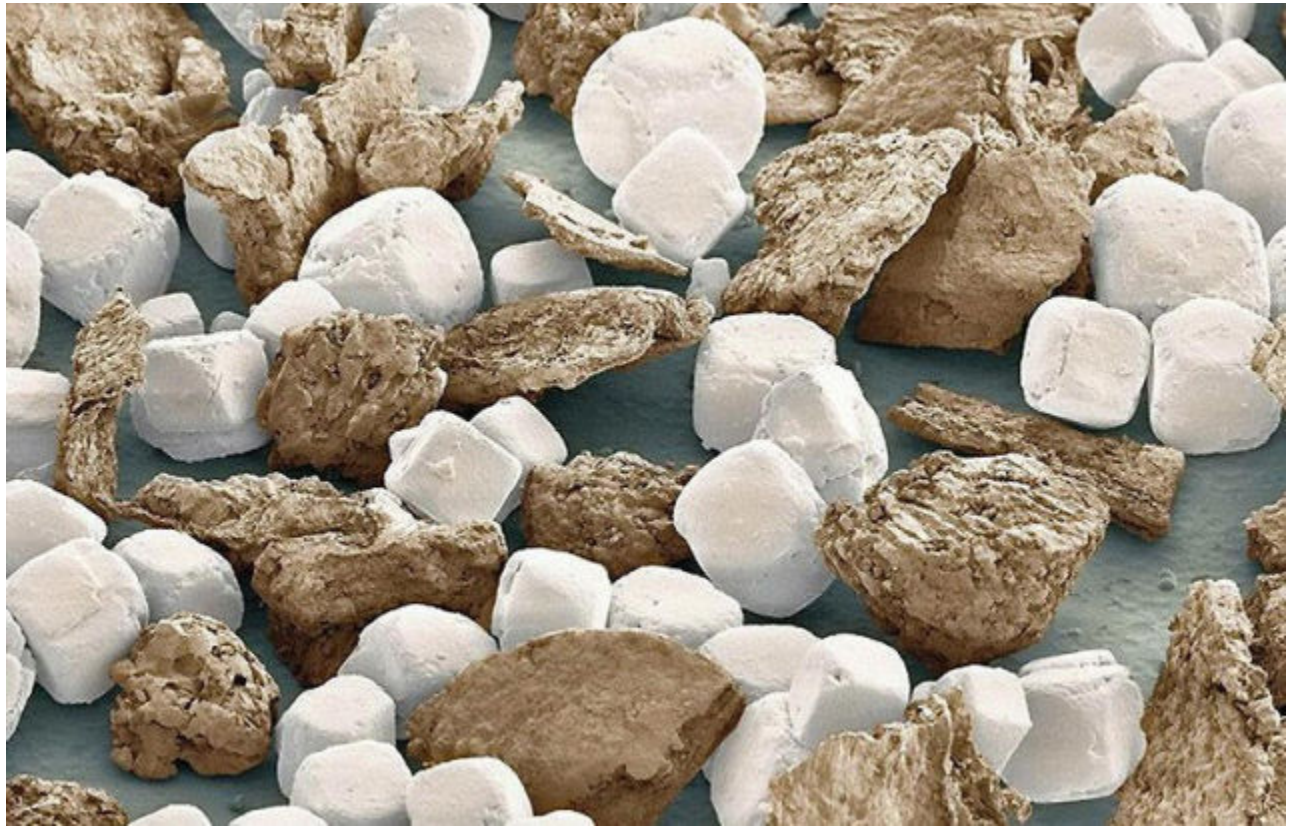
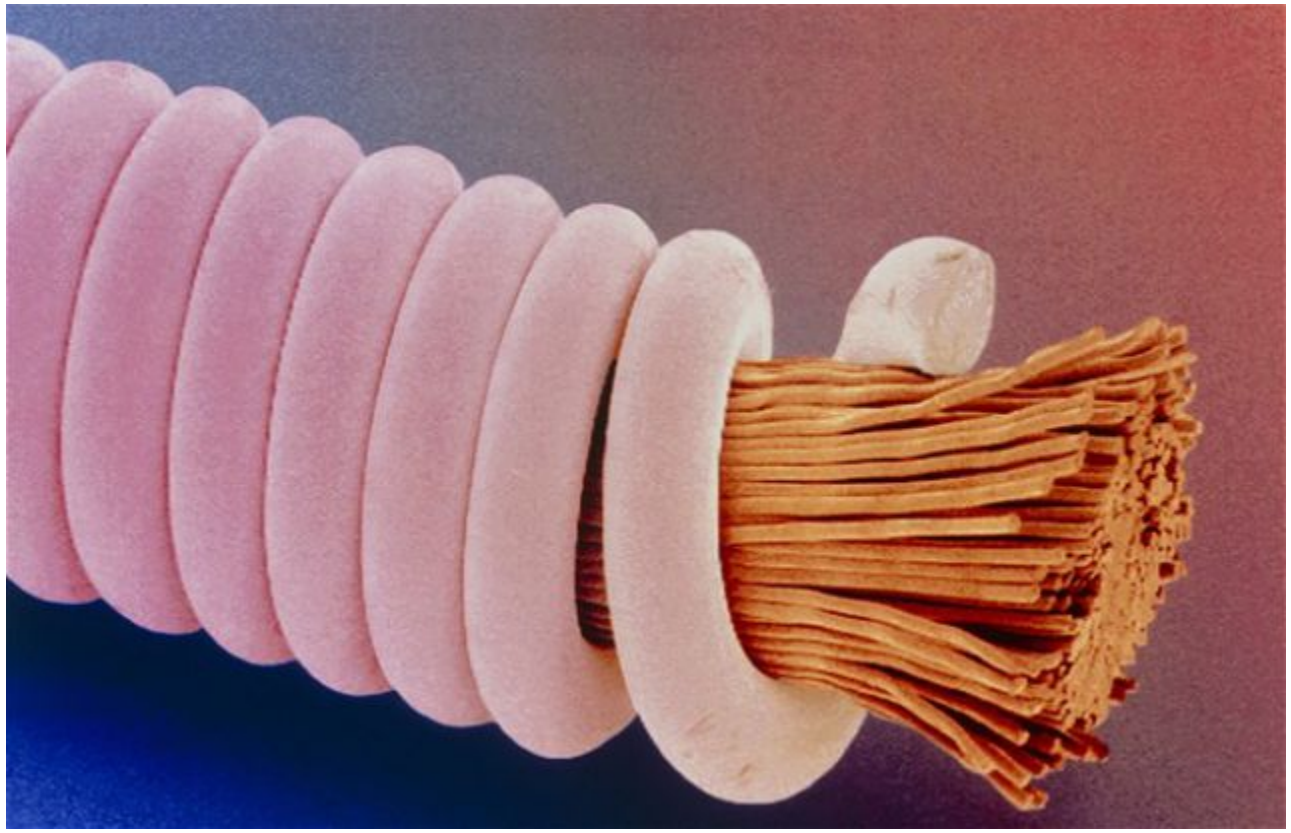


Human Eyelashes

Guitar String



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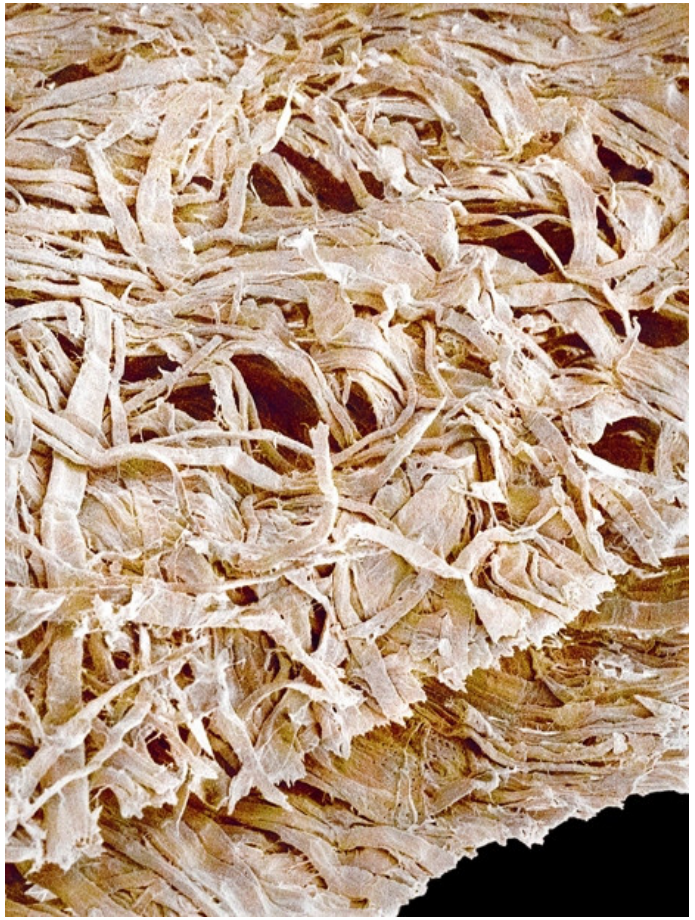
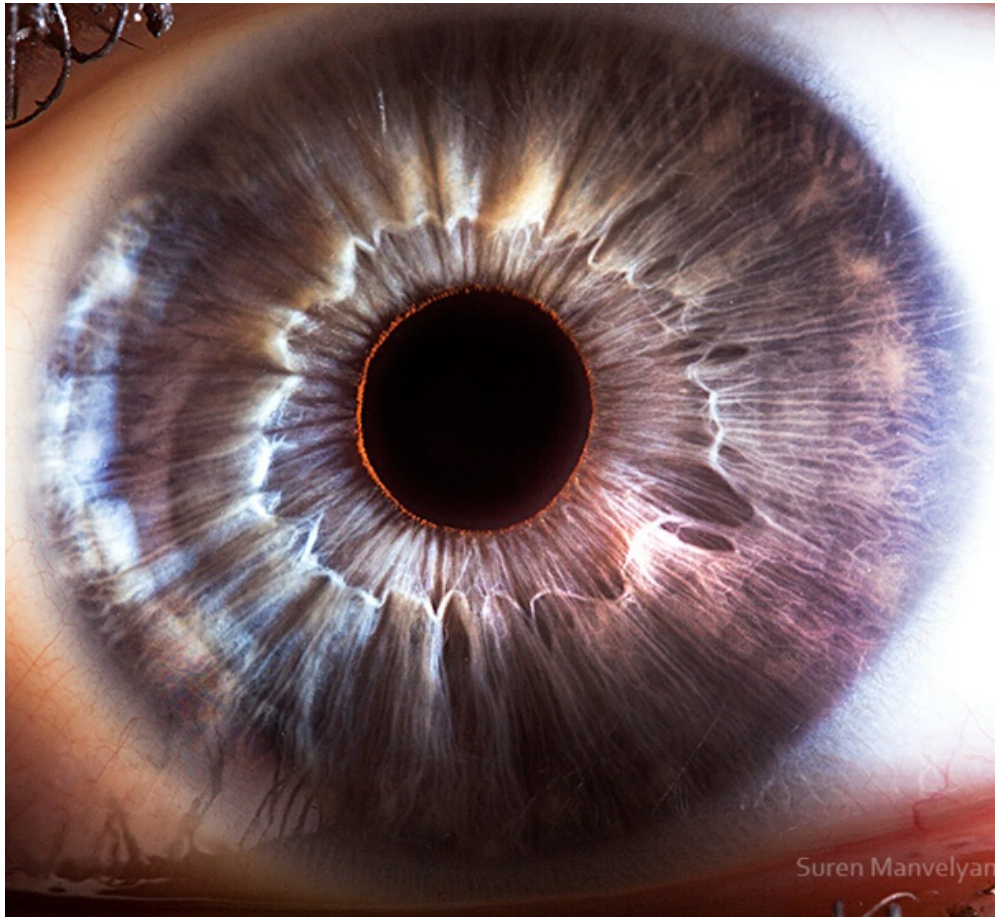
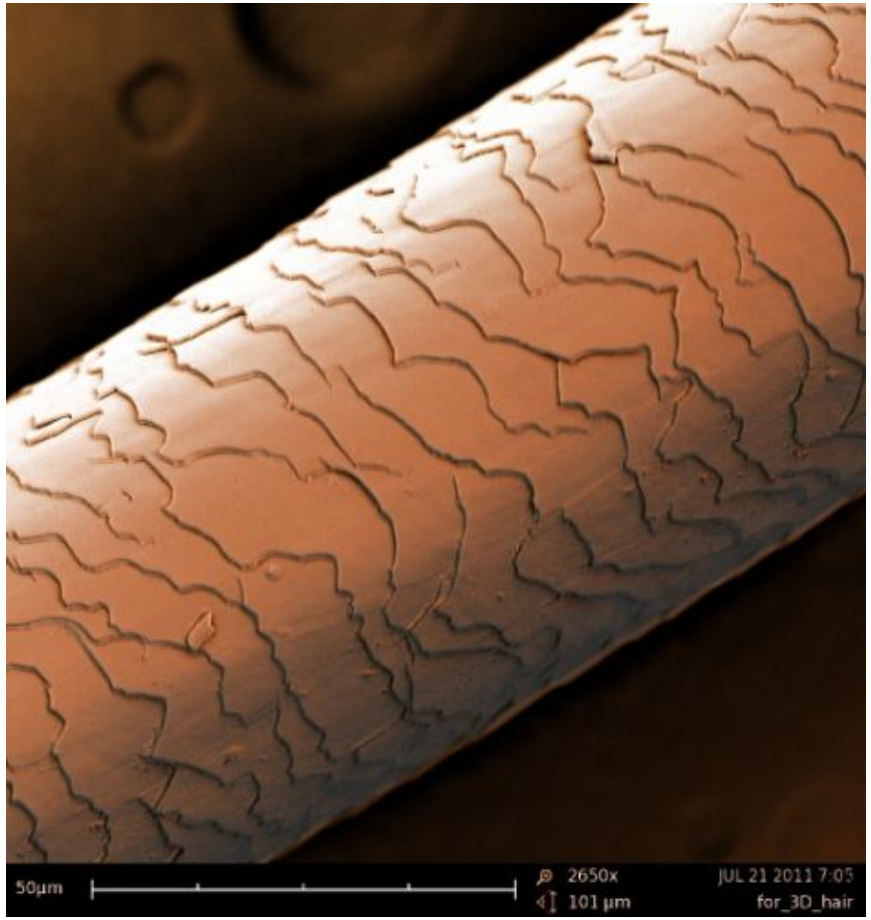



Suren Manvelyan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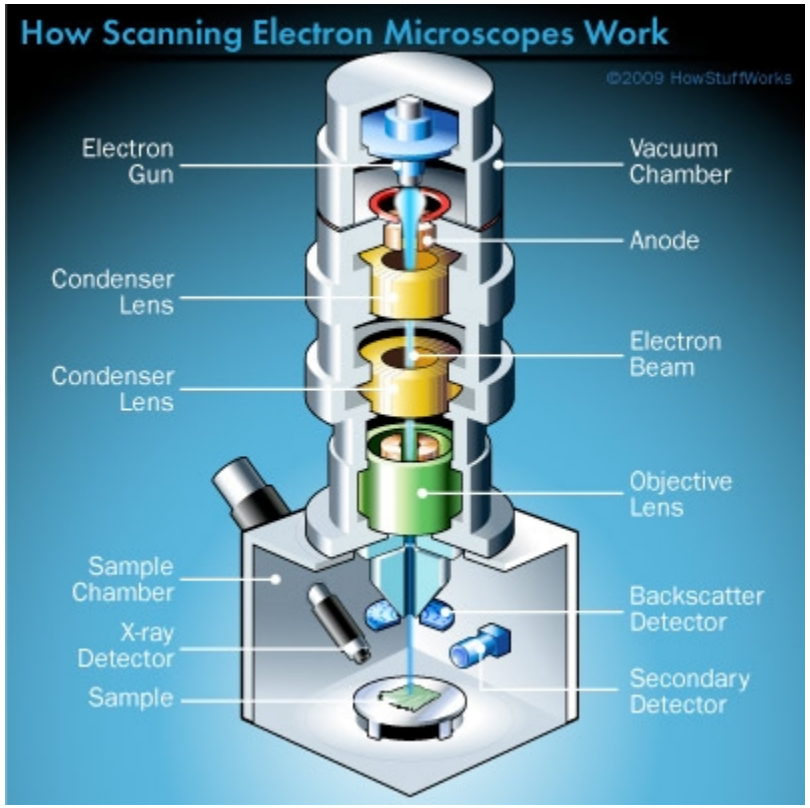
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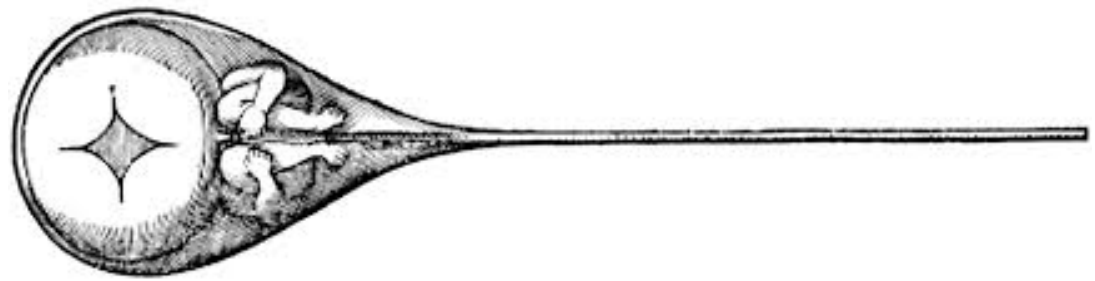
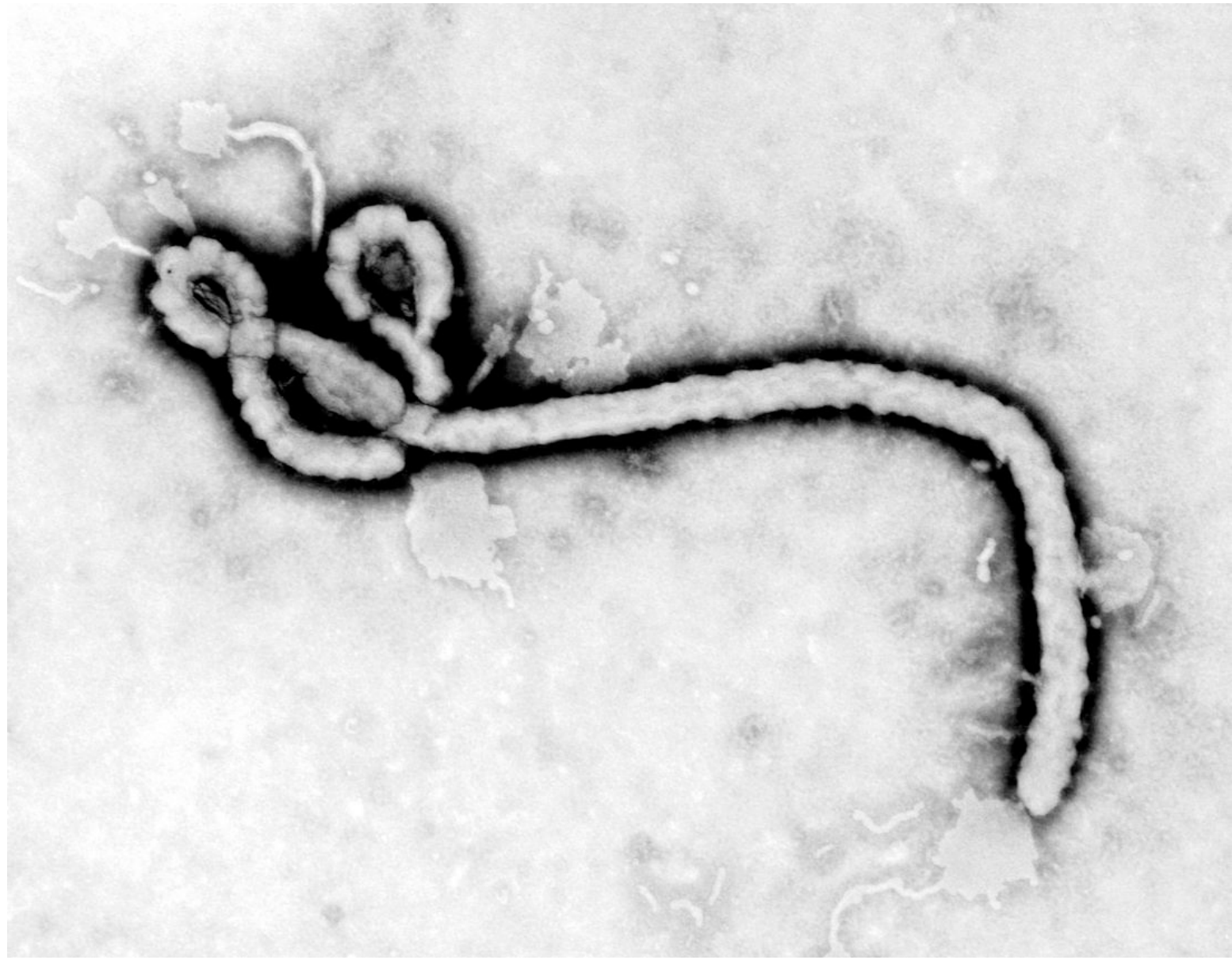
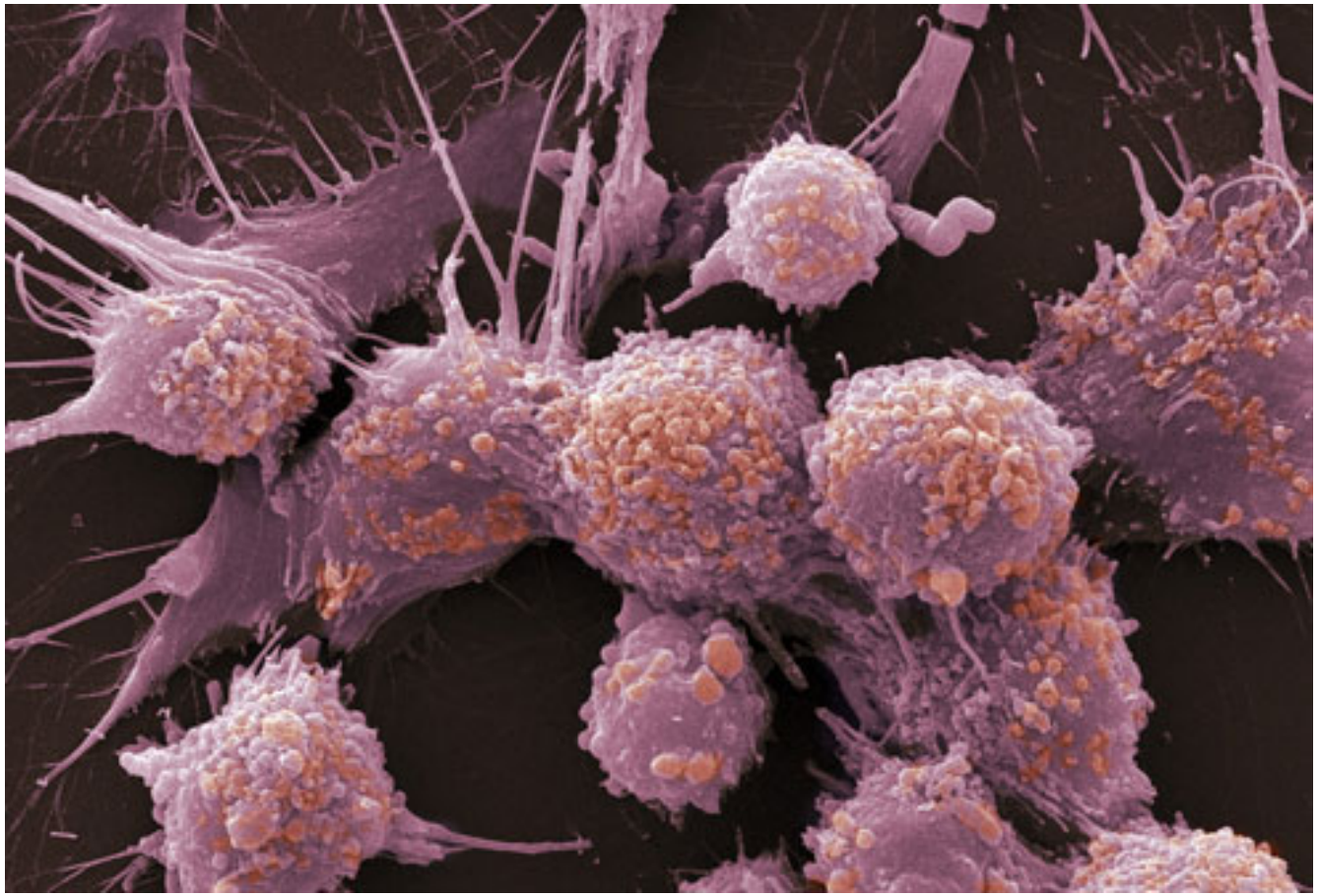
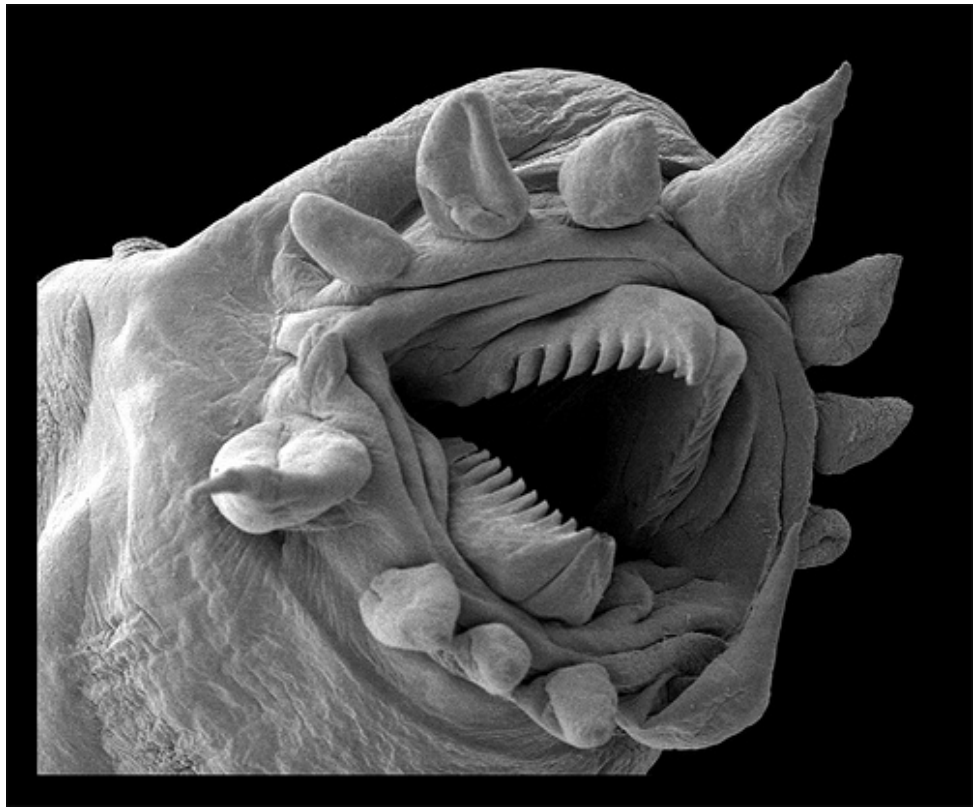
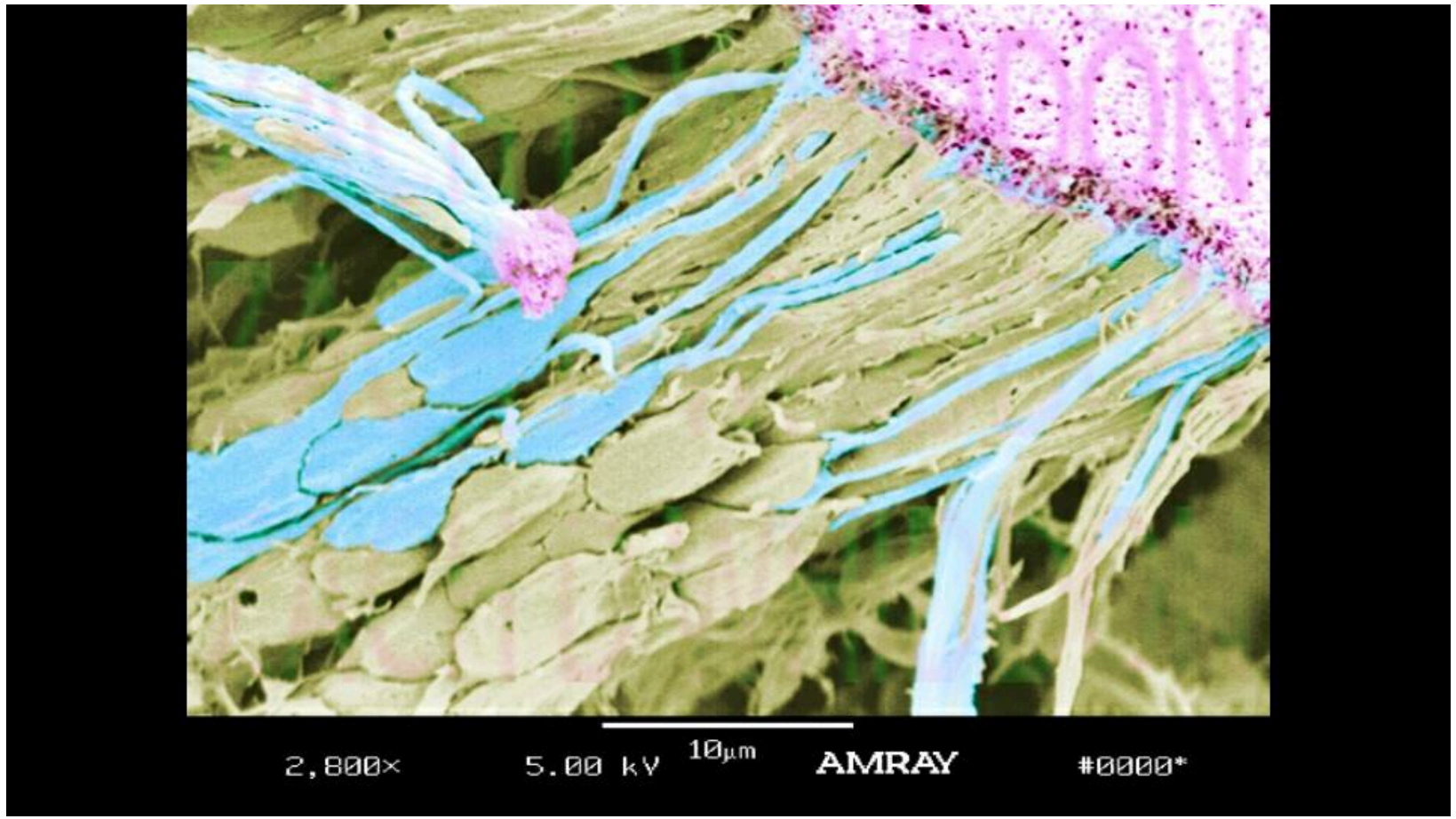
Sample Chamber
Backscatter Detector
X-ray Detector
Secondary Detector
Sample







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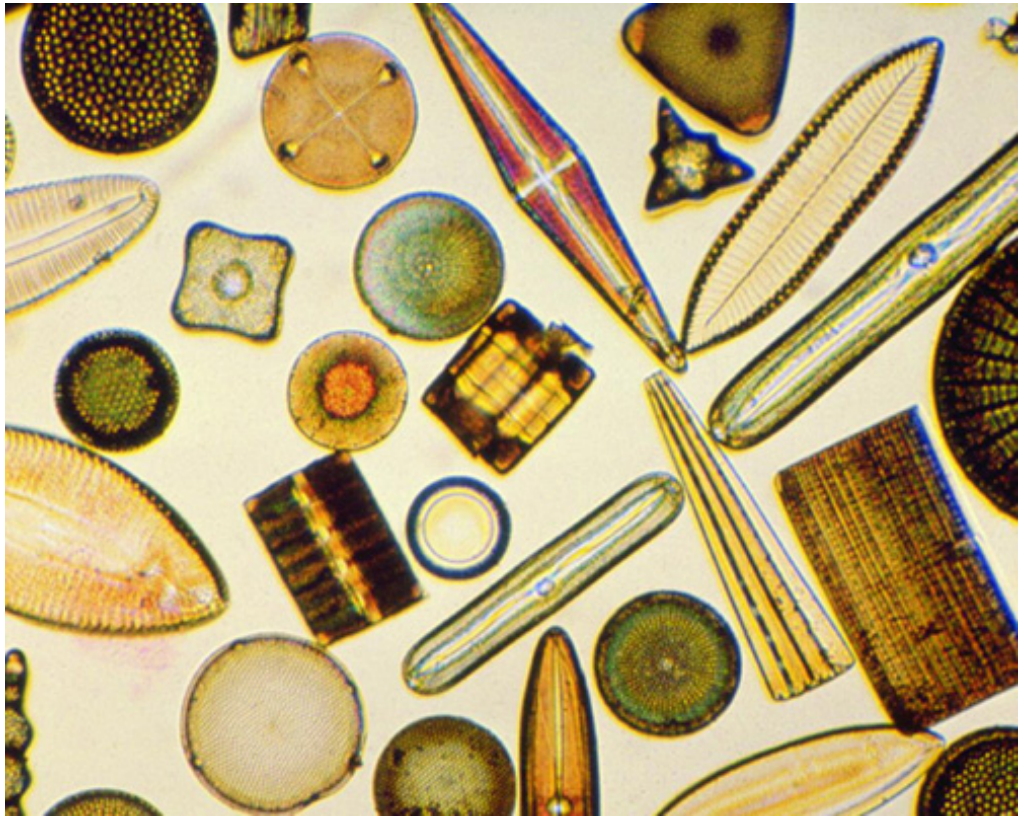

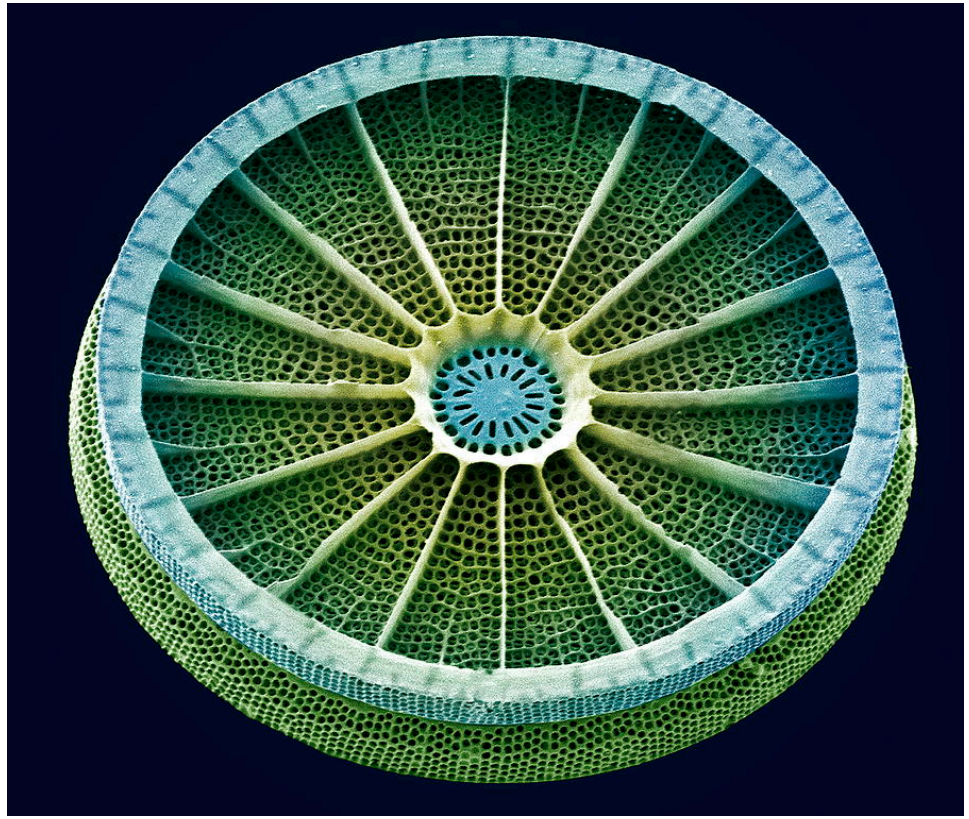

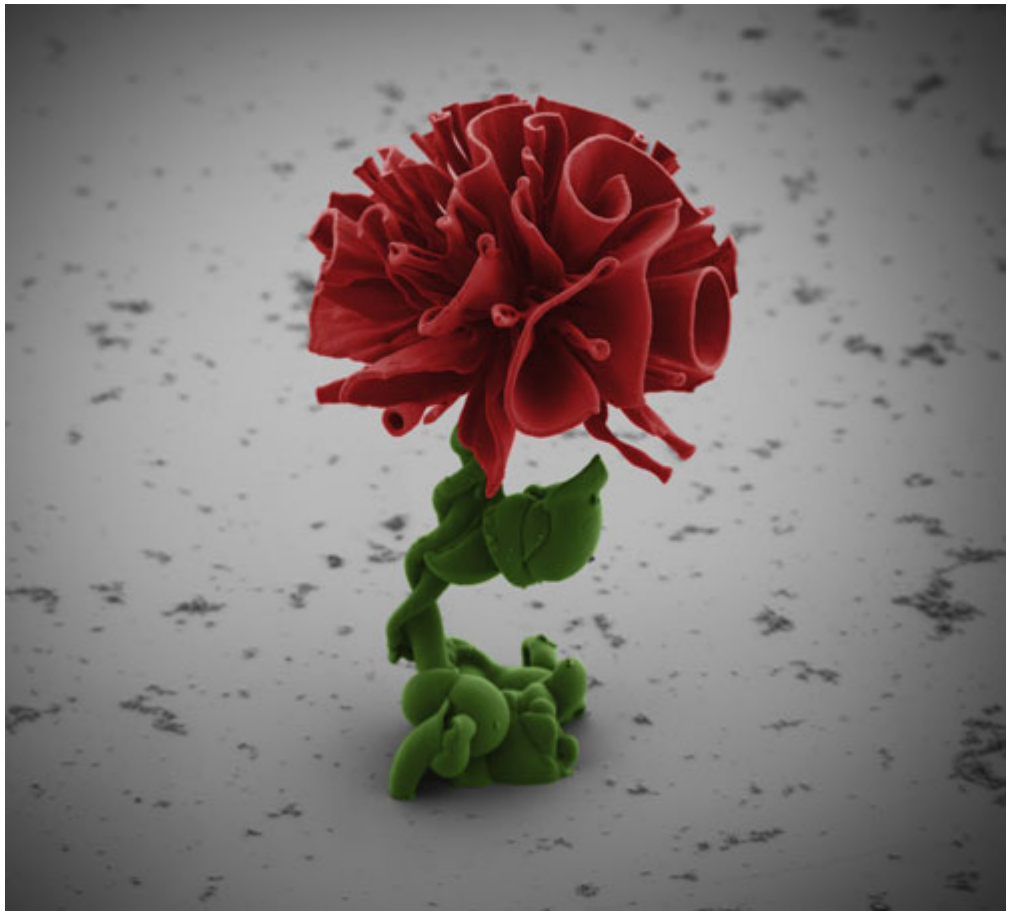

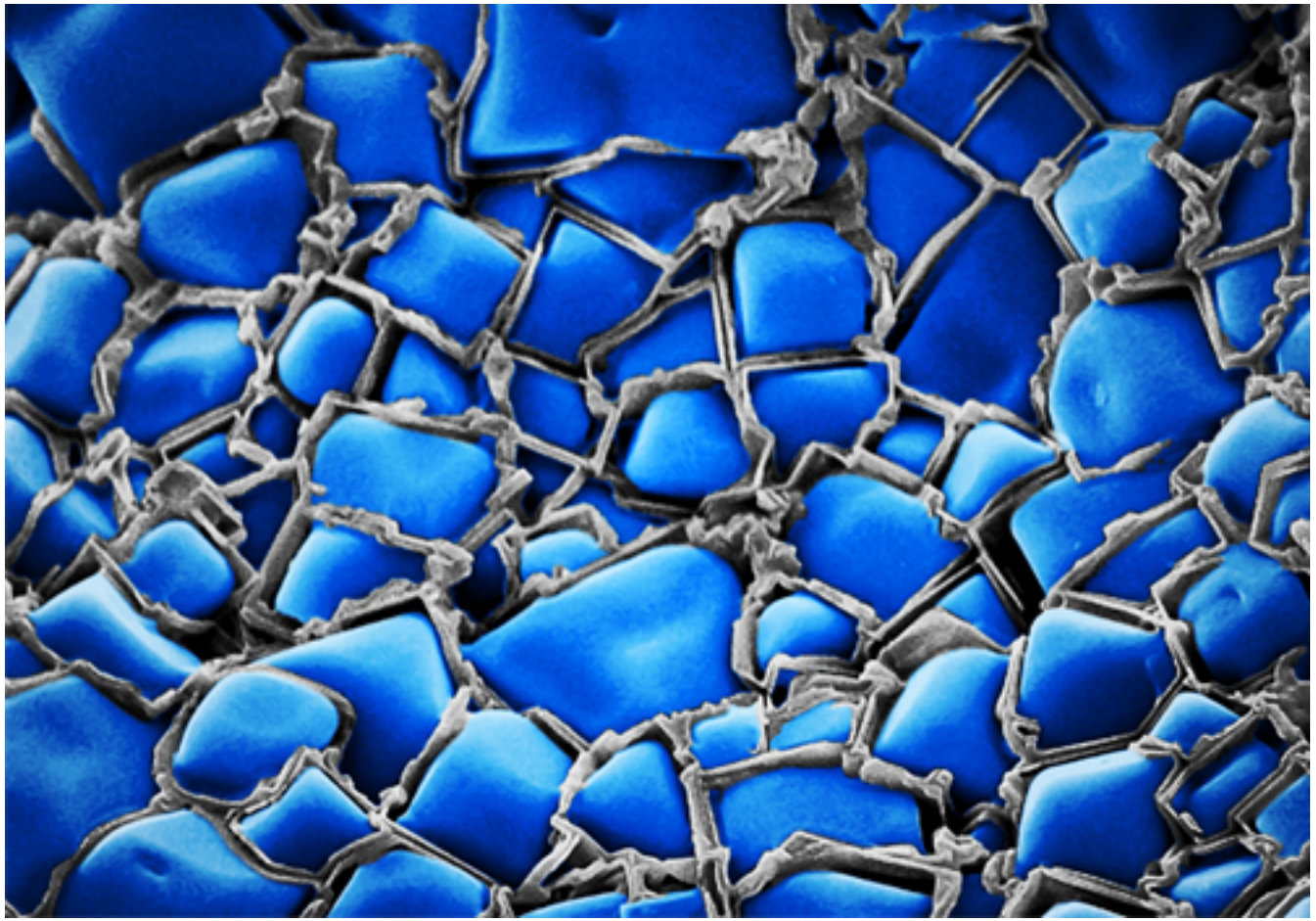

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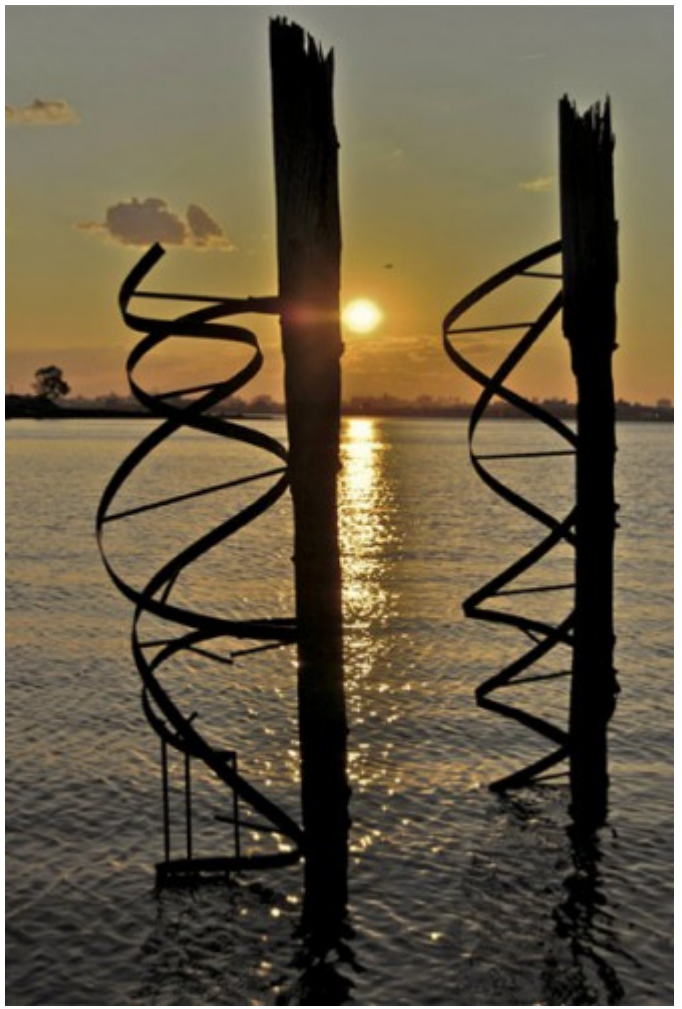

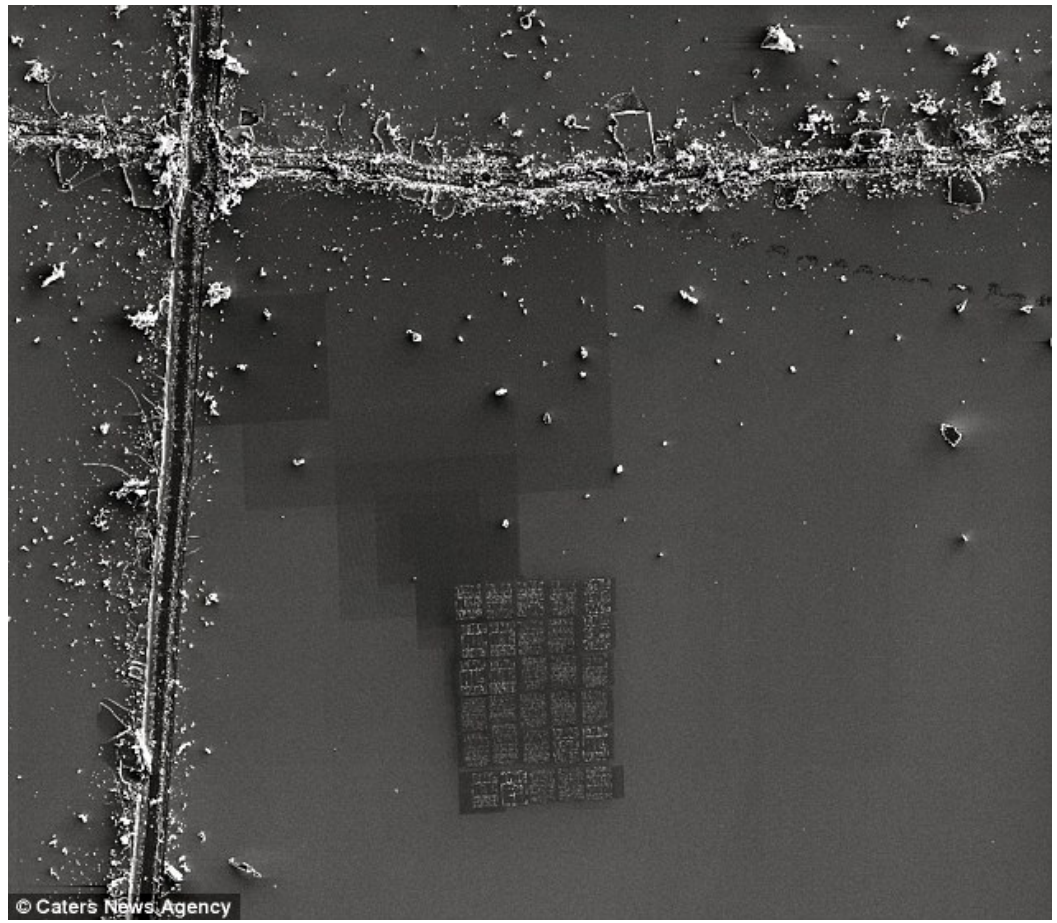
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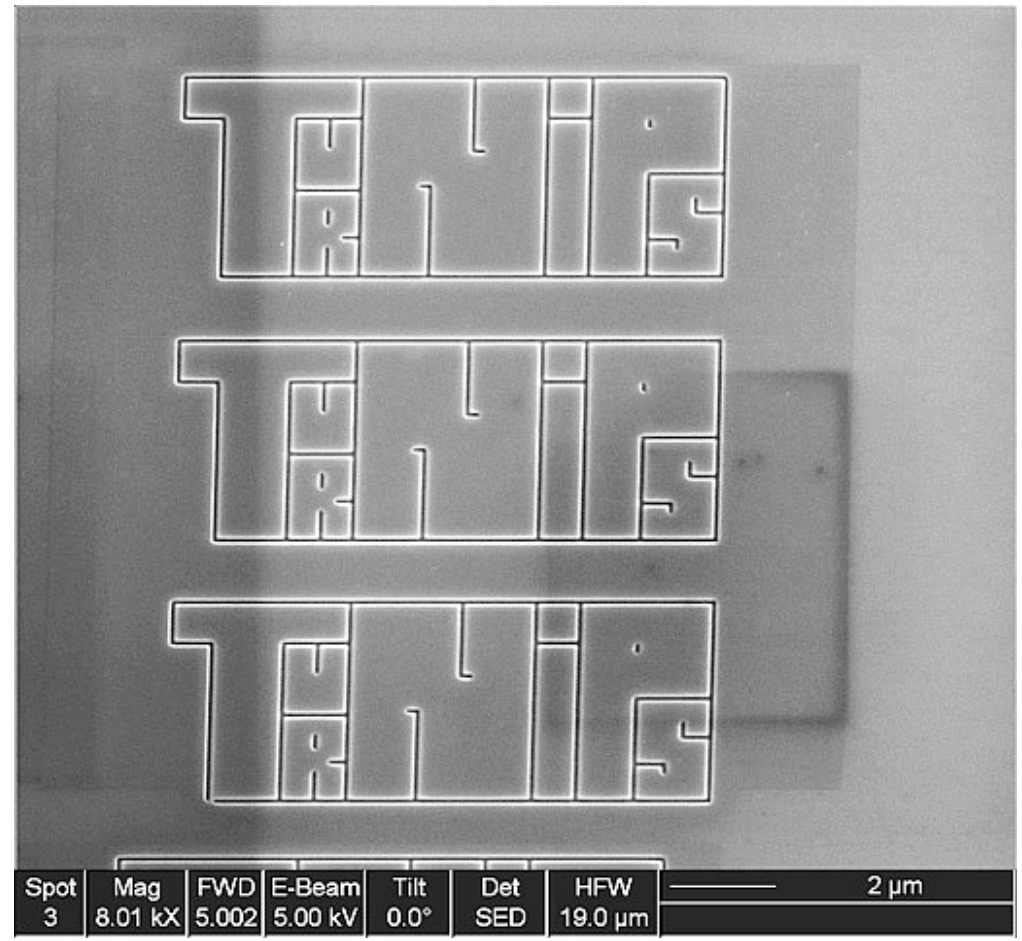
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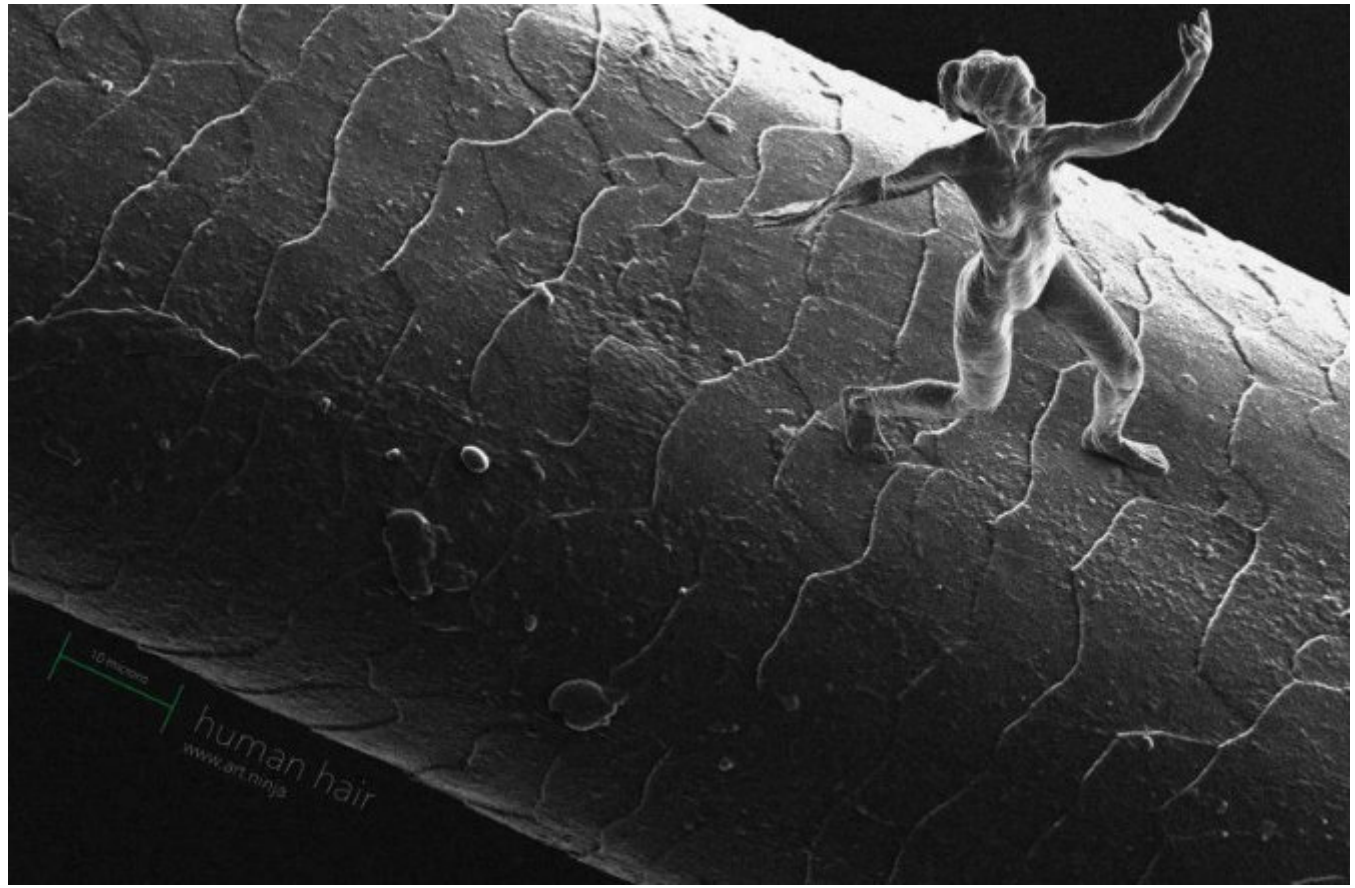
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