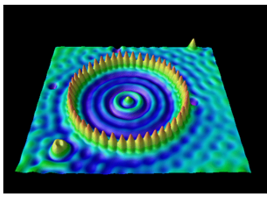
Γενική Φυσική

Κωνσταντίνος Χ. Παύλου
Φυσικός – Ραδιοηλεκτρολόγος (MSc)
Καστοριά, Ιούλιος 14

Οι κλίμακες της Φυσικής

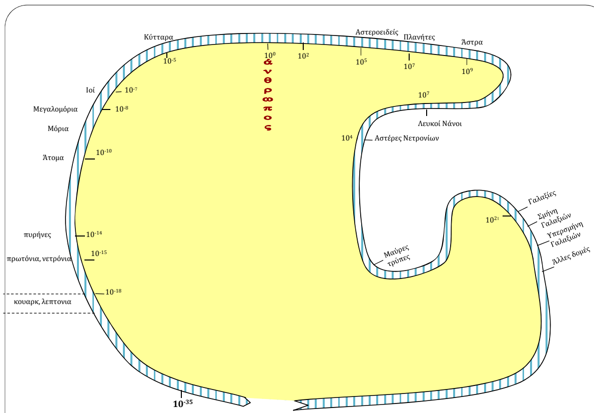
Τα όρια της Φυσικής

Από το πολύ μικρό:
Άτομα, κβαντικά κύματα, …



στο πολύ μεγάλο:
γαλαξίες, σύμπαν

25-Ιουλ-14

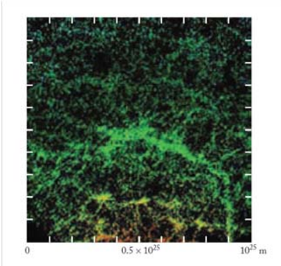


25-Ιουλ-14

Πιν.2.1. Τα βασικά επίπεδα οργάνωσης της ύλης

Επίπεδο Οργάνωσης της ύλης	Κλίμακα Μήκους (σε m)	Συστατικά	Είδος αλληλεπιδράσεων που καθορίζουν τη δομή του
Κουάρκ u και d	$<10^{-18}$	Φαίνεται ότι είναι στοιχειώδη	-
Ηλεκτρόνιο	$<10^{-18}$	Φαίνεται ότι είναι στοιχειώδες	-
Πρωτόνιο	10^{-15}	uud κουάρκ	Ισχυρές, ασθενείς, Η/Μ
Νετρόνιο	10^{-15}	udd κουάρκ	Ισχυρές, ασθενείς, Η/Μ
Πυρήνες ατόμων	10^{-15} - 10^{-14}	πρωτόνια, νετρόνια	Ισχυρές, ασθενείς, ΗΜ
Ατομα	10^{-10}	πυρήνας, ηλεκτρόνια	Η/Μ
Μόρια	$>10^{-10}$	άτομα ή /και ιόντα και ηλεκτρόνια	Η/Μ
Στερεά (θεμελιώδης κυψελίδα) (π.χ. μέταλλα)	$>10^{-10}$	άτομα ή /και ιόντα και ηλεκτρόνια	Η/Μ
Κύτταρα	$\geq 10^{-6}$	μόρια	Η/Μ
Βιολογικοί οργανισμοί (π.χ. άνθρωπος)	10^{-8}-10^{2} (10^{0})	μόρια, κύτταρα, ιστοί, όργανα, κλπ	Η/Μ
Πλανήτες	10^{6}-10^{7}	στερεά, υγρά	Η/Μ, Βαρυτικές
Αστρα	10^{9}	ιόντα, ηλεκτρόνια, πυρήνες	Βαρυτικές, Ισχυρές, ασθενείς, Η/Μ
Γαλαξίες	10^{21}	άστρα+…	Βαρυτικές +…
Σύμπαν	10^{26}	Γαλαξίες+…	Βαρυτικές +…

10.000.000.000.000.000.000.000.000



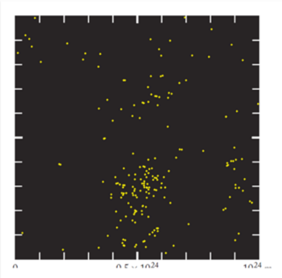
This plot shows the positions of about 100,000 galaxies in a patch of the sky at distances of up to 1 x 10^{9} light years from the Earth. The false color in this image indicates the distance-red for shorter distances, blue for
larger distances.

The visible galaxies plotted here contribute only about 5% of the total mass in the universe. The dark matter near the galaxies contribute another 25%. The remaining 70% of the total mass in the universe is in the form of dark energy, which is uniformly distributed over the vast reaches of intergalactic space.

This is the last of our pictures in the ascending series. We have reached the limits of our zoom out. If we wanted to draw another picture, 10 times larger than this, we would need to know the shape and size of the entire Universe. We do not yet know that.

25-Ιουλ-14

1.000.000.000.000.000.000.000.000



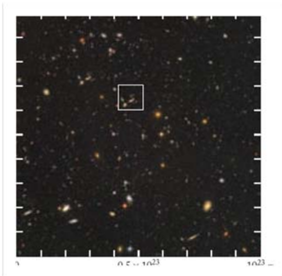
On this scale a galaxy equal in size to our own Galaxy would look like a fuzzy dot, 0.1 millimeter across. Thus, the galaxies are too small to show up clearly on a photograph. Instead we must rely on a plot of the positions of the galaxies. The plot shows the positions of about 200 galaxies. The dense cluster of galaxies in the lower half of the plot is the Virgo Cluster.

Since we are looking into a volume of space, some of the galaxies are in the foreground, some are in the background; but our plot takes no account of perspective.

The luminous stars in the galaxies constitute only a small fraction of the total mass of the Universe. The space around the galaxies and the clusters of galaxies contains dark matter, and the space between the clusters contains dark energy, a strange form of matter that causes an acceleration of the expansion of the Universe.

25-Ιουλ-14

100.000.000.000.000.000.000.000

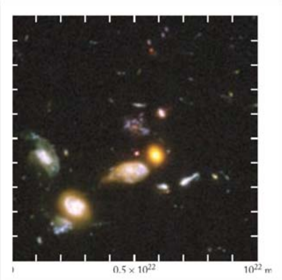


The Local Group lies on the fringes of a very large cluster of galaxies, called the Local Supercluster. This is a cluster of clusters of galaxies. At the center of the Local Supercluster is the Virgo Cluster with several thousand galaxies. Seen from a large distance, our super-cluster would present a view comparable with this photograph, which shows a multitude of galaxies beyond the constellation Fornax, all at a very large distance from us. The photograph was taken with the Hubble Space Telescope coupled to two very sensitive cameras using an exposure time of almost 300 hours.

All these distant galaxies are moving away from us and away from each other. The very distant galaxies in the photo are moving away from us at speeds almost equal to the speed of light. This motion of recession of the galaxies is analogous to the outward motion of, say, the fragments of a grenade after its explosion. The motion of the galaxies suggests that the Universe began with a big explosion, the Big Bang, that launched the galaxies away from each other.

25-Ιουλ-14

10.000.000.000.000.000.000.000



Galaxies are often found in clusters of several galaxies. Some of these clusters consist of just a few galaxies, others of hundreds or even thousands. The photograph shows a cluster, or group, of galaxies beyond the constellation Fornax. The group contains an elliptical galaxy like a luminous yellow egg (center), three large spiral galaxies (left), and a spiral with a bar (bottom left).

Our Galaxy is part of a modest cluster, the Local Group, consisting of our own Galaxy, the great Andromeda Galaxy, the Triangulum Galaxy, the Large Magellanic Cloud, plus 16 other small galaxies.

According to recent investigations, the dark, apparently empty, space near galaxies contains some form of distributed matter, with a total mass 20 or 30 times as large as the mass in the luminous, visible galaxies. But the composition of this invisible, extragalactic dark matter is not known.

25-Ιουλ-14

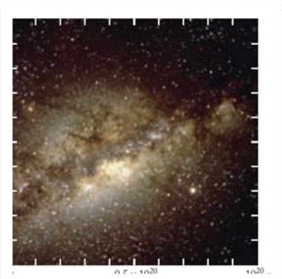
1.000.000.000.000.000.000.000

This is the spiral galaxy NGC 2997. Its clouds of stars are arranged in spiral arms wound around a central bulge. The bright central bulge is the nucleus of the galaxy; it has a more or less spherical shape. The surrounding region, with the spiral arms, is the disk of the galaxy. This disk is quite thin; it has a thickness of only about 3% of its diameter. The stars making up the disk circle around the galactic center in a clockwise direction.

Our Sun is in a spiral galaxy of roughly similar shape and size: the Milky Way Galaxy. The total number of stars in this galaxy is about 10^{11} . The Sun is in one of the spiral arms, roughly one-third inward from the edge of the disk toward the center.

25-Ιουλ-14

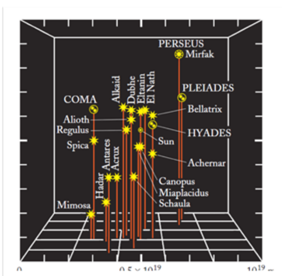
100.000.000.000.000.000.000



This photograph shows a view of the Milky Way in the direction of the constellation Sagittarius. Now there are so many stars in our field of view that they appear to form clouds of stars. There are about a million stars in this photograph, and there are many more stars too faint to show up distinctly. Although this photograph is not centered on the Sun, it is similar to what we would see if we could look toward the Solar System from very far away.

25-Ιουλ-14

10.000.000.000.000.000.000

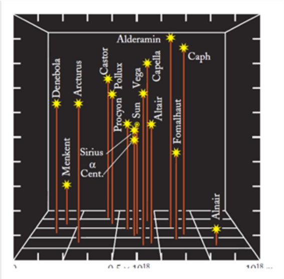


Here we expand our box to 10^{19} meters x 10^{19} meters x 10^{19} meters, again showing only the brightest stars and omitting many others. The total number of stars within this box is about 2 million. We recognize several clusters of stars in this picture: the Pleiades Cluster, the Hyades Cluster, the Coma Berenices Cluster, and the Perseus Cluster.

Each of these has hundreds of stars crowded into a fairly small patch of sky. In this diagram, Starbursts signify single stars, circles with starbursts indicate star clusters, and a circle with a single star indicate a star cluster with its brightest star.

25-Ιουλ-14

1.000.000.000.000.000.000

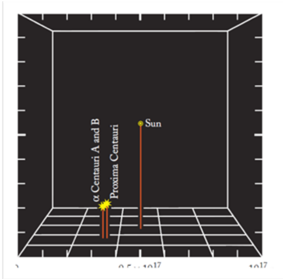


This picture displays the brightest stars within a cubical box 10^{18} meters x 10^{18} meters x 10^{18} meters centered on the Sun. There are many more stars in this box besides those shown—the total number of stars in this box is close to 2000.

Sirius is the brightest of all the stars in the night sky. If it were at the same distance from the Earth as the Sun, it would be 28 times brighter than the Sun.

25-Ιουλ-14

100.000.000.000.000.000

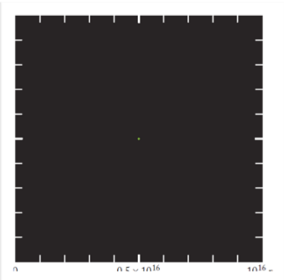


Here, at last, we see the stars nearest to the Sun. The picture shows all the stars within a cubical box 10^{17} meters x 10^{17} meters x 10^{17} meters centered on the Sun: Alpha Centauri A, Alpha Centauri B, and Proxima Centauri. All three are in the constellation Centaurus, in the southern sky.

The star closest to the Sun is Proxima Centauri. This is a very faint, reddish star (a "red dwarf"), at a distance of 4 x 10^{16} meters from the Sun. Astronomers like to express stellar distances in light-years: Proxima Centauri is 4.2 light-years from the Sun, which means light takes 4.2 years to travel from this star to the Sun.

25-Ιουλ-14

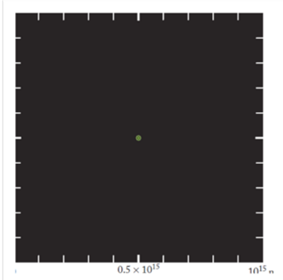
10.000.000.000.000.000



And more interstellar space. On this scale, the Solar System looks like a minuscule dot, 0.1 millimeter across.

25-Ιουλ-14

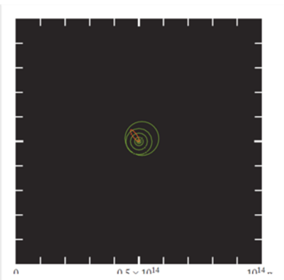
1.000.000.000.000.000



More interstellar space. The small circle is the orbit of Pluto.

25-Ιουλ-14

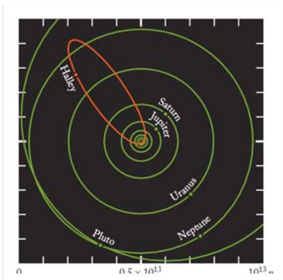
100.000.000.000.000



We now see that the Solar System is surrounded by a vast expanse of space. Although this space is shown empty in the picture, the Solar System is encircled by a large cloud of millions of comets whose orbits crisscross the sky in all directions. Furthermore, the interstellar space in this picture and in the succeeding pictures contains traces of gas and of dust. The interstellar gas is mainly hydrogen; its density is typically 1 atom per cubic centimeter.

25-Ιουλ-14

10.000.000.000.000



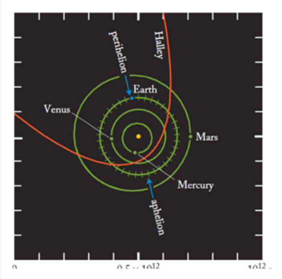
This picture shows the positions of the outer planets of the Solar System: Jupiter, Saturn, Uranus, Neptune, and Pluto. On this scale, the orbits of the inner planets are barely visible. As in our other pictures, the positions of the planets are those of January 1, 2000.

The outer planets move slowly and their orbits are very large; thus they take a long time to go once around their orbit. The extreme case is that of Pluto, which takes 248 years to complete one orbit.

Uranus, Neptune, and Pluto are so far away and so faint that their discovery became possible only through the use of telescopes. Uranus was discovered in 1781, Neptune in 1846, and the tiny Pluto in 1930. Pluto is now known as one of several dwarf planets.

25-Ιουλ-14

1.000.000.000.000



This drawing shows the positions of the Sun and the inner planets: Mercury, Venus, Earth, and Mars. The positions of the planets are those of January 1,2000.

The orbits of all these planets are ellipses, but they are close to circles. The point of the orbit nearest to the Sun is called the perihelion and the point farthest from the Sun is called the aphelion. The Earth reaches perihelion about January 3 and aphelion about July 6 of each year.

All the planets travel around their orbits in the same direction: counterclockwise in our picture. The marks along the orbit of the Earth indicate the successive positions at intervals of 10 days.

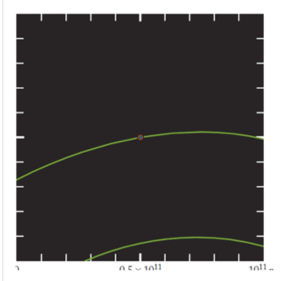
Beyond the orbit of Mars, a large number of asteroids orbit around the Sun; these have been omitted to prevent excessive clutter. Furthermore, a large number of comets orbit around the Sun. Most of these have pronounced elliptical orbits. The comet Halley has been included in our drawing.

The Sun is a sphere of radius 6.96×10^8 meters. On the scale of the picture, the Sun looks like a very small dot, even smaller than the dot drawn here. The mass of the Sun is 1.99×10^{30} kilograms.

The matter in the Sun is in the plasma state, sometimes called the fourth state of matter. Plasma is a very hot gas in which violent collisions between the atoms in their random thermal motion have fragmented the atoms, ripping electrons off them. An atom that has lost one or more electrons is called an ion. Thus, plasma consists of a mixture of electrons and ions engaging in frequent collisions. These collisions are accompanied by the emission of light, making the plasma luminous.

25-Ιουλ-14

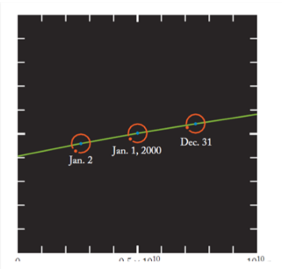
100.000.000.000



Here we see the orbits of the Earth and of Venus. However, Venus itself is beyond the edge of the picture. The small circle is the orbit of the Moon. The dot representing the Earth is much larger than what it should be, although the artist has drawn it as minuscule as possible. On this scale, even the Sun is quite small; if it were included in this picture, it would be only 1 millimeter across.

25-Ιουλ-14

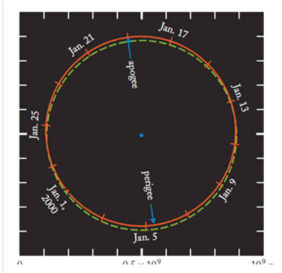
10.000.000.000



This picture shows the Earth, the Moon, and portions of their orbits around the Sun. On this scale, both the Earth and the Moon look like small dots. Again, the Sun is far below the bottom of the picture. In the middle, we see the Earth and the Moon in their positions for January 1, 2000. On the right and on the left we see, respectively, their positions for 1 day before and 1 day after this date. Note that the net motion of the Moon consists of the combination of two simultaneous motions: the Moon orbits around the Earth, which in turn orbits around the Sun.

25-Ιουλ-14

1.000.000.000

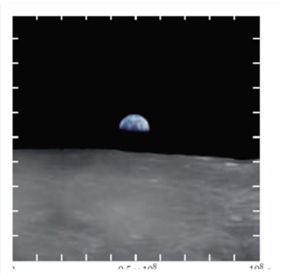


In this drawing, the dot at the center represents the Earth, and the solid line indicates the orbit of the Moon around the Earth (many of the pictures on the following pages are also drawings). As in the preceding picture, the Sun is far below the bottom of the picture. The position of the Moon is that of January 1, 2000.

The orbit of the Moon around the Earth is an ellipse, but an ellipse that is very close to a circle. The solid red curve in the drawing is the orbit of the Moon, and the dashed green curve is a circle; by comparing these two curves we can see how little the ellipse deviates from a circle centered on the Earth. The point on the ellipse closest to the Earth is called the perigee, and the point farthest from the Earth is called the apogee. The distance between the Moon and the Earth is roughly 30 times the diameter of the Earth. The Moon takes 27.3 days to travel once around the Earth.

25-Ιουλ-14

100.000.000

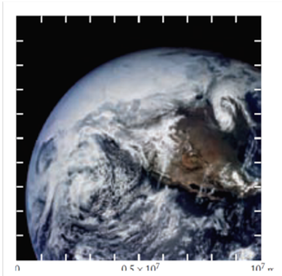


This photograph of the Earth was taken by the Apollo 16 astronauts standing on the surface of the Moon. Sunlight is striking the Earth from the top of the picture.

As is obvious from this and from the preceding photograph, the Earth is a sphere. Its radius is 6.37×10^6 meters and its mass is 5.98×10^{24} kilograms.

25-Ιουλ-14

10.000.000



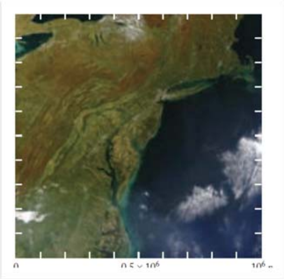
In this photograph, taken by the Apollo 16 astronauts during their trip to the Moon, we see a large part of the

Earth. Through the gap in the clouds in the lower middle of the picture, we can see the coast of California and Mexico. We can recognize the peninsula of Baja California and the Gulf of California. Erin's location, the East Coast of the United States, is covered by a big system of swirling clouds on the right of the photograph.

Note that a large part of the area visible in this photograph is ocean. About 71% of the surface of the Earth is ocean; only 29% is land. The atmosphere covering this surface is about 100 kilometers thick; on the scale of this photograph, its thickness is about 0.7 millimeter. Seen from a large distance, the predominant colors of the planet Earth are blue (oceans) and white (clouds).

25-Ιουλ-14

1.000.000



Here we see the eastern coast of the United States, from Cape Cod to Cape Fear. Cape Cod is the hook near the northern end of the coasdine, and Cape Fear is the promontory near the southern end of the coastine. Note that on this scale no signs of human habitation are visible. However, at night the lights of large cities would stand out clearly.

This photograph was taken in the fall, when leaves had brilliant colors. Streaks of orange trace out the spine of the Appalachian mountains.

25-Ιουλ-14

100.000

In this photograph, Manhattan is in the upper middle. On this scale, we can no longer distinguish the pattern of streets in the city. The vast expanse of water in the lower right of the picture is part of the Atlantic Ocean. The mass of land in the upper right is Long Island. Parallel to the south shore of Long Island we can see a string of very narrow islands; they almost look man-made. These are barrier islands; they are heaps of sand piled up by ocean waves in the course of thousands of years.

25-Ιουλ-14

10.000

This photograph shows a large portion of New York City. We can barely recognize the library and its park as a small rectangular patch slightly above the center of the picture. The central mass of land is the island of Manhattan, with the Hudson River on the left and the East River on the right.

This photograph and the next two were taken by satellites orbiting the Earth at an altitude of about 700 kilometers.

25-Ιουλ-14

1.000

This aerial photograph shows an area of 1 kilometer x 1 kilometer in the vicinity of the New York Public Library. The streets in this part of the city are laid out in a regular rectangular pattern. The library is the building in the park in the middle of the picture. The photograph was taken early in the morning, and the high buildings typical of New York cast long shadows.

The photograph was taken from an airplane flying at an altitude of a few thousand meters. North is t the top of the photograph.

25-Ιουλ-14

100

The New York Public Library is located at the corner of Fifth Avenue and 42nd Street, in the middle of New York City, with Bryant Park immediately behind it.

25-Ιουλ-14

10

The building behind Erin is the New York Public Library, one of the largest libraries on Earth. This library holds 1.4×10^{10} volumes, containing roughly 10% of the total accumulated knowledge of our terrestrial civilization.

25-Ιουλ-14

1

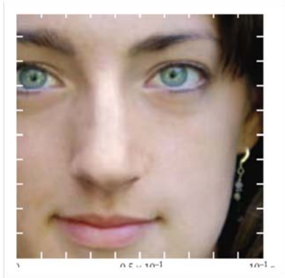
Erin has a height of 1.7 meters and a mass of 57 kilograms. Her chemical composition (by mass) is 65% oxygen, 18.5% carbon, 9.5% hydrogen, 3.3% nitrogen, 1.5% calcium, 1% phosphorus, and 1.2% other elements.

The matter in Erin's body and the matter in her immediate environment occur in three states of aggregation: solid, liquid, and gas. All these forms of matter are made of atoms and molecules, but solid, liquid, and gas are qualitatively different because the arrangements of the atomic and molecular building blocks are different.

In a solid, each building block occupies a definite place. When a solid is assembled out of molecular or atomic building blocks, these blocks are locked in place once and for all, and they cannot move or drift about except with great difficulty. This rigidity of the arrangement is what makes the aggregate hard—it makes the solid "solid." In a liquid, the molecular or atomic building blocks are not rigidly connected. They are thrown together at random and they move about fairly freely, but there is enough adhesion between neighboring blocks to prevent the liquid from dispersing. Finally, in a gas, the molecules or atoms are almost completely independent of one another. They are distributed at random over the volume of the gas and are separated by appreciable distances, coming in touch only occasionally during collisions. A gas will disperse spontaneously if it is not held in confinement by a container or by some restraining force.

25-Ιουλ-14

0,1



This is Erin, an intelligent biped of the planet Earth, Solar System, Orion Spiral Arm, Milky Way Galaxy, Local Group, Local Supercluster. Erin belongs to the phylum Chordata, class Mammalia, order Primates, family Hominidae, genus Homo, species sapiens. She is made of 5.4 x 10^{27} atoms, with 1.9 x 10^{28} electrons, the same number of protons, and 1.5 x 10^{28} neutrons.

We now return to Erin and zoom in on her eye. The surface of her skin appears smooth and firm. But this is an illusion. Matter appears continuous because the number of atoms in each cubic centimeter is extremely large. In a cubic centimeter of human tissue there are about 10 ^{3} atoms.
This large number creates the illusion that matter is continuously distributed—we see only the forest and not the individual trees. The solidity of matter is also an illusion. The atoms in our bodies are mostly vacuum. As we will discover in the following pictures, within each atom the volume actually occupied by subatomic particles is only a very small fraction of the total volume.

25-Ιουλ-14

0,01

Our eyes are very sophisticated sense organs; they collect more information than all our other sense organs taken together. The photograph shows the pupil and the iris of Erin's eye. Annular muscles in the iris change the size of the pupil and thereby control the amount of light that enters the eye. In strong light the pupil automatically shrinks to about 2 millimeters; in very weak light it expands to as much as 7 millimeters.

25-Ιουλ-14

0,001

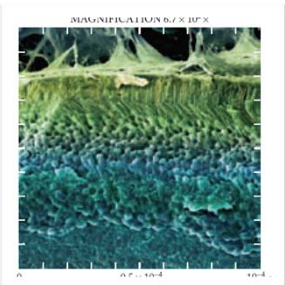
This false-color photograph shows the delicate network of blood vessels on the front surface of the retina, the light-sensitive membrane lining the interior of the eyeball. The rear surface of the retina is densely packed with two kinds of cells that sense light: cone cells and

rod cells. In a human retina there are about 6 million cone cells and 120 million rod cells. The cone cells distinguish colors; the rod cells distinguish only brightness and darkness, but they are more sensitive than the cone cells and therefore give us vision in faint light ("night vision").

This and the following photographs were made with various kinds of electron microscopes. An ordinary microscope uses a beam of light to illuminate the object; an electron microscope uses a beam of electrons. Electron microscopes can achieve much sharper contrast and much higher magnification than ordinary microscopes.

25-Ιουλ-14

0,000.1



Here we have a false-color photograph of rod cells prepared with a scanning electron microscope (SEM). For this photograph, the retina was cut apart and the microscope was aimed at the edge of the cut. In the top half of the picture we see tightly packed rods. Each rod is connected to the main body of a cell containing the nucleus. In the bottom part of the picture we can distinguish tightly packed cell bodies of the cell.

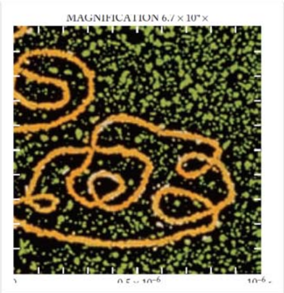
25-Ιουλ-14

0,000.01

This is a close-up view of a few rods cells. The upper portions of the rods contain a special pigment—visual purple—which is very sensitive to light. The absorption of light by this pigment initiates a chain of chemical reactions that finally trigger nerve pulses from the eye to the brain.

25-Ιουλ-14

0,000.001

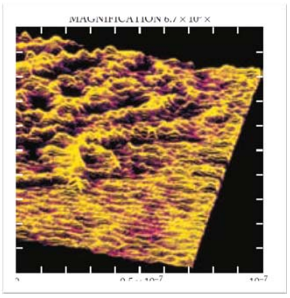


These are strands of DNA, or deoxyribonucleic acid, as seen with a transmission electron microscope (TEM) at very high magnification. DNA is found in the nuclei of cells. It is a long molecule made by stringing together a large number of nitrogenous base molecules on a backbone of sugar and phosphate molecules. The base molecules are of four kinds, the same in all living organisms. But the sequence in which they are strung together varies from one organism to another. This sequence spells out a message—the base molecules are the "letters" in this message. The message contains all the genetic instructions governing the metabolism, growth, and reproduction of the cell.

The strands of DNA in the photograph are encrusted with a variety of small protein molecules. At intervals, the strands of DNA are wrapped around larger protein molecules that form lumps looking like the beads of a necklace.

25-Ιουλ-14

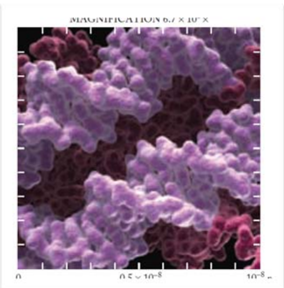
0,000.000.1



The highest magnifications are attained by a newer kind of electron microscope, the scanning tunneling microscope (STM). This picture was prepared with such a microscope. The picture shows strands of DNA deposited on a substrate of graphite. In contrast to the strands of the preceding picture, these strands are uncoated; that is, they are without protein encrustations.

25-Ιουλ-14

0,000.000.01



This close-up picture of strands of DNA reveals the helical structure of this molecule. The strand consists of a pair of helical coils wrapped around each other. This picture was generated by a computer from data obtained by illuminating DNA samples with X rays (X-ray scattering).

25-Ιουλ-14

0,000.000.001

This picture shows a layer of palladium atoms on surface of graphite as seen with an STM.

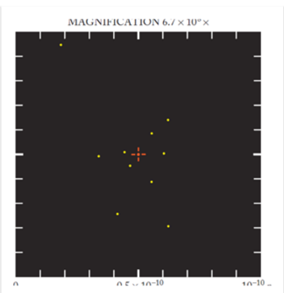
Here we have visual evidence of the atomic structure of matter. The palladium atoms are arranged in a symmetric, repetitive hexagonal pattern. Materials with such regular arrangements of atoms are called crystals.

Each of the palladium atoms is approximately a sphere, about 3×10^{-10} meter across. However, the atom does not have a sharply defined boundary; its surface is somewhat fuzzy. Atoms of other elements are also approximately spheres, with sizes that range from 2×10^{-10} to 4×10^{-10} meter across.

At present we know of more than 100 kinds of atoms or chemical elements. The lightest atom is hydrogen, with a mass of 1.67×10^{-27} kilogram; the heaviest is element 114, ununquadium, with a mass about 289 times as large.

25-Ιουλ-14

0,000.000.000.1



The drawing shows the interior of an atom of neon. This atom consists of 10 electrons orbiting around a nucleus. In the drawing, the electrons have been indicated by small dots, and the nucleus by a slightly larger dot at the center of the picture. These dots have been drawn as small as possible, but even so the size of these dots does not give a correct impression of the actual sizes of the electrons and of the nucleus. The electron is smaller than any other particle we know; maybe the electron is truly pointlike and has no size at all. The nucleus has a finite size, but this size is much too small to show up on the drawing. Note that the electrons tend to

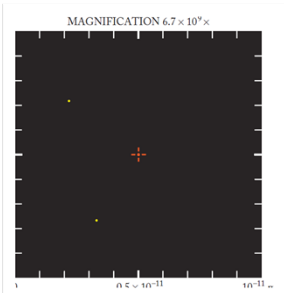
cluster near the center of the atom. However, the overall size of the atom depends on the distance to the outermost electron; this electron defines the outer edge of the atom.

The electrons move around the nucleus in a very complicated motion, and so the resulting electron distribution resembles a fuzzy cloud, similar to the STM image of the previous picture. This drawing, however, shows the electrons as they would be seen at one instant of time with a hypothetical microscope that employs gamma rays instead of light rays to illuminate an object; no such microscope has yet been built.

The mass of each electron is 9.11×10^{-31} kilogram, but most of the mass of the atom is in the nucleus; the 10 electrons of the neon atom have only 0.03% of the total mass of the atom.

25-Ιουλ-14

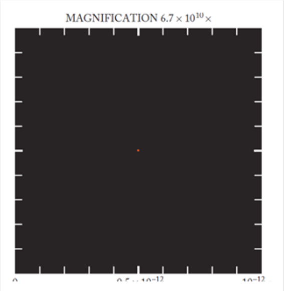
0,000.000.000.01



Here we are closing in on the nucleus. We are seeing the central part of the atom. Only two electrons are in our field of view; the others are beyond the margin of the drawing. The size of the nucleus is still much smaller than the size of the dot at the center of the drawing.

25-Ιουλ-14

0,000.000.000.001

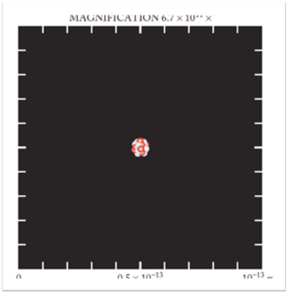


In this drawing we finally see the nucleus in its true size. At this magnification, the nucleus of the neon atom looks like a small dot, 0.5 millimeter in

diameter. Since the nucleus is extremely small and yet contains most of the mass of the atom, the density of the nuclear material is enormous. If we could assemble a drop of pure nuclear material of a volume of 1 cubic centimeter, it would have a mass of 2.3 x 10^{11} kilograms, or 230 million metric tons! Our drawings show clearly that most of the volume within the atom is empty space. The nucleus occupies only a very small fraction of this volume.

25-Ιουλ-14

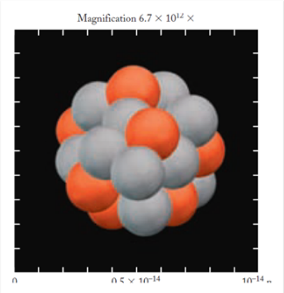
0,000.000.000.000.1



We can now begin to distinguish the nuclear structure. The nucleus has a nearly spherical shape, but its surface is slightly fuzzy.

25-Ιουλ-14

0,000.000.000.000.01

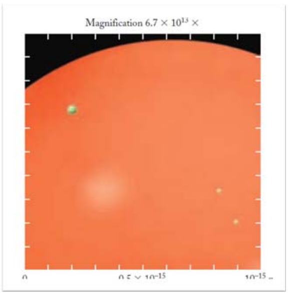


At this extreme magnification we can see the details of the nuclear structure. The nucleus of the neon atom is made up of 10 protons (white balls) and 10 neutrons (red balls). Each proton and each neutron is a sphere with a diameter of about 2 x 10^{-15} meter, and a mass of 1.67 x 10^{-27} kilogram. In the nucleus, these protons and neutrons are tightly packed together, so tightly that they almost touch. The protons and neutrons move around the

volume of the nucleus at high speed in a complicated motion.

25-Ιουλ-14

0,000.000.000.000.001

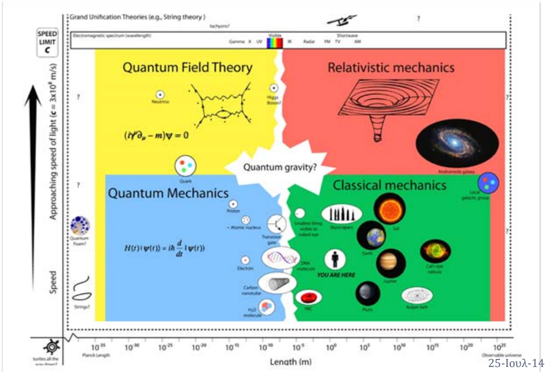


This final picture shows three pointlike bodies within a proton. hese pointlike bodies are quarks—each proton and each neutron is made of three quarks. Recent experiments have told us that the quarks are much smaller than protons, but we do not yet know their precise size. Hence the dots in the drawing probably do not give a fair description of the size of the quarks. The quarks within protons and neutrons are of two kinds, called up and down. The proton consists of two up quarks and one down quark joined together; the neutron consists of one up quark and two down quarks joined together.

This final picture takes us to the limits of our knowledge of the subatomic world. As a next step we would like to zoom in on the quarks and show what they are made of. According to a speculative theory, they are made of small snippets or loops of strings, 10-35m long. But we do not yet have any evidence for this theory

25-Ιουλ-14

Από το10^{-25} μέχρι το 10^{-15}…



25-Ιουλ-14

Φωτογραφίες & κείμενα

Hans C. Ohanian, John T. Markert

Physics for engineers and scientists

(3^{rd} ed, Vol I)

25-Ιουλ-14