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Macro, Micro, Nano Scales – A Brief Overview

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Abstract : The whole Universe could be viewed grossly in three scales, namely, the macro, micro and nano scales. Each scales have some significant features. Interestingly, some physical properties have different implications in these three scales. In this paper, we would like to compare some of the physical properties in macro, micro and nano scales. We also try to distinguish different features of these scales here. The reasons for such changes will be addressed in the main text. Impacts and implications will also be discussed.

Keywords: Macro, micro, nano, scales.

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1. Introduction

Sometimes, we would like to ask ourselves, "How vast is the Universe? Trying to find the answer, we find that there is no specific answer. Or, on the other hand, how small it is? Could we imagine the vastness or smallness of the Universe? Could all the physical properties behave uniformly in all the three scales?" Truly speaking, we have NO definite answer for the first two questions. And for the third one, the answer is, again, no. The mere fact is that the size of the Universe is unknown but the size of the objects within the Universe is known. We see that there is a huge range of scales – from vastness to smallness. Accordingly, we divide the scales grossly in three categories, namely, macro, micro and nano scales. The main problem for the materials is that their properties behave differently in these three scales. A systematic material design is necessary to cope with the different material scales. Many researches have been undergoing to design a proper material so that their properties could show some systematic characters in different scales. Very recently, for high precision positioning of the electronic devices, a macro-micro motion platform is proposed by a group of scientists. [1]

In this article, we would like to demonstrate some of the properties which differ from macro to nano scales in different arena. The objective of the paper is to review some of the basic properties of some physical systems which play key roles in different scales.

The organization of the paper is as follows: The second part consists of Results and discussions followed by the conclusions.

Fig.1: The Milky way Galaxy [12]

2. Results and Discussions

2.1 From Macro to Micro

We do not know the exact volume of the Universe. But we know the materials situated in the Universe, could measure their volume and compare them in such a way that we could have a gross idea about the hugeness of it. For example, our sun is a member of Milky Way Galaxy (Fig. 1). This galaxy is one of the billions of galaxies in the Universe. How big is the Milky Way Galaxy? Well, this spiral galaxy's vast rotating disk of stars spans at least 170,000 light years.[2] It is hard to realize how far it is. The time taken by a light beam (speed ~ $3x10^8$ meter/sec.) to pass from one side of the disk to another side is 170,000 years. This galaxy contains some 100 billion of sun-like stars. Almost 50000 billion stars are in the Universe.

Again, if we consider the size of the sun against other stars, we find that it is an average sized star.(Fig. 2)It's diameter is 864,000 miles. Its diameter is 109 times larger than the earth which simply means sun could accommodate 130,000 earths. Can we imagine the vastness of the Universe?

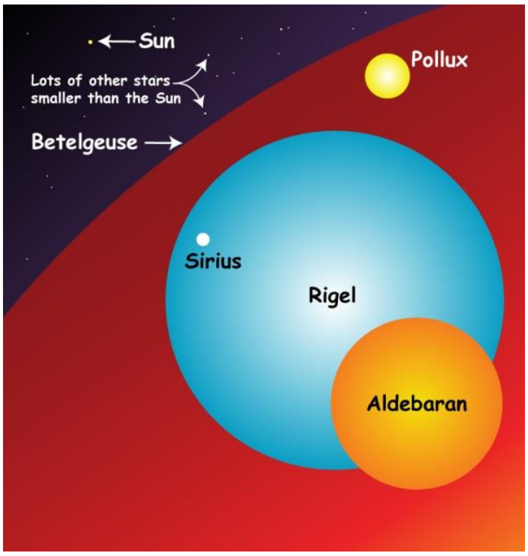

Fig. 2: Comparison of sun with other stars [13]

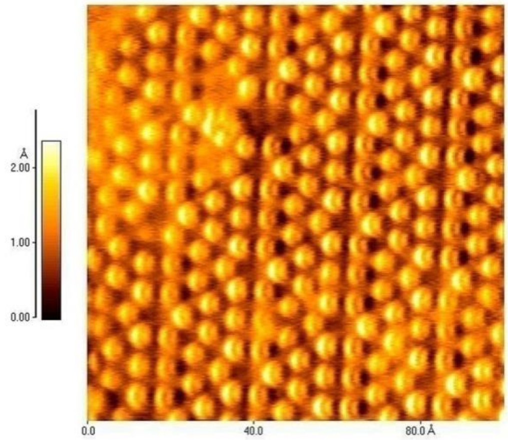

Fig. 3: Silicon molecule as seen by Atomic Force Microscope [14]

Side by side, people have been also trying to explore the smallness of the Universe. Researches show that this 'small' world is not so small rather it is another vast world. In this world, even millimetre is large! Here we measure the length in micrometer, nanometer or in atomic scale unit! Sometimes we go beyond when we speak sub-nuclear particles. Here, we show a photograph of Silicon molecules (Fig. 3)

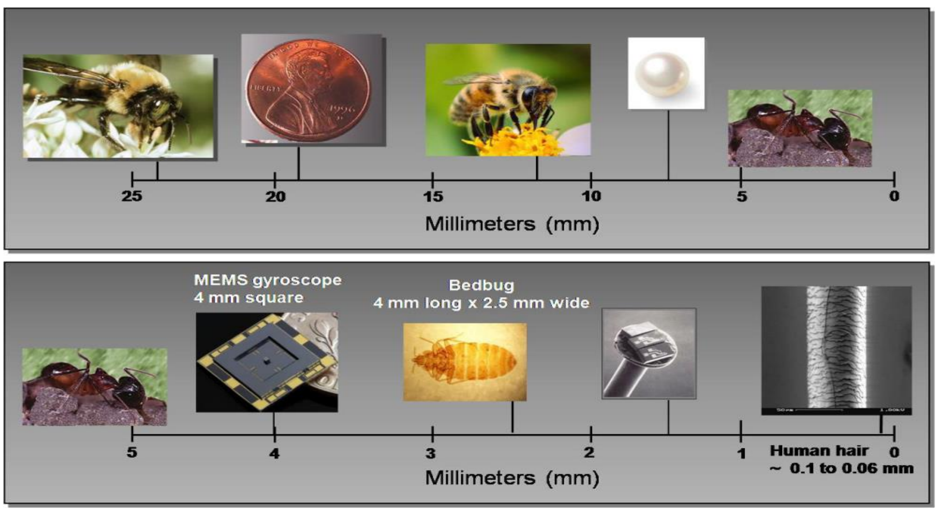

Fig. 4: Relative smallness or largeness of an ant

Sometimes largeness or smallness seems to be relative against the perspective. When we say, an ant is small, then we need to mention the background against which we measure.(Fig. 4) So, in order to make a concrete statement for largeness or smallness we have to make a scale from which we could say whether the matter is in macro level, micro level or in nano level. In (Fig. 5) we show a comparative view of different scales. A few points might be addressed from this figure: 1) we do not mention here the scales higher than meter; for example, Kilometer(10^3 meter) or light year(~9.461×10^{15}Meters); 2) same is true for the scales beyond atomic level, i.e.nuclear level (~10^{-15}Meters). Thus the scale spans from$\{10^{15}, 10^{-15}\}$ Meters.

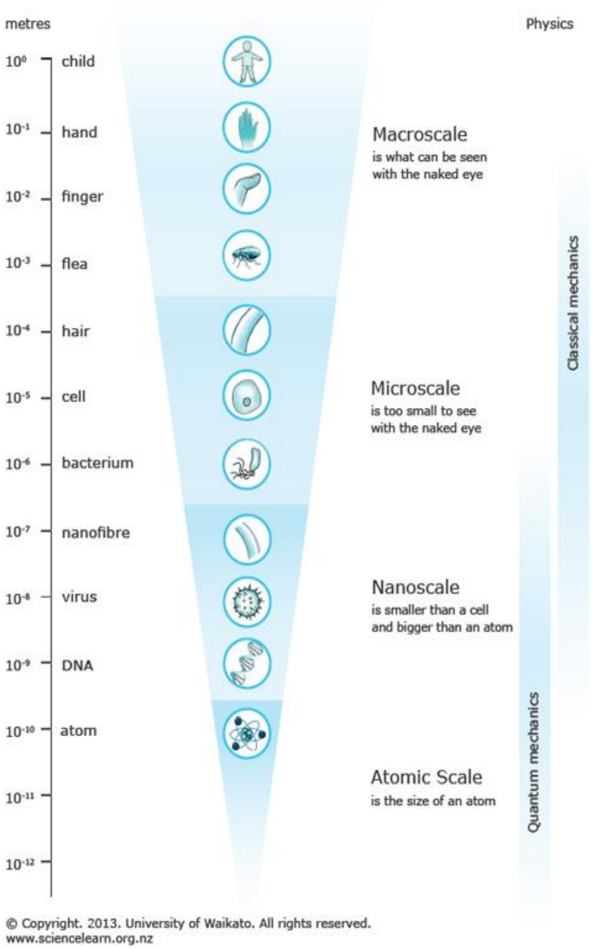

Fig.5: From Macro to Nano [15]

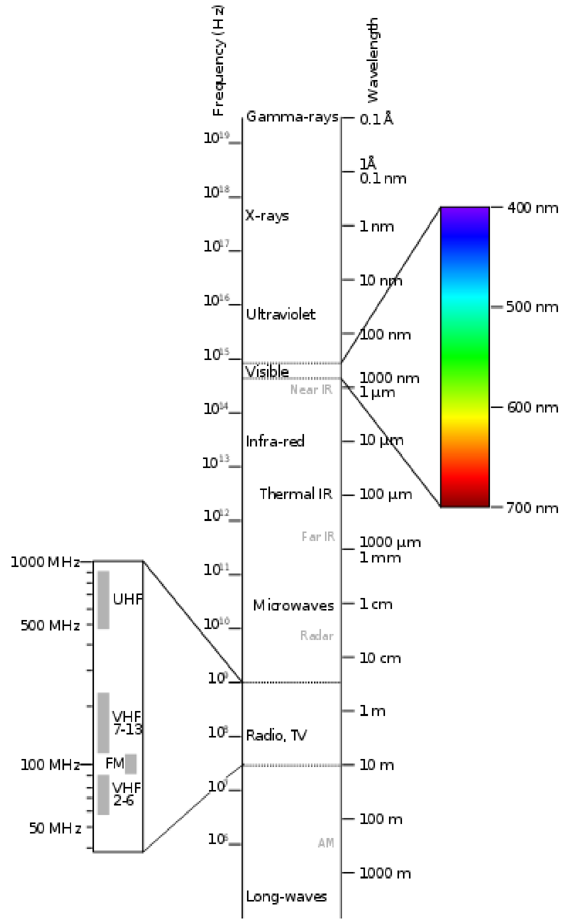

Fig. 6: Electromagnetic Waves

In general, we could name the matter as macro bodies which have dimensions 100 micrometers or more; dimensions in between 100 micrometers to 100 nanometers could be termed as microparticles and dimensions in between 100 nanometres to1 nanometers could be said as nanopartilcles.

2.2. Comparison of Some Properties

The different properties of matter change with the change of scales. One property which might play a prominent role in one scale might be an obscure property in another scale. Let us consider, for example, gravitational field. Though the field has had its effect on each matter in the Universe, we could neglect it for micro or nano particles as its effect is negligibly small. Sometimes reverse would be taken place. For example, the surface/interface properties of materials play the key role in micro and nano materials and differ negligibly in macro level.[3]

When we go from macro to nano level, we are facing two types of changes: 1) first phase of changes comes when we go from macro to micro level. The laws and the mode of thinking we use for narrating the macro level incidents differ from describing micro level experiments. We need to redefine them in the light of new findings in the micro level. There is no definitive boundary between macro and micro level. (Fig.5) Experiments would show how we change the relations from macro to micro scales. 2) The second phase is from micro to nano levels. Again we would try to redefine the laws in the nano-level context. And when we go to the atomic level then quantum effects become prominent.

The scaling law should be treated very carefully when we move from one level to another level. Details works have been published elsewhere.[4] We would like to address here some universal laws in these three levels.

At first, let us consider the law of gravitation and the properties of matter. According to general theory of relativity (GTR), gravitational field emerges totally from space-time scenario. And the curvature of any space-time point depends on the mass on that point. Newton's Law of gravitation is the special case of the general theory of relativity. We know, in general, length, mass and time are three primary unit in physics. But, according to general theory of relativity, all three units can be described by the length L. [space and time are treated as same dimensions in GTR, so they have the length L. And the mass $M \sim L^3$, L^3 is the volume of a body.]The gravitational force of the earth $F_{gr} = mg \sim L^3$; here g is the acceleration due to gravity. Thus the gravitational pressure on the surface of the Earth $p_{gr} = F_{gr}/A \sim L$; A = area.

But when we go to the micro or nano level, another type of force, named as Van der Waals force, comes into play. This force is distant-dependant and works mostly at atomic level. It is seen after certain distance, called Van der Waals contact distance, the attractive nature of force changes to repulsive one and after certain distance it has no effect. The force shows its repulsive nature between 0.4 nm to 0.6 nm and after 0.6 nm it has no effect at all. [Actually, a lizard moves in the wall with the help of this force.] It can be shown the Van der Waal force, F_{vdw}, can be expressed in terms of length; $F_{vdw} \sim L^2$; So that, $F_{vdw}/F_{gr} \sim L^{-1}$.[5]Thus we could neglect gravitational force in micro or nano level.

Let us consider another physical property, heat conduction of materials. This process has its effect in macro level though their causes lie in the micro level. The collisions between the particles in the microscopic level and the drift velocity of the electrons result the conduction of heat in macroscopic level. Conduction of heat depends on the change of internal energy and inclination of temperature. We know Fourier equation would suffice to define the conduction in macro level.

But when we consider the conduction in micro or nano level this Fourier equation is no longer valid. We need to alter this equation after considering the following effects: 1) the effective length of the conductor becomes equivalent to the length of the system; and 2) the effective time of the conductor is equivalent to effective stimulant time. For example, thin film thermal conductivity plays important roles in many applications of microelectronics, microelectrochemical systems and in the design of thermal managements such as dissipation or thermal isolation.[6]On the other hand LASER heating provides most suitable choice of heating the materials during microforming processes as it offers several advantages like 1) local heating (~ 10 nm range), 2) regulated via diode laser 3) control of temperature gradient by using laser power.[7]

Let us come to another important aspect, electromagnetic waves. (Fig.6)It is known that the visible light is a very small part of a very wide range of electromagnetic waves. The range starts from the smallest gamma rays (wavelength ~ 1picometer) to radio wave (wavelength ~ 10^3 meter). We use different ranges in different aspects of sciences. For example, Radio waves are used for communication purposes, microwaves are for satellite signals and cooking, Infrared are for remote controls, x-rays are used for treatments, etc.

We know electromagnetic waves are composed of electrical and magnetic fields. One is depending on the other. Let us now consider electrical and magnetic separately.

From Ohm's law, we know, $R_{EL} = \rho_{EL}L/A$, where R_{EL} and ρ_{EL} are the electrical resistance and electrical conductivity of a substance respectively. Then, $R_{EL} \sim L^{-1}$. For a fixed potential difference, we could write the current $I_{EL} \sim L$. And the power dissipated per unit area $W_{EL} \sim L^{-1}$. If we reduce the dimension, the more power would be dissipated. It is a common problem in micro or nano level.

Again, if current I_{EL} flows through a solenoid of length L and n turns, the magnetic field produced $B = \mu n I_{EL}/L$. If the current density is taken as constant, then $I_{EL} \sim L^2$ and $B \sim L$. We try to shorten the length of the solenoid without changing number of turns, we see that as the area is reduced the amount of current diminished and after certain area (~1 cubic mm) we could not be able to reduce it further. There is some technical difficulties as the dissipation of energy becomes larger.

Recently some remarkable works have been performed in electromagnetics at the nano level.[8-10]Nano-electronics, nano-electro optics or some complex electro-magnetic compound like $Pb(Mn_{1/3}Nb_{2/3})O_3$-$PbTiO_3$, carbon nano-tubeare the some of the research areas in the nano scale. By using electromagnetism in nano scale, we open up a huge space which we need to explore.

3. Conclusion

At present, the world we see seems to be much larger as we expect. Every day, some new vistas open up and change our domain of knowledge. For example, very recently, we are able to take a snap of the black hole (10 April, 2019).[11] This black hole is situated in a galaxy M87 staying 55 million lightyears from the earth. This is one side of the card. On the other side, a formidable work has been performed in nano level with graphene, bio-medicine and other bio-degradable materials. We could say, by the words of Rabindranath Tagore, “You are the Infinite in the finite, play your own tune.″Let us see what would come next.

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