MODULE 2: Difference in sizes (nano, macro, etc.)

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"It is still believed that SIZE does matter but directly proportional Size does not necessarily produce MATTER" – Amit Abraham, Author

LEARNING OBJECTIVES

1. Compare the difference between macro, micro, and nano sizes
2. Distinguish how sizes of features can affect material properties

BACKGROUND

As you may or may not know from your studies (and your general observations), the world comes in many shapes and sizes. Materials are no different: they come in a variety of shapes and sizes. Specifically, in this module we are focusing on materials and their sizes. Size is considered a physical property as you may remember from MODULE 1 about graphene. If you have not read the background section in this module, I highly recommend reading the subsection on material properties in order to understand the rest of this module.

Now, why spend a module talking about materials and their sizes? Well, this concept becomes important when we consider that material size can affect material **properties**. But, before we can even begin delving deeper into the relationship between size and properties, we first need to understand the different "categories of size".

There are three main "categories of size" that we will be discussing. They are **macroscale**, **microscale**, and **nanoscale**. Figure 1 shows a great breakdown of the difference between the three. **Macroscale** is the size that is visible to the naked eye. They are the things that you can see in your normal day-to-day life, like an apple. **Microscale** is the next size. Now, unlike things that are visible on the macro scale, things on the micro level require a microscope that magnifies the specified object. **Nanoscale** on the other hand is a very special size. On the nanoscale some of the smallest parts of life exist, like DNA. To put things into perspective, the size of an atom is about 0.1-0.2 nanometers (nm). So, as you can see, when we talk about nanomaterials, we are looking at small numbers of atoms. Now, let's take it a step further and think about how many layers of graphene it would take to make a 1 mm thick sheet? When you remember the structure of graphene and think about how small it is (0.142 nm small), it would take quite a lot of graphene to make a 1 mm thick sheet of this material.

All macro, micro, and nano sizes are important for researchers making observations and measurements, but they have their special uses for certain applications. Table 1 breaks down the typical value (in meters) of the three types of sizes.

Table 1. Macro, Micro, vs. Nano values in meters

Macro	10^{-2}	0.01
Micro	10^{-6}	0.000001
Nano	10^{-9}	0.000000001

Comparing back to the first module on graphene, which category do you think best represents how we go about researching this material? If you were to say nano, then that would be a good candidate. Though at different sizes, graphene can be investigated for different properties and more information can be understood from viewing it at all three sizes: macro, micro, and nano.

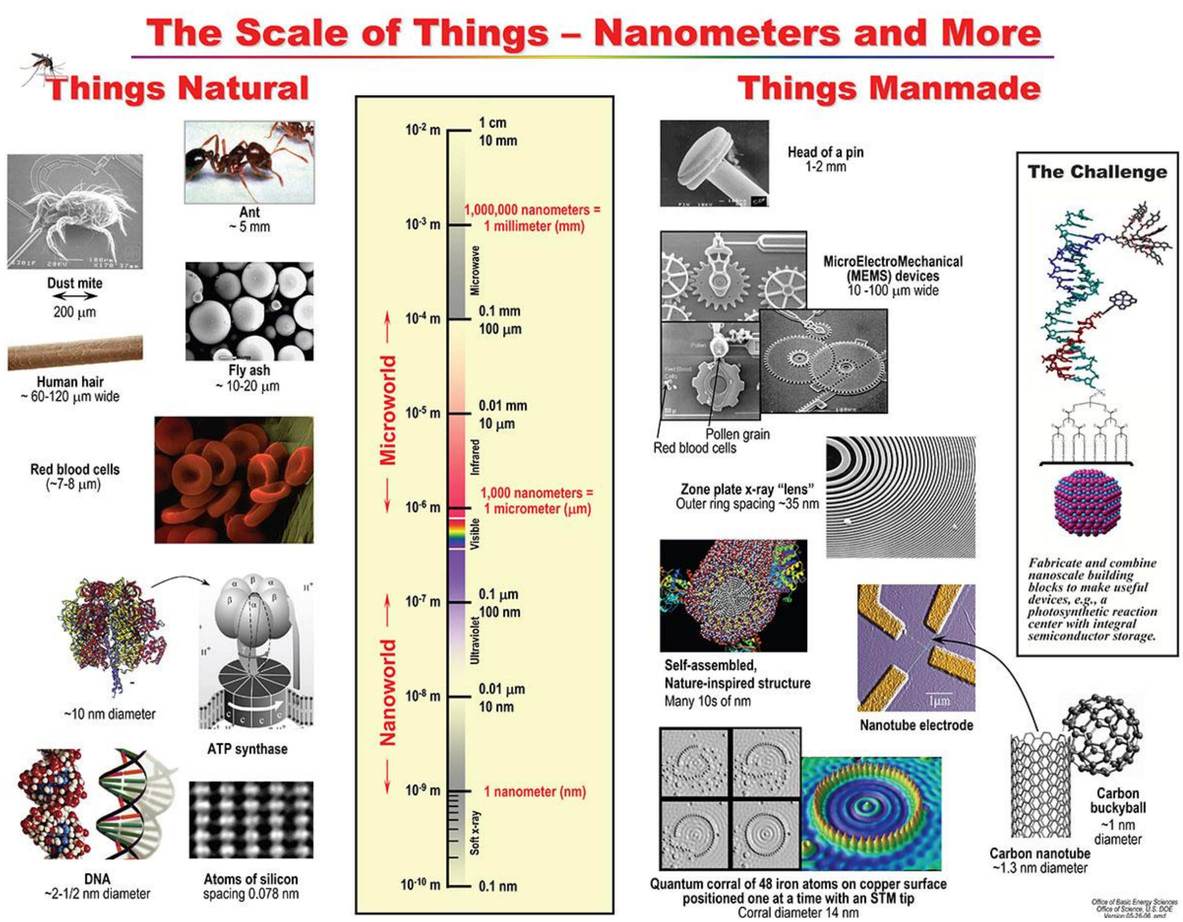


Figure 1. The relative size scale (including macro, micro, and nanoscopic) objects [1].

Consider: Which of the three, macro, micro and nano have the most interesting properties at their specific size? Why do you think this?

Well, there is a whole field of study (**Nanoscience**) dedicated to studying things on the 'Nanoscale'. Nanoscience can be applied to the precise manipulation control and use of matter at nanoscale for design, characterization, and production for different applications through **nanotechnology**. This field of research was presented by Nobel Laureate Richard P. Feynman. Nanotechnology is technological applications that utilize nanosize materials or phenomena. Nanotechnology plays a role in MODULE 4 about Quantum Mechanics (specifically about quantum dots).

We've been talking about the nanoscale quite a bit…. This is because at the very small nanoscale, some really cool things can be observed. Importantly, physical, chemical, and biological properties of **bulk** materials and single atoms or molecules can differ at the nanoscale. For example, bulk materials have constant physical properties regardless of size. However, the size of a nanoparticle dictates its physical and chemical properties. The properties of a material change as its size approaches nanoscale proportions. One of the reasons for this is that nanomaterials have a large percentage of their atoms on the surface, rather than on the inside. Some nanostructure materials are stronger or have different magnetic properties compared to other forms or sizes of the same material. For example, like how diamond is stronger than graphene or graphite, but graphite is more magnetic compared to graphene and diamond. Similarly, others can be better at conducting heat or electricity. Can you guess (from graphene, graphite, and diamond) which one conducts more heat? Yes, it is graphene. [2] As such, they may become more chemically reactive or reflect light better or change color as their size or structure is altered (structure will be discussed in the next module). You will see in the activity, "Turning Fruit Juice into Graphene Quantum Dots" resource, that colors can change based on their size, structure, and quantum mechanics (topics that will be discussed in later modules).

Properties and Size

In terms of the properties we have discussed in MODULE 1, what type of material property would you think correlates most to size? (Hint: it is technically all of them, but what's the best choice). If you guessed mechanical properties and behaviors, then you would've guessed right.

REFERENCES

[1] U.S. Department of Energy. (2005). "The Scale of Things- Nanometers and More," *Office of Basic Energy Sciences*. https://www.nist.gov/system/files/documents/2017/05/09/doe-scale-of-things-18-jan-05.pdf

[2] Khan, Ibrahim, Khalid Saeed, Idrees Khan. (2019). "Nanoparticles: Properties, applications and toxicities," *Arabian Journal of Chemistry*. https://www.sciencedirect.com/science/article/pii/S1878535217300990

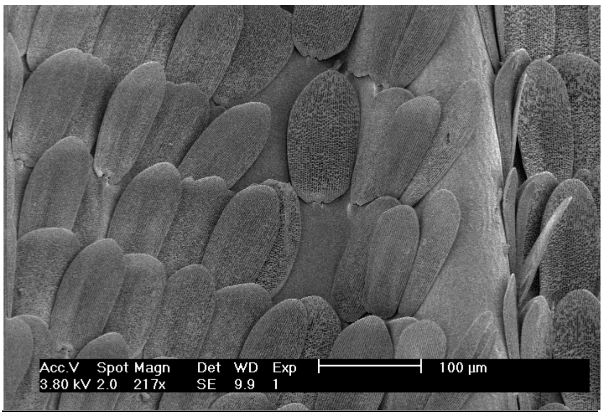
[1] Dangi, Ritu. (2011). "NanoTechnology," *Engineers Garage: An EE World Online Resources*. https://www.engineersgarage.com/article_page/nanotechnology/

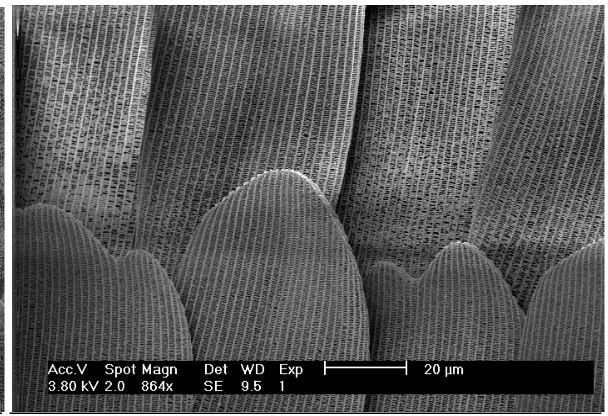
ACTIVITY

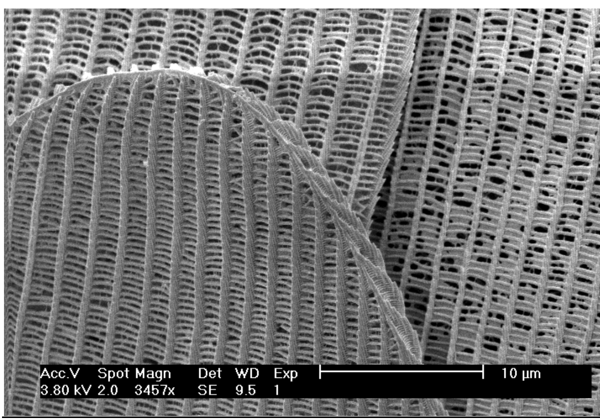
Identify

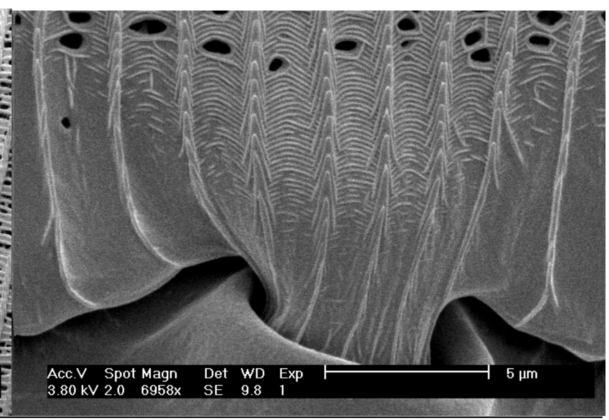
Level of Difficulty: Beginner

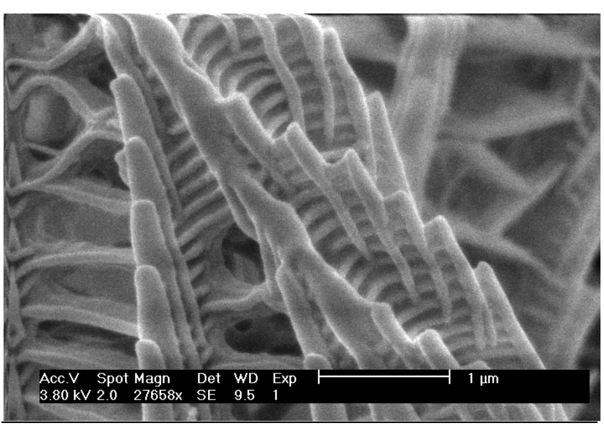
Instructions: The following six pictures show a macroscale butterfly wing that is viewed using a microscope in a laboratory. For each of these, try your best to identify whether the object could be considered to be on the nano or macroscale. Micro and nano are very hard to distinguish. Hint: I would recommend considering the magnification on each microscope picture.

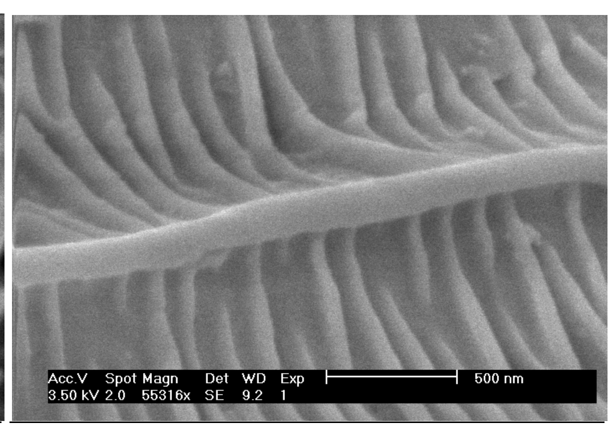












Check your Learning

Level of Difficulty: Intermediate

Instructions: Answer the following questions based on the knowledge you have learned.

1. A micrometer is
    a. One one-hundredth of a meter
    b. One one-thousandth of a meter
    c. One one-millionth of a meter
    d. One one-billionth of a meter
2. A nanometer is
    a. 10^{-1} meter
    b. 10^{-3} meter
    c. 10^{-6} meter
    d. 10^{-9} meter
3. What is the correct ranking of the length scales from largest to smallest?
    a. Micro, Nano, Macro
    b. Macro, Micro, Nano
    c. Nano, Micro, Macro
    d. Macro, Nano, Micro
4. Which of these is not a materials property? Hint: review the Material Properties section of Module 1!
    a. Physical
    b. Optical
    c. Mechanical
    d. Size

[1] Southwest Center for Microsystems Education (SCME) NSF ATE Center. (2009). "A Comparison of Scale: Macro, Micro, Nano Learning Module," *Southwest Center for Microsystems Education (SCME) University of New Mexico's*.

CONCLUSION

In this module, we learned about the three most important "categorizes of sizes": macro, micro, and nano. We then connected that understanding with the effects of size on differing materials properties. Building from our knowledge from MODULE 1 on graphene, specific details were discussed about the nanoscale and the importance of this field of study.

Key Takeaway: Expand our learning more holistically and begin putting together the "bigger picture" with all the different pieces of knowledge…

"Nanotechnology is an idea that most people simply didn't believe"
– Ralph Merkle, Computer Scientist