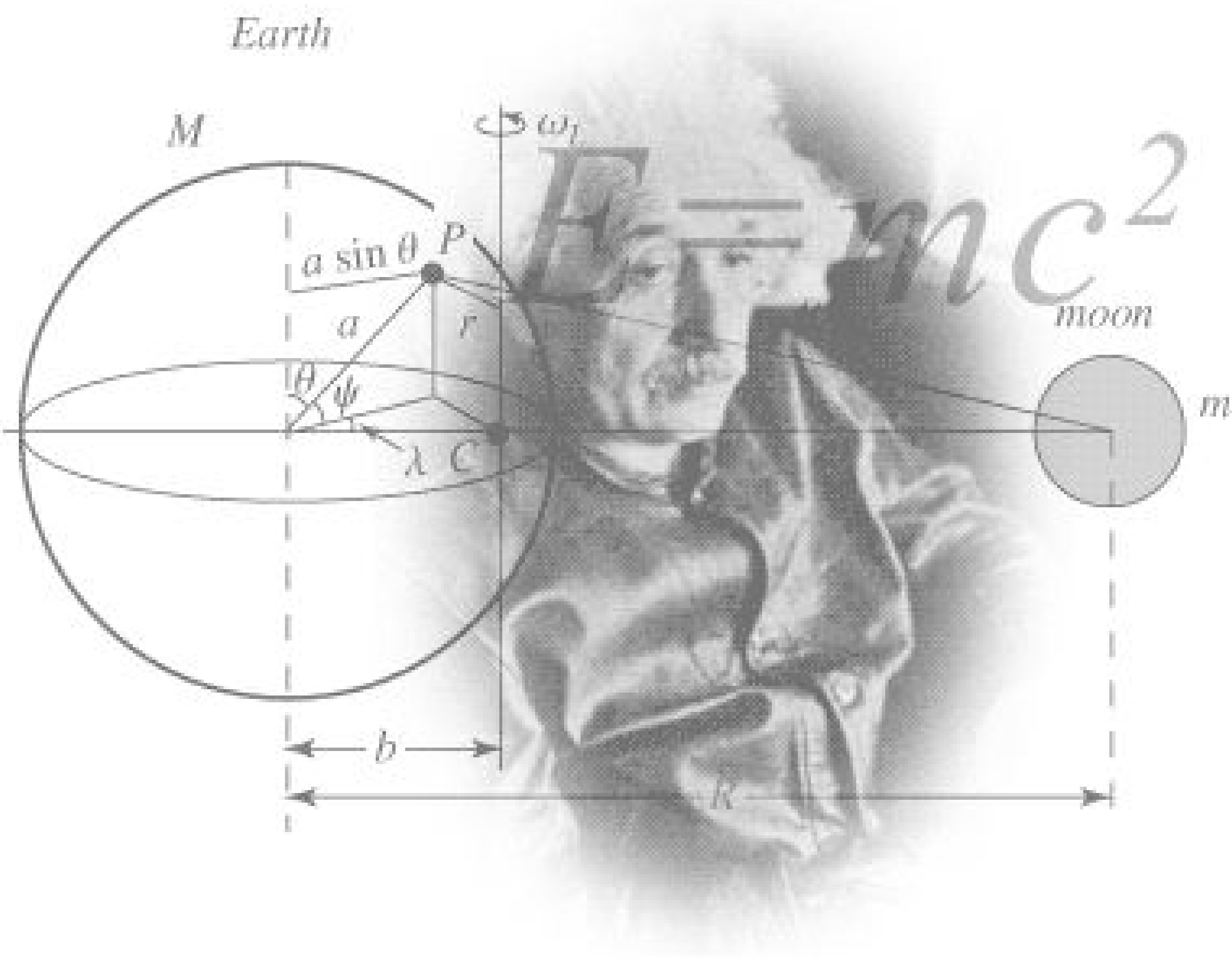
Sveučilište J.J. Strossmayera

Odjel za fiziku, Osijek

ENGLISH IN PHYSICS II

Lidija Kraljević

Knežević Karmen



Osijek, 2008.

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ATOMIC THEORY OF MATTER

The idea that matter is made up of atoms dates back to the ancient Greeks. According to the Greek philosopher Democritus, if a pure substance – say, a piece of iron – were cut into smaller and smaller bits, eventually a smallest piece of that substance would be obtained which could not be divided further. This smallest part was called an atom, which in Greek means "indivisible".

Today the atomic theory is generally accepted. The experimental evidence in its favour, however, came mainly in the eighteenth, nineteenth, and twentieth centuries and much of it was obtained from the analysis of chemical reactions.

We will often speak of the relative masses of atoms and molecules – what we call the atomic mass or molecular mass, respectively.

An important piece of evidence for the atomic theory is called Brownian motion, named after the biologist Robert Brown, who is credited with its discovery in 1827. while he was observing tiny pollen grains moved about in tortuous paths, even though the water appeared to be perfectly still. The atomic theory easily explains Brownian motion if the further reasonable assumption is made that the atoms of any substance are continually in motion.

In 1905, Albert Einstein examined Brownian motion from a theoretical point of view and was able to calculate from the experimental data the approximate size and mass of atoms and molecules. His calculations showed that the diameter of a typical atom is about 10^{-10m}.

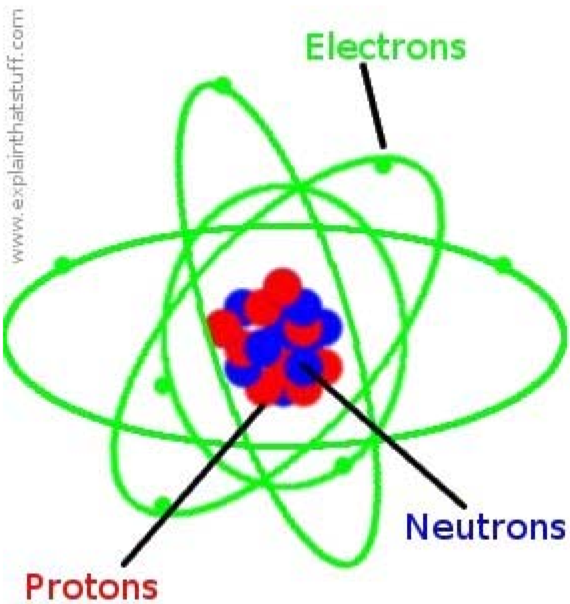


Fig. 1. Inside an atom

There are the three common states, or phases, of matter – solid, liquid, gas – based on the macroscopic properties. Now let us see how these three states of matter differ from the atomic or microscopic point of view. Clearly, atoms and molecules must exert attractive forces on each other. These forces are of an electrical nature. When molecules come too close together, the forces between them must become repulsive, for how else could matter take up space? Thus molecules maintain a minimum distance for each other. In a solid material, the attractive forces are strong enough that the atom or molecules move only slightly about relatively fixed position, often in an array known as a crystal lattice. In a liquid, the atoms or molecules move more rapidly, or the forces between them are weaker, so that they are sufficiently free to pass over one another. In a gas, the forces are so weak, to the speeds so high, that the molecules do not even stay close together. They move rapidly every which way, filling any container and occasionally colliding with one another. When this happens, the force of attraction is not strong enough to keep them close together and they fly off in a new directions.

EXERCISES:

1. Complete the text with the words given in the brackets below the text

All matter is made up of atoms. An atom is like a tiny solar system. In the centre of the atom is the nucleus which is a cluster of protons and neutrons. The **protons** have a **positive** electric charge while the **neutrons** are electrically **neutral**. The nucleus makes up almost all of an atom's mass or weight. Whirling at fantastic speeds around the nucleus are smaller and lighter particles called **electrons** which have a **negative** electric charge.

An atom has the same number of electrons (- ve charge) and protons (+ ve charge) to make the atom electrically neutral. An extremely powerful force, called the nuclear force, holds the protons together in the nucleus as they naturally repelled one another electrically.

2. Give nouns related to these adjectives:

   electric, attractive, relative, chemical, perfect, continual

3. Fill in the missing words given below:

   imagination, altered, rest, motion, observation, predictions

1. One important aspect of science is________________, which includes the design and carrying out of experiments.
2. Observation requires_____________, for scientists can never include everything in a description of what they observe.
3. Aristotle argued that the natural state of an object is at__________,
4. Galileo concluded that for an object to be in_________ was just as natural.
5. Einstein's theory of relativity gives ___________that differ very little from the older theories of Galileo and Newton.
6. As a result of Einstein's theory of relativity, our concepts of space and time have been completely _________________.

4. Make sentences using these words as a noun or as a verb:

   rest, place, support, lecture, leak

   ____
   ____
   ____
   ____
   ____

Lesson 2

TEMPERATURE AND THERMOMETERS

In everyday life, temperature is a measure of how hot or cold something is. Many properties of matter change with temperature. For example, most materials expand when heated. An iron beam is longer when hot than when cold. Concrete rods and sidewalks expand and contract slightly according to temperature, which is why compressible spacer are placed at regular intervals.

Instruments designed to measure temperature are called thermometers. There are many kinds of thermometers, but their operation always depends on some property of matter that changes with temperature. Most common thermometers rely on the expansion of a material with an increase in temperature. The first idea for a thermometer, by Galileo, made use of the expansion of a gas. Common thermometers today consist of a hollow gas tube filled with mercury or with alcohol coloured with a red dye.

In order to measure temperature quantitatively, some sort of numerical scale must be defined. The most common scale today is the Celsius scale, sometimes called the centigrade scale. In the United States, the Fahrenheit scale is also common. The most important scale in scientific work is the absolute, or Kelvin, scale.

One way to define a temperature scale is to assign arbitrary values to two readily reproducible temperatures. For both the Celsius and Fahrenheit scales these two fixed points are chosen to be the freezing point and the boiling point of water, both taken at atmospheric pressure. On the Celsius scale, the freezing point of water is chosen to be 0ºC and the boiling point 100 ºC. on the Fahrenheit scale, the freezing point is defined as 32 ºC and the boiling point 212 ºC.

A Galileo thermometer

A Galileo thermometer or a *Galilean thermometer* is a thermometer made of a sealed glass cylinder containing a clear liquid and a series of objects whose densities are designed to sink in sequence as the liquid is warmed and decreases in density.

Fig. 2 Closeup of bulbs

The Galileo thermometer works due to the principle of buoyancy. Buoyancy determines whether objects float or sink in a liquid, and is responsible for the fact that even boats made of steel can float (of course, a solid bar of steel by itself will sink). The only factor that determines whether a large object will float or sink in a particular liquid relates the object's density to the density of the liquid in which it is placed. Small objects, such as a pin, can float through surface tension. If the object's mass is greater than the mass of liquid displaced, the object will sink. If the object's mass is less than the mass of liquid displaced, the object will float.

EXERCISES:

I .Answer the following questions:

1. What are thermometers?
2. How did Galilean thermometer measure temperature?
3. What do common thermometres consist of?
4. What are the most common numerical scales today?
5. What is the difference between the Celsius and Fahrenheit scale?
6. Describe the Galileo thermometer?
7. How does it work?

II. Write an adjective in front of a noun:

_________ temperature

_________ theory

_________ force

_________ gas

_________ law

III. Summarize the text using the key words:

temperature, thermometer, numerical scale, Fahrenheit, Celsius, Kelvin, Galileo thermometer

____
____
____
____
____
____
____

Lesson 3

VIBRATIONS AND WAVES

Many objects vibrate or oscillate – an object on the end of a spring, a plastic ruler held firmly over the edge of a table and gently struck, the strings of a guitar or piano. Electrical oscillations occur in radio and television sets. At the atomic level, atoms vibrate within a molecule, and the atoms of a solid vibrate about their relatively fixed position. Because it is so common in everyday life and occurs in so may areas of physics, oscillatory or vibrational motion is of great importance. Mechanical vibrations are fully described on the basis of Newtonian mechanics.

Vibrations and wave motion are intimately related subjects. Waves, whether ocean waves, waves on a string, earthquake waves or sound waves in air – have as their source a vibration.

In a transverse wave, the oscillations are perpendicular to the direction in which the wave travels. An example is a wave on a string. In a longitudinal wave, the oscillations are along the line of travel; sound is an example.

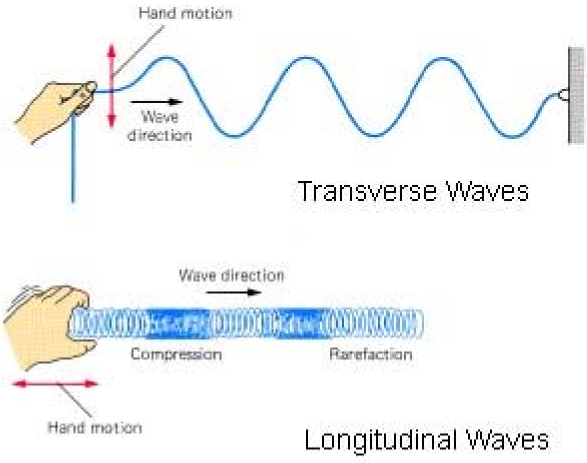


Fig 1. Transverse and Longitudinal Waves

The high points on a wave are called crests and the low points troughs. The amplitude is the maximum height of a crest, or depth of a trough, relative to the normal level. The total swing from a crest to a trough is twice the amplitude. The distance between two successive crests is called the wavelength. The frequency is the number of crests that pass a given point per unit time. The wave velocity is equal to the product of wavelength and frequency.

When two waves pass through the same region of space at the same time, they interfere. Waves change direction, or refract, when travelling from one medium into a second medium where their speed is different. Waves spread, or diffract, as they travel and encounter obstacles.

EXERCISES:

1. Translate the text about vibrations and wave
2. Choose the most appropriate word or phrase and fill in the blanks

FORCE

Motion cannot be induced in a body without the ______________ (removal, model, application) and, except in certain theoretical cases, that ______________ (exertion, motion, force) cannot be maintained without the continued _______________ (exertion, balance, behaviour) of some force. Equally, and less obviously at first sight, a body at rest is also_____________ (provided by, applied to, subject to) to forces which are in balance when it is stationary. Forces are therefore responsible for promoting and preventing movement, and it is clear that they are very important in ________________ (explaining, determining, requiring) whether a process of material transport can take place.

A force is an action in a specified direction which tends to change the state of motion of a body and is always balanced by an _________________ (equal, greater, smaller) called the _____________ (reaction, limit, level). If we imagine a boulder resting upon the ground it is quite apparent that it ______________ (removes, exerts, releases) a vertical force on the ground due to its own weight. Equally, the ground must exert a force of the same ________________ (amount, quantity, magnitude) in the opposite direction on the boulder; if this were not the case, the boulder would sink into the ground due to its weight.

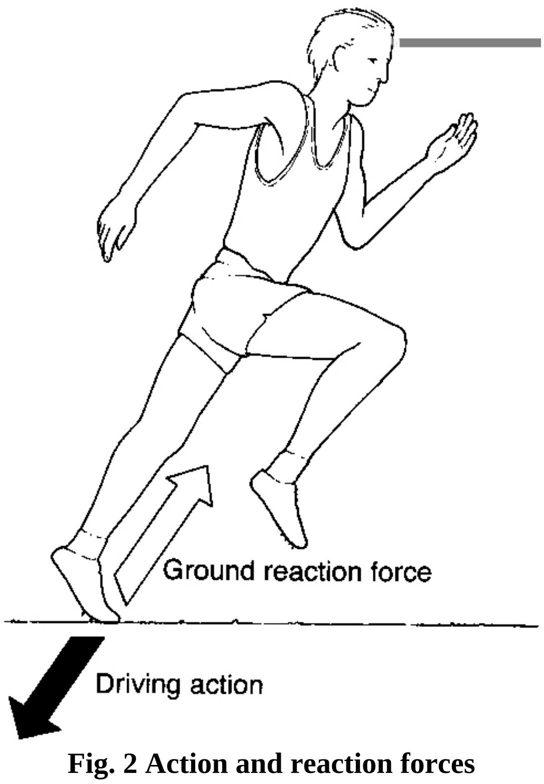


Fig. 2 Action and reaction forces

(A force exerted by the ground in response to the forces a body exerts on it. If the body is pushing down and forwards, the ground reaction force is up and backward; if the body pushes down and backward, the ground reaction force is up and forwards.)

Lesson 4

FOUR DIMENSIONAL SPACE-TIME

When Albert Einstein developed his equations for time and space dilation within the context of his special theory of relativity, one of the consequences was to show that the three dimensions of space possessed a very definite relationship with the dimension of time. The very fact that the very same relativistic equations could be utilized to define them both was quite a remarkable achievement, and led to scientific advancements which could not possibly have been predicted.

The Theories of Minkowski

Soon after the publication of Einstein's theory in 1905, the German Mathematician Hermann Minkowski became one of the first scientists to fully recognize the significance of the theory and attempt to carry it even further from a mathematical perspective.

Minkowski, who had consequently been a professor of Einstein's years before at the Swiss Federal Institute of Technology became the first person to develop a fully-functional and highly advance mathematical foundation upon which the special theory of relativity could be based.

With his mathematics, the four dimensions of space-time became impossible to fully separate from each other, for they were all part of the same universe.

Like so many other aspects of theoretical physics, adding a fourth dimension to the three dimensions of space works very well on paper, and becomes an invaluable mathematical tool for understanding the still-unrevealing laws of physics, but it creates no end of difficulties when one attempts to visualize exactly what this looks like. In this sense, it is simply something we have to accept as a consequence of special relativity, which declares that as your motion changes, so also does your relationship to both space and time.

In the context of Einstein's *General* theory of relativity, developed eleven years later, this fourth-dimensional thinking becomes even more important, as it explains how both space and time can be affected by the affects of gravity and how both space and time can be made to *curve*.

More Than Four Dimensions

In today's physics, which has grown to include such seemingly bizarre topics of research as String theory and Many-Worlds theory, there has become newly-intensified uncertainty as to how many dimensions actually exist in our universe. According to some of the most popular string theories, in fact, there could be as many as ten dimensions – the three of space and one of time that we are aware of, plus six more space dimensions somehow curled up into tiny little invisible balls (at the risk of over-simplifying). Some scientists believe there to be an almost infinite number of little dimensions all over the place.

EXERCISES:

I. Answer the questions

1. What is the importance of Hermann Minkowski?
2. What is the problem with the fourth dimension of space?
3. What can we understand better thanks to the four-dimensional thinking?
4. How many dimensions actually do exist in our universe?

II. Supply the correct preposition in the gaps:

1. We can no longer regard time ……. an absolute quantity.
2. The time interval between two events depends……… the observer's reference frame.
3. Einstein's theory required us to give ……. commonsense notions …… time and space.
4. Relativity has shown that space and time are not independent …. one another.
5. Space and time are seen to be intimately connected, ….. the time being the fourth dimension ….. addition to the three dimensions of space.
6. The photoelectric effect has placed the particle theory ….. light ….. a firm experimental basis.

III. Complete the text with the words given in brackets

The great Danish physicist Niels Bohr proposed his famous principle of complementarity. It states that to understand an experiment, sometimes we find an explanation using wave theory and sometimes using a particle theory. Yet we must be ………… of both the wave and particle aspects of light if we are to have a full understanding of light. Therefore these two aspects of light ……………. one another.

It is not easy to visualize this duality. We cannot readily ………….. a combination of wave and particle. Instead, we must recognize that the two aspects of light are different faces that light shows to experimenters.

Part of the difficulty stems from how we think. Visual pictures in our minds are based on what we see in the everyday world. We ……… the concepts of waves and particles to light because in the macroscopic world we see that energy is ………………….. from place to place by these two methods. We cannot see directly whether light is a wave or particle – so we do indirect experiments. To explain the experiments we apply the models of waves or of particles to the nature of light. But these are abstractions of the human mind. When we try to conceive of what light really is, we …………. on a visual picture. Yet there is no reason why light should ………… to these models (or visual images) taken from the macroscopic world. The true nature of light is not possible to visualize.

(complement, apply, conform, insist, transferred, picture, aware)

BIG BANG THEORY

The Big Bang theory is an effort to explain what happened at the very beginning of our universe. Discoveries in astronomy and physics have shown beyond a reasonable doubt that our universe did in fact have a beginning. Prior to that moment there was nothing; during and after that moment there was something: our universe. The big bang theory is an effort to explain what happened during and after that moment.

According to the standard theory, our universe sprang into existence as "singularity" around 13.7 billion years ago. What is a "singularity" and where does it come from? Well, to be honest, we don't know for sure. Singularities are zones which defy our current understanding of physics. They are thought to exist at the core of "black holes." Black holes are areas of intense gravitational pressure. The pressure is thought to be so intense that finite matter is actually squished into infinite density. These zones of infinite density are called "singularities." Our universe is thought to have begun as an infinitesimally small, infinitely hot, infinitely dense, something - a singularity. Where did it come from? We don't know. Why did it appear? We don't know.

After its initial appearance, it apparently inflated (the "Big Bang"), expanded and cooled, going from very, very small and very, very hot, to the size and temperature of our current universe. It continues to expand and cool to this day and we are inside of it: incredible creatures living on a unique planet, circling a beautiful star clustered together with several hundred billion other stars in a galaxy soaring through the cosmos, all of which is inside of an expanding universe that began as an infinitesimal singularity which appeared out of nowhere for reasons unknown. This is the Big Bang theory.

Big Bang Theory - Common Misconceptions

There are many misconceptions surrounding the Big Bang theory. For example, we tend to imagine a giant explosion. Experts however say that there was no explosion; there was (and continues to be) an expansion. Rather than imagining a balloon popping and releasing its contents, imagine a balloon expanding: an infinitesimally small balloon expanding to the size of our current universe.

Another misconception is that we tend to image the singularity as a little fireball appearing somewhere in space. According to the many experts however, space didn't exist prior to the Big Bang. Back in the late '60s and early '70s, when men first walked upon the moon, "three British astrophysicists, Steven Hawking, George Ellis, and Roger Penrose turned their attention to the Theory of Relativity and its implications regarding our notions of time. In 1968 and 1970, they published papers in which they extended Einstein's Theory of General Relativity to include measurements of time and space.1, 2 According to their calculations, time and space had a finite beginning that corresponded to the origin of matter and energy."3 The singularity didn't appear in space; rather, space began inside of the singularity. Prior to the singularity, nothing existed, not space, time, matter, or energy - nothing. So where and in what did the singularity appear if not in space? We don't know. We don't know where it came from, why it's here, or even where it is. All we really know is that we are inside of it and at one time it didn't exist and neither did we.

Big Bang Theory - Evidence for the Theory

What are the major evidences which support the Big Bang theory? First of all, we are reasonably certain that the universe had a beginning. Second, galaxies appear to be moving away from us at speeds proportional to their distance. This is called "Hubble's Law," named after Edwin Hubble (1889-1953) who discovered this phenomenon in 1929. This observation supports the expansion of the universe and suggests that the universe was once compacted. Third, if the universe was initially very, very hot as the Big Bang suggests, we should be able to find some remnant of this heat. In 1965, Radioastronomers Arno Penzias and Robert Wilson discovered a 2.725 degree Kelvin (-454.765 degree Fahrenheit, -270.425 degree Celsius) Cosmic Microwave Background radiation (CMB) which pervades the observable universe. This is thought to be the remnant which scientists were looking for. Penzias and Wilson shared in the 1978 Nobel Prize for Physics for their discovery.

Finally, the abundance of the "light elements" Hydrogen and Helium found in the observable universe are thought to support the Big Bang model of origins.

Fig.3 A conceptual representation of The Big Bang that theoretically created universe 13.7 billion years ago. The image is incorrect, of course. The Big Bang was an explosion of space, not in space, so it would not have been possibe to have seen it from this exterior viewpoint.

EXERCISES:

1. Write notes of the text mentioning the most important pieces of information.
2. Choose a paragraph from the text and translate it.
3. Write a verb behind a noun

to detect _____________

to observe ________________

to apply ____________________

to calrify ________________

to visualize______________

to develop_______________

Lesson 6

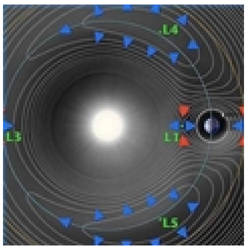
HOW DOES A SATELLITE STAY IN ORBIT

The best way to imagine how a satellite stays in orbit is to think of it as constantly falling towards the Earth, but it keeps missing. It does this because of its altitude and velocity, and the curvature of the Earth. Sir Isaac Newton described this by imagining a cannon firing a cannonball. A small charge of gunpowder fires it neither very far or very high, because of the low speed. Increasing the charge will make the ball faster, allowing the ball to go farther, and to do so out of proportion due to the curvature of the Earth. With enough velocity, the ground curves away faster than the ball falls, causing it to "achieve orbit." It is literally in perpetual free fall, always plummeting towards Earth, but missing.

Practical Satellite Orbits

The problem with staying in orbit is friction. Space is not a perfect vacuum, and orbital space is less so. Although it is very, very thin, there are still bits of gas and dust in orbital space, and this exerts drag on a satellite, slowing it down. As a satellite slows down, its altitude drops, drag increases, the curvature of the Earth starts to catch up, and eventually the satellite plummets back to Earth in a self-increasing feedback loop. A satellite maintains it orbits by using on-board thrusters to boost its speed and altitude, and sometimes other space craft dock and give the satellite a boost. This is only a temporary solution, however. Unless it is refueled or boosted, a satellite eventually slows down, experiences orbital decay, loses orbit, and then returns to Earth.

Lagrange Points

1. 

Lagrange points are orbital "pockets" where the objects within enjoy a balance between the gravity of the Earth and the gravity of another celestial body, such as the sun or the moon. This balance creates a different kind of orbit from that described by Newton and his cannonball, and so long as the object remains in a place where the gravitational forces are balanced perfectly, it can remain in space indefinitely.

KEY WORDS

curvature of the earth, centripetal force, counter-balance, velocity, altitude, circular orbit, elliptical orbit, lagrange points

EXERCISES:

I Supply the correct prepositions in the gaps:

the reflection ......sound
use ..... ultrasonic frequencies
to move..... subsonic speed
body ..... rest
carried .... a wave
to decrease ...... distance
proportional ...... the square ..... the amplitude
distance ....two hilltops

II Replace the underlined words with expressions which have a similar meaning:

1. We cover <u>fundamental</u> aspects of the wave nature.
2. The most <u>important</u> simple optical <u>instrument</u> is no doubt the thin lens.
3. <u>Accurate</u> measurements are an important part of physics.
4. Scientists normally <u>do</u> their work as if the accepted laws and theories were true.
5. They <u>are obliged</u> to keep an open mind in case new information should <u>change</u> the validity of any given law or theory.
6. Physical quantities can be <u>divided</u> into two <u>categories</u>: base quantities and derived quantities.

III Fill in the gaps with the appropriate words and then translate

Johannes Kepler was the first to accurately describe the mathematical _________ of the orbits of planets. Our Moon and the planets travel in orbits that are very close to being circular. A circle is a special kind of ellipse. By definition, an ellipse is a geometrical figure that has two_____ In a circle, both foci of the ellipse are at the same________. Orbits of artificial satellites can be _________or circular. A satellite that stays in orbit with just the right speed will retrace its path, just like the Moon continues to orbit the Earth. Artificial satellites also need just the right speed to stay in orbit around the Earth. Those with a smaller speed will return to the Earth as _______ pulls it down, those with a large enough speed can actually leave the Earth's gravitational tug and travel into deep space. To make this point, imagine a baseball ________ standing on a 100-mile-high mound above the Earth. If the pitcher throws the ball horizontally at 100 miles/hour, the speed is not great enough to stay in orbit so the ball will travel ________some distance but then fall back to Earth. Now, if the pitcher throws the ball at approximately 18,000 miles/hour straight out, then the ball will have just the right speed to orbit the Earth. In this case, the ball will circle the Earth and hit the pitcher in the back of the head one orbital period later (about 90 minutes later)! You can imagine it as continuously falling around the Earth in a circle.

(elliptical, shape, circle, foci, gravity, point, pitcher, falling, outward)

TAKE A FUN PHYSICS QUIZ

1. The weak nuclear force is responsible for:
beta decay
alpha decay
pi beta kappa decay
holding the nucleus together.

2. Energy will dissipate from an area of ____________ energy to one of ____________ energy without the input of additional energy.
heat...light

lower...higher
higher...lower
fusion...fission

3. Newton's Second Law of Motion is which formula:
AF=m
A=F*m
A/F=m
A=F/m

4.Mass and energy can change into each other ... True/False
True
False

5.Light is a:
particle
wave
all of the above
none of the above

6.The speed of sound is approximately:
344 m/s or 1240 ft/s
334 m/s or 1140 ft/s
334 m/s or 1240 ft/s
344 m/s or 1140 ft/s

7.High fluid velocity causes ________ pressure:
high
low
either of the above
none of the above

8.A two cubic meter block of steel in Pat's pool (provided its completely submerged in water) would mass at:
70020 N
80020 N
98000 N
137592 N

9.The principle that the volume of a gas times its pressure is constant at a fixed temperature:
Bohr Theory
Coulomb's Law
Jones' Hypothesis
Boyle's Law

Results of the quiz:

1. beta decay
2. higher/lower.
3. A=F/m
4. True
5. all of the above
6. 334/1140
7. low
8 137592
9. Boyle

Lesson 7

WHY DO THINGS FLOAT?

Archimedes of Syracuse was a Greek mathematician, physicist, engineer, inventor, and astronomer. Although few details of his life are known, he is regarded as one of the leading scientists in classical antiquity. Among his advances in physics are the foundations of hydrostatics, statics and an explanation of the principle of the lever. He is credited with designing innovative machines, including siege engines and the screw pump that bears his name. Modern experiments have tested claims that Archimedes designed machines capable of lifting attacking ships out of the water and setting ships on fire using an array of mirrors.

The most widely known anecdote about Archimedes tells of how he invented a method for determining the volume of an object with an irregular shape. According to Vitruvius, a new crown in the shape of a laurel wreath had been made for King Hiero II, and Archimedes was asked to determine whether it was of solid gold, or whether silver had been added by a dishonest goldsmith. Archimedes had to solve the problem without damaging the crown, so he could not melt it down into a regularly shaped body in order to calculate its density. While taking a bath, he noticed that the level of the water in the tub rose as he got in, and realized that this effect could be used to determine the volume of the crown. For practical purposes water is incompressible, so the submerged crown would displace an amount of water equal to its own volume. By dividing the weight of the crown by the volume of water displaced, the density of the crown could be obtained. This density would be lower than that of gold if cheaper and less dense metals had been added. Archimedes then took to the streets naked, so excited by his discovery that he had forgotten to dress, crying "Eureka!" (Greek: "εὕρηκα!," meaning "I have found it!")

The story of the golden crown does not appear in the known works of Archimedes. Moreover, the practicality of the method it describes has been called into question, due to the extreme accuracy with which one would have to measure the water displacement. Archimedes may have instead sought a solution that applied the principle known in hydrostatics as Archimedes' Principle, which he describes in his treatise On Floating Bodies. This principle states that a body immersed in a fluid experiences a buoyant force equal to the weight of the fluid it displaces. Using this principle, it would have been possible to compare the density of the golden crown to that of solid gold by balancing the crown on a scale with a gold reference sample, then immersing the apparatus in water. If the crown was less dense than gold, it would displace more water due to its larger volume, and thus experience a greater buoyant force than the reference sample. This difference in buoyancy would cause the scale to tip accordingly. Galileo considered it "probable that this method is the same that Archimedes followed, since, besides being very accurate, it is based on demonstrations found by Archimedes himself."

Fig. 4 Archimedes' Famous Words

Lesson 8

TIME TRAVEL ... IS IT REALLY POSSIBLE?

So, where do we start? How about time? What is time? The Oxford English Dictionary defines time as "a limited stretch or space of continued existence", or "as the interval between two successive events". We glance at our wristwatches and notice the second hand slowly counting the passing seconds. We are in our own time machines: Our hearts are pumping blood, we're breathing; we are existing through time.

What are the possibilities of moving through time at a rate different to one day per day? Common sense tells us that it's all nonsense - time travel is impossible. However, common sense is not always such a good guide. Some hundred years ago common sense said man could never fly; now we travel all over the world.

The commonest objections to time travel are the so-called paradoxes. For example, if we could travel through time, imagine what would happen to a time traveller if he (or she) travelled back in time and killed their own grandmother at birth. In theory the time traveller will therefore never be born, so the journey could never have been made in the first place; but if the journey never occurred then the grandmother would be born which means the time traveller would have been born and could make the journey ... and so on and so on. This is a paradox.

There are two possibilities to resolve this paradox. The first is that the past is totally defined, i.e. everything that has happened or must happen, including the time traveller's attempt to kill his grandmother, cannot be altered and so nothing will change the course of history. In other words, the time traveller will experience endless "mishaps" in trying to kill their grandmother and will never achieve the murder, thus keeping time (or at least events) intact.

The second possibility is more complex and involves the quantum rules which govern the subatomic level of the universe. Put simply, when the time traveller kills their grandmother they immediately create a new quantum universe, in essence a parallel universe where the young grandmother never existed and where the time traveller is never born. The original universe still remains. Stephen Hawking believes he can explain the origin of our universe as a variation of this parallel worlds theme.

Having explained these paradoxes how does one travel through time? The secret is to travel at speeds close to the speed of light. The main text of the web site explains this in greater detail. The obvious problem with travelling very near the speed of light is that as you approach C (the speed of light) time slows down until at C time stops. How can you go faster if time has stopped? The answer involves a complex process called quantum tunnelling and is discussed at length in the main text of this web site. Then once the velocity becomes greater than C time moves backwards and the traveller has entered the realms of negative time.

EXERCISES:

1. Translate the text

2. Write synonyms for the following words from the text:

main - __________ , attempt - ______________, journey - _______________, to alter - _____________,

obvious - ____________, velocity - ________________, complex- _____________, remain - ___________

faster - _____________, answer - ______________, kill - _____________

Lesson 9

TELEPORTATION

We see teleporters used all the time in Sci-Fi, so, how realistic can it be?
Suppose we have a man who weighs 60 kg. Now, in order to teleport this man, first you need to know where every atom in his body is located and how that atom is connected to its neighbours in order to recreate the person. For this example let's assume that the man is made of carbon (this is a very poor assumption as we are made from lots of different types of atoms).We know from Avogadro's number that there are 1023 atoms of carbon for every 24g of material, so that totals 2.5 x 1026 atoms. We would need to know the (x,y,z) co-ordinates of each atom in relation to time and how they are located to every other atom at that time. Even this simplistic approach illustrates the huge amount of data storage required.
This illustration is assuming a very basic level of physics, if we go up a gear in complexity we require further information on the instantaneous configuration of the atoms themselves. At such small dimensions quantum effects become very significant and it becomes an impossible task to assign fixed positions for everything. Even if we could then the amount of data would require a hard disk bigger than our solar system and a phenomenal energy source to create the matter. Supposing even that were possible, it would mean that it would be possible to create an exact copy of yourself, complete with your own thoughts and memories. What would you do with the original copy? For a teleporter to work the original you would have to be destroyed (perhaps to aid the energy requirement) or there will be multiple copies. In summary, we don't ever see a day when teleporters will be invented. The random quantum fluctuations would mean that it would be impossible to create an exact duplicate of an original person, even if you could generate the vast amount of energy required and use it to form matter.

In 1993 an international group of six scientists, including IBM Fellow Charles H. Bennett, confirmed the intuitions of the majority of science fiction writers by showing that perfect teleportation is indeed possible in principle, but only if the original is destroyed. In subsequent years, other scientists have demonstrated teleportation experimentally in a variety of systems, including single photons, coherent light fields, nuclear spins, and trapped ions. Teleportation promises to be quite useful as an information processing primitive, facilitating long range quantum communication (perhaps ultimately leading to a "quantum internet"), and making it much easier to build a working quantum computer. But science fiction fans will be disappointed to learn that no one expects to be able to teleport people or other macroscopic objects in the foreseeable future, for a variety of engineering reasons, even though it would not violate any fundamental law to do so.

(top, left) Richard Jozsa, William K. Wootters, Charles H. Bennett. (bottom, left) Gilles Brassard, Claude Crépeau, Asher Peres. Photo: André Berthiaume.

Fig.5 International group of scientists

EXERCISE:

1. Write a short essay in which you will express your view and opinion on teleportation or time travel.

QUANTUM MECHANICS OF ATOMS

Bohr's model of the atom gave us a first picture of what an atom is like. It proposed explanations for why there is emission and absorption of light by atoms at only certain wavelengths Though the Bohr theory had some limitations, it presented a landmark of history of science.

However, in the early 1920's it became increasingly evident that a new, more comprehensive theory was needed. Less than two years after de Broglie gave us his matter-wave hypothesis, Ervin Schrödinger and Werner Heisenberg independently developed a new comprehensive theory. This new theory was called quantum mechanics.

It unifies the wave-particle duality into a single consistent theory and has successfully dealt with the spectra emitted by complex atoms from molecules. It is also a much more general theory that covers all quantum phenomena from blackbody radiation to atoms and molecules. It has explained a wide range of natural phenomena and from its predictions many new practical devices have become possible. Indeed, it has been so successful that it is accepted today by nearly all physicists as the fundamental theory underlying physical processes.

Quantum physics deals mainly with the microscopic world of atoms and light. But this theory, when it is applied to macroscopic phenomena, must be able to produce the old classical laws. This correspondence principle is fully satisfied by quantum mechanics.

This does not mean we throw away classical theories such as Newton's laws. In the everyday world, the latter are far easier to apply and they give sufficiently accurate descriptions. But when we deal with high speeds, close to the speed of light, we must use the theory of relativity; and when we deal with the tiny world of the atoms, we use quantum mechanics.

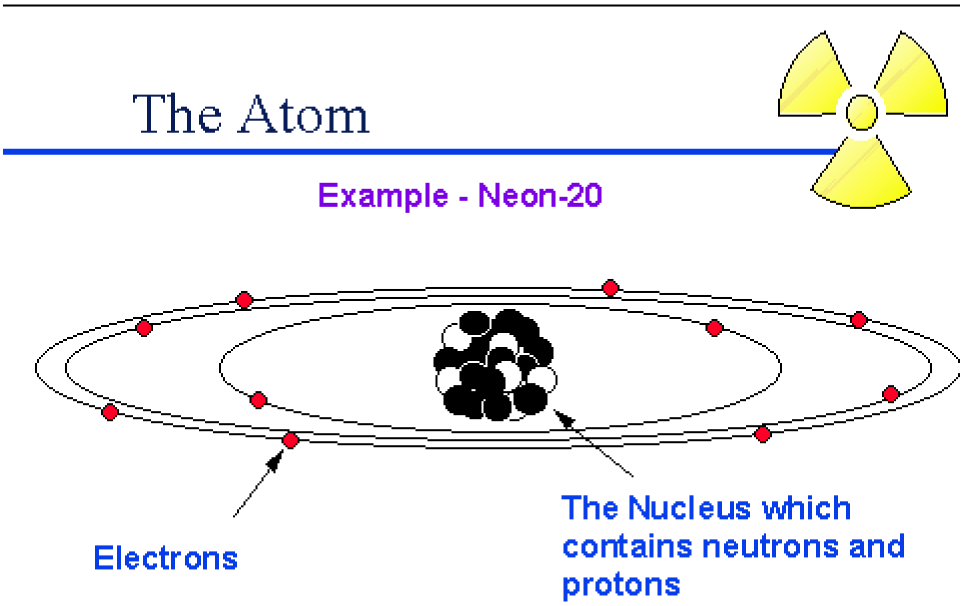


Fig. 6 A typical model of the atom is called the Bohr Model, in honor of Niels Bohr who proposed the structure in 1913. The Bohr atom consists of a central nucleus composed of neutrons and protons, which is surrounded by electrons which "orbit" around the nucleus.

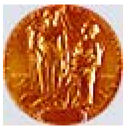


Fig. 7 The Nobel Prize in Physics 1922

Fig. 8 Niels Bohr (1885-1962)

E**XERCISES:**

I. Answer the questions:

1. In what way did Bohr's model of the atom presented a landmark of history of science?
2. What do you know about quantum mechanics?
3. Can quantum mechanics be applied to macroscopic phenomena?
4. When do we use the theory of relativity and when quantum mechanics?

II. Complete the sentences:

1. Ervin Schrödinger and Werner Heisenberg …………………………………………………..
   ……………………………………………………………………………………………..
2. Quantum physics deals mainly ………………………………………………………………
   ………………………………………………………………………………………………
3. This does not mean ……………………………………………………………………………

   ………………………………………………………………………………………………

II. Translate the text

Lesson 11

THE BEGINNING OF TIME I

Professor Hawking has given many lectures to the general public. Many of these past lectures have been released in his 1993 book, 'Black Holes and Baby Universes, and other essays'. Here is an extract from his public lecture entitled *The Beginning of Time*

In this lecture, I would like to discuss whether time itself has a beginning, and whether it will have an end. All the evidence seems to indicate, that the universe has not existed forever, but that it had a beginning, about 15 billion years ago. This is probably the most remarkable discovery of modern cosmology. Yet it is now taken for granted. We are not yet certain whether the universe will have an end. When I gave a lecture in Japan, I was asked not to mention the possible re-collapse of the universe, because it might affect the stock market. However, I can re-assure anyone who is nervous about their investments that it is a bit early to sell: even if the universe does come to an end, it won't be for at least twenty billion years.

The time scale of the universe is very long compared to that for human life. It was therefore not surprising that until recently, the universe was thought to be essentially static, and unchanging in time. On the other hand, it must have been obvious, that society is evolving in culture and technology. This indicates that the present phase of human history can not have been going for more than a few thousand years. Otherwise, we would be more advanced than we are. It was therefore natural to believe that the human race, and maybe the whole universe, had a beginning in the fairly recent past. However, many people were unhappy with the idea that the universe had a beginning, because it seemed to imply the existence of a supernatural being who created the universe. They preferred to believe that the universe, and the human race, had existed forever. Their explanation for human progress was that there had been periodic floods, or other natural disasters, which repeatedly set back the human race to a primitive state.

At this time, the Big Bang, all the matter in the universe, would have been on top of itself. The density would have been infinite. It would have been what is called, a singularity. At a singularity, all the laws of physics would have broken down. This means that the state of the universe, after the Big Bang, will not depend on anything that may have happened before, because the deterministic laws that govern the universe will break down in the Big Bang. The universe will evolve from the Big Bang, completely independently of what it was like before. Even the amount of matter in the universe, can be different to what it was before the Big Bang, as the Law of Conservation of Matter, will break down at the Big Bang.

Since events before the Big Bang have no observational consequences, one may as well cut them out of the theory, and say that time began at the Big Bang. Events before the Big Bang, are simply not defined, because there's no way one could measure what happened at them. This kind of beginning to the universe, and of time itself, is very different to the beginnings that had been considered earlier. These had to be imposed on the universe by some external agency. There is no dynamical reason why the motion of bodies in the solar system can not be extrapolated back in time, far beyond four thousand and four BC, the date for the creation of the universe, according to the book of Genesis. Thus it would require the direct intervention of God, if the universe began at that date. By contrast, the Big Bang is a beginning that is required by the dynamical laws that govern the universe. It is therefore intrinsic to the universe, and is not imposed on it from outside.

Although the laws of science seemed to predict the universe had a beginning, they also seemed to predict that they could not determine how the universe would have begun. This was obviously very unsatisfactory. So there were a number of attempts to get round the conclusion, that there was a singularity of infinite density in the past.

Lesson 12

THE BEGINNING OF TIME II

Another attempt to avoid a beginning to time, was the suggestion, that maybe all the galaxies didn't meet up at a single point in the past. Although on average, the galaxies are moving apart from each other at a steady rate, they also have small additional velocities, relative to the uniform expansion. These so-called "peculiar velocities" of the galaxies, may be directed sideways to the main expansion. It was argued, that as you plotted the position of the galaxies back in time, the sideways peculiar velocities, would have meant that the galaxies wouldn't have all met up. Instead, there could have been a previous contracting phase of the universe, in which galaxies were moving towards each other. The sideways velocities could have meant that the galaxies didn't collide, but rushed past each other, and then started to move apart. There wouldn't have been any singularity of infinite density, or any breakdown of the laws of physics. Thus there would be no necessity for the universe, and time itself, to have a beginning. Indeed, one might suppose that the universe had oscillated, though that still wouldn't solve the problem with the Second Law of Thermodynamics: one would expect that the universe would become more disordered each oscillation. It is therefore difficult to see how the universe could have been oscillating for an infinite time.

This possibility, that the galaxies would have missed each other, was supported by a paper by two Russians. They claimed that there would be no singularities in a solution of the field equations of general relativity, which was fully general, in the sense that it didn't have any exact symmetry. However, their claim was proved wrong, by a number of theorems by Roger Penrose and myself. These showed that general relativity predicted singularities, whenever more than a certain amount of mass was present in a region. The first theorems were designed to show that time came to an end, inside a black hole, formed by the collapse of a star. However, the expansion of the universe, is like the time reverse of the collapse of a star. I therefore want to show you, that observational evidence indicates the universe contains sufficient matter, that it is like the time reverse of a black hole, and so contains a singularity.

In order to discuss observations in cosmology, it is helpful to draw a diagram of events in space and time, with time going upward, and the space directions horizontal. To show this diagram properly, I would really need a four dimensional screen.

As we look out at the universe, we are looking back in time, because light had to leave distant objects a long time ago, to reach us at the present time. This means that the events we observe lie on what is called our past light cone. The point of the cone is at our position, at the present time. As one goes back in time on the diagram, the light cone spreads out to greater distances, and its area increases. However, if there is sufficient matter on our past light cone, it will bend the rays of light towards each other. This will mean that, as one goes back into the past, the area of our past light cone will reach a maximum, and then start to decrease. It is this focussing of our past light cone, by the gravitational effect of the matter in the universe, that is the signal that the universe is within its horizon, like the time reverse of a black hole. If one can determine that there is enough matter in the universe, to focus our past light cone, one can then apply the singularity theorems, to show that time must have a beginning.

How can we tell from the observations, whether there is enough matter on our past light cone, to focus it? We observe a number of galaxies, but we can not measure directly how much matter they contain. Nor can we be sure that every line of sight from us will pass through a galaxy. So I will give a different argument, to show that the universe contains enough matter, to focus our past light cone. The argument is based on the spectrum of the microwave background radiation. This is characteristic of radiation that has been in thermal equilibrium, with matter at the same temperature. To achieve such an equilibrium, it is necessary for the radiation to be scattered by matter, many times. For example, the light that we receive from the Sun has a characteristically thermal spectrum. This is not because the nuclear reactions, which go on in the centre of the Sun, produce radiation with a thermal spectrum. Rather, it is because the radiation has been scattered, by the matter in the Sun, many times on its way from the centre.

Lesson 13

THE BEGINNING OF TIME III

Time must have a beginning, if the General Theory of relativity is correct. But one might raise the question, of whether General Relativity really is correct. It certainly agrees with all the observational tests that have been carried out. However these test General Relativity, only cover fairly large distances. We know that General Relativity cannot be quite correct on very small distances, because it is a classical theory. This means, it doesn't take into account, the Uncertainty Principle of Quantum Mechanics, which says that an object can not have both a well defined position, and a well defined speed: the more accurately one measures the position, the less accurately one can measure the speed, and vice versa. Therefore, to understand the very high-density stage, when the universe was very small, one needs a quantum theory of gravity, which will combine General Relativity with the Uncertainty Principle.

It seems that Quantum theory, on the other hand, can predict how the universe will begin. Quantum theory introduces a new idea, that of imaginary time. Imaginary time may sound like science fiction, but nevertheless, it is a genuine scientific concept. One can picture it in the following way. One can think of ordinary, real, time as a horizontal line. On the left, one has the past, and on the right, the future. But there's another kind of time in the vertical direction. This is called imaginary time, because it is not the kind of time we normally experience. But in a sense, it is just as real, as what we call real time.

The three directions in space, and the one direction of imaginary time, make up what is called a Euclidean space-time. I don't think anyone can picture a four dimensional curve space. But it is not too difficult to visualise a two dimensional surface, like a saddle, or the surface of a football.

If space and imaginary time are indeed like the surface of the Earth, there wouldn't be any singularities in the imaginary time direction, at which the laws of physics would break down. And there wouldn't be any boundaries, to the imaginary time space-time, just as there aren't any boundaries to the surface of the Earth. This absence of boundaries means that the laws of physics would determine the state of the universe uniquely, in imaginary time. But if one knows the state of the universe in imaginary time, one can calculate the state of the universe in real time. One would still expect some sort of Big Bang singularity in real time. So real time would still have a beginning. But one wouldn't have to appeal to something outside the universe, to determine how the universe began. Instead, the way the universe started out at the Big Bang would be determined by the state of the universe in imaginary time. Thus, the universe would be a completely self-contained system. It would not be determined by anything outside the physical universe, that we observe.

Originally, I thought that the collapse, would be the time reverse of the expansion. This would have meant that the arrow of time would have pointed the other way in the contracting phase. People would have gotten younger, as the universe got smaller. Eventually, they would have disappeared back into the womb.

However, I now realise I was wrong, as these solutions show. The collapse is not the time reverse of the expansion. The expansion will start with an inflationary phase, but the collapse will not in general end with an anti inflationary phase. Moreover, the small departures from uniform density will continue to grow in the contracting phase. The universe will get more and more lumpy and irregular, as it gets smaller, and disorder will increase. This means that the arrow of time will not reverse. People will continue to get older, even after the universe has begun to contract. So it is no good waiting until the universe re-collapses, to return to your youth. You would be a bit past it, anyway, by then.

The conclusion of this lecture is that the universe has not existed forever. Rather, the universe, and time itself, had a beginning in the Big Bang, about 15 billion years ago. The beginning of real time, would have been a singularity, at which the laws of physics would have broken down. Nevertheless, the way the universe began would have been determined by the laws of physics, if the universe satisfied the no boundary condition. This says that in the imaginary time direction, space-time is finite in extent, but doesn't have any boundary or edge. The predictions of the no boundary proposal seem to agree with observation. The no boundary hypothesis also predicts that the universe will eventually collapse again. However, the contracting phase, will not have the opposite arrow of time, to the expanding phase. So we will keep on getting older, and we won't return to our youth. Because time is not going to go backwards.

A BRIEF HISTORY OF STRING THEORY

Here is a very brief outline of the development of string theory, the details of which will eventually fill many large volumes written by many people directly and indirectly involved in this rich and fascinating story.

1921 Kaluza- Klein theory

Electromagnetism can be derived from gravity in a unified theory if there are four space dimensions instead of three, and the fourth is curled into a tiny circle. Kaluza and Klein made this discovery independently of each other.

1970 String theory is born

Three particle theorists independently realize that the dual theories developed in 1968 to describe the particle spectrum also describe the quantum mechanics of oscillating strings. This marks the official birth of string theory.

1971 Supersymmety

Supersymmetry is invented in two contexts at once: in ordinary particle field theory and as a consequence of introducing fermions into string theory. It holds the promise of resolving many problems in particle theory, but requires equal numbers of fermions and bosons, so it cannot be an exact symmetry of Nature.

1974 Gravitons

String theory using closed strings fails to describe hadronic physics because the spin 2 excitation has zero mass. Oops, that makes it an ideal candidate for the missing theory of quantum gravity!! This marks the advent of string theory as a proposed unified theory of all four observed forces in Nature.

1976 Supergravity

Supersymmetry is added to gravity, making supergravity. This progress is especially important to string theory, where gravity can't be separated from the spectrum of excitations.

1980 Superstrings

String theory plus supersymmetry yields an excitation spectrum that has equal numbers of fermions and bosons, showing that string theory can be made totally supersymmetric. The resulting objects are called superstrings.

1984 The Big Year

This was the year for string theory! Deadly anomalies that threatened to make the theory senseless were discovered to cancel each other when the underlying symmetries in the theory belong two special groups. Finally string theory is accepted by the mainstream physics community as an actual candidate theory uniting quantum mechanics, particle physics and gravity.

1991- 1995 The Duality Revolution

Interesting work on stringy black holes in higher dimensions leads to a revolution in understanding how different versions of string theory are related through duality transformations. This unlocks a surge of progress towards a deeper nonperturbative picture of string theory.

1996 Black Hole Entropy

Using Einstein relativity and Hawking radiation, there were hints in the past that black holes have thermodynamic properties that need to be understood microscopically. A microscopic origin for black hole thermodynamics is finally achieved in string theory. String theory sheds amazing light on the entire perplexing subject of black hole quantum mechanics.

HOW OLD IS THE UNIVERSE?

The age of the Universe has been a subject of religious, mythological and scientific importance. On the scientific side, Sir Isaac Newton's guess for the age of the Universe was only a few thousand years. Einstein, the developer of the General Theory of Relativity, preferred to believe that the Universe was ageless and eternal. However, in 1929, observational evidence proved his fantasy was not to be fulfilled by Nature.

In order to understand this evidence, let's think about how a train sounds to a person standing on the platform. An arriving train makes a noise that starts low and gets higher pitched as the train approaches the listener, sounding like ooooooohEEEEEEEE. A departing train makes a noise that gets lower pitched as the train goes away from the listener, sounding like EEEEEEEEoooooooh. This change in the sound of the pitch of the train noise depending on whether it is arriving or departing the listener is called the Doppler shift.

The Doppler shift happens with light as well as with sound. A source of light that is approaching the viewer will seem to the viewer to have a higher frequency than a source of light that is receding from that viewer. In 1929, observations of distant galaxies showed that the light from those galaxies behaved as if they were going away from us. If all the distant galaxies are all receding from us on the average, that means that the Universe as a whole could be expanding. It could be blowing up like a balloon.

If the Universe is expanding, then what did it expand from?

This is what tells us that the Universe probably does have a finite age, it probably is not eternal and ageless as Einstein wanted to believe.

But then, okay, how old is the Universe?

We know from studies of radioactivity of the Earth and Sun that our solar system probably formed about 4.5 billions years ago, which means that the Universe must be at least twice that old, because before our solar system formed, our Milky Way galaxy had to form, and that probably took several billions years by itself.

It would be reasonable to guess that the Universe is at least twice as old as our Sun and Earth. However, we can't do radioactive dating on distant stars and galaxies. The best we can do is balance a lot of different measurements of the brightness and distance of stars and the red shifting of their light to come up with some ballpark figure. The oldest star clusters whose age we can estimate are about 12 to 15 billions years old.

So it seems safe to estimate that the age of the Universe is at least 15 billion years old, but probably not more than 20 billion years old.

This matter is far from being settled by astrophysicists and cosmologists, so stay tuned. There could be radical new developments in the future.

GRAVITATIONAL COLLAPSE

Try to jump so high that you fly right off of the Earth into outer space. What happens? Why don't you get very far? The gravitational force pulls you back down again very quickly. You could jump much higher on Mars, still higher on the moon, because they're both less massive than the Earth. The strength of gravity at the surface of the moon is only 1/6 the strength of gravity at the surface of the Earth.

You are essentially trapped on Earth, unless you can find a rocket that can travel at escape velocity away from the Earth. This is how our space program works. If you shoot something fast enough, it can escape gravity and make it to outer space.

But hold the phone -- there's supposedly a maximum speed in the Universe, the speed of light. What happens if the escape velocity of a planet were greater than the speed of light? In other words, what if gravity were strong enough to trap light itself?

Then you'd have yourself a black hole. A black hole is a gravitating object whose gravitational field is so strong that light cannot escape. The event horizon is where light loses the ability to escape from the black hole. Nothing that goes inside the event horizon can ever get back out again, not even light.

Black holes can be created by the gravitational collapse of large stars that are at least twice as massive as our Sun. Normally, stars balance the gravitational force with the pressure from the nuclear fusion reactions inside. When a star gets old and burns up all of its hydrogen into helium and then turns the helium into heavier elements like iron and nickel, it can have three fates. The first two fates occur for stars less than about twice the mass of our Sun (and one of them will be our Sun's eventual fate). These two fates both depend on the fermionic repulsion pressure described by quantum mechanics -- two fermions cannot be in the same quantum state at the same time. This means that the two stable destinies for a collapsing star will be:

1. a white dwarf supported by the fermionic repulsion pressure of the electrons in the heavy atoms in the core

2. a neutron star supported by the fermionic repulsion pressure of the neutrons in the nuclei of the heavy atoms in the core

If the mass of the collapsing star is too large, bigger than twice the mass of our Sun, the fermionic repulsion pressure of either the electrons or the neutrons is not strong enough to prevent the ultimate gravitational collapse into a black hole.

The estimated age of the Universe is several times the lifespan of an average star. This means there must have been a lot of stars bigger than twice the mass of our Sun that have burned their hydrogen and collapsed since the Universe began. Our Universe ought to contain many black holes, if the model that astrophysicists use to describe their formation is correct. Black holes created by the collapse of individual stars should only be about 2 to 100 times as massive as our Sun.

Another way that black holes can be created is the gravitational collapse of the center of a large cluster of stars. These types of black holes can be very much more massive than our Sun. There may be one of them in the center of every galaxy, including our galaxy, the Milky Way. The black hole shown above sits in the middle of the galaxy called NGC 7052, surrounded by a bright cloud of dust 3,700 light-years in diameter. The mass of this black hole is 300 million times the mass of our Sun.

Lesson 17

LOOKING FOR EXTRA DIMENSIONS

What is a dimension?

When we say that the space we live in has three dimensions, what does that mean?

When we describe the size of an object, or of a space like a room, we use three numbers: the height, the width and the depth. The height, width and depth of a room are numbers that can vary independently from one another. That's one way to see that space is three dimensional. Another way is that we need three numbers to exactly locate ourselves on the Earth: longitude, latitude and elevation above sea level. That's another argument for space being three-dimensional. That's what we see.

When mathematicians or physicists talk about dimensions, they mean the number of independent coordinates needed to specify any point in a given space. The tradition is to label these three coordinates (x,y,z), with z usually denoting the up direction or the direction of height.

One of the big discoveries of early classical physics was the similarity between the forces of gravity and electrostatics. The gravitational force between two planets and the electrostatic force between two electric charges were both observed to vary as the inverse square of the distance between the two objects. So if r is your distance from the center of a planet, then the gravitational force of that planet on you will vary like r-2. If you go twice as far away, the force will only be one fourth as strong.

But the number of coordinates in a mathematical equation is easy to increase on paper. When the gravitational and electrostatic equations are solved in a space with D dimensions, then the force varies with distance like r1-D. (Notice this gives the right answer when D=3.)

This gives physicists an interesting way to do fine measurements of the numbers of dimensions of space. They can look at the gravitational force and put quantitative limits on any funny behavior that would come from possible extra dimensions.

If three space dimensions is consistent with current gravitational physics and interior decorating, then why look more closely at the force law? Because there are ways that extra dimensions of space can become undetectable or at least very difficult to detect by our world, so we can eat our cake and hide it, too, so to speak.

Why is time a dimension?According to Isaac Newton, time was universal for all objects no matter their motion relative to one another. This point of view held until Einstein turned it on its head, because he was bothered that it wasn't consistent with the propagation of light as electromagnetic radiation.

Einstein's special theory of relativity, which makes classical mechanics consistent with classical electromagnetism, treats time like a coordinate in a unified spacetime geometry. If time is a coordinate, then instead of three coordinates to describe a point in space, we have four coordinates to describe an event in spacetime. So that's what is meant by saying that our spacetime has four dimensions. Usually we label them (t,x,y,z).

Special relativity is an approximate theory that is a good approximation when we can neglect the force of gravity and the acceleration of observers in the system. Einstein's full theory of spacetime, called general relativity, takes the concept of a four dimensional spacetime and extends it to a curved spacetime, where time and space make one united fabric that is curved and stretched and twisted by the distribution of matter and energy in the fabric.

From a mathematical point of view, both special and general relativity can be extended easily to higher space dimensions. If we have D dimensions of space and one time, then we say there are $d = D + 1$ dimensions of spacetime. The equations of motion can be solved and classified in d dimensions just like in four spacetime dimensions.

Why have more dimensions?

It's not so hard to construct higher dimensional worlds using the Einstein equations. But the question is then: WHY BOTHER?

It's because physicists dream of a unified theory: a single mathematical framework in which all fundamental forces and units of matter can be described together in a manner that is internally consistent and consistent with current and future observation.

And it turns out that having extra dimensions of space makes it possible to build candidates for such a theory.

Extra dimensions in string theory

Superstring theory is a possible unified theory of all fundamental forces, but superstring theory requires a 10 dimensional spacetime, or else bad quantum states called ghosts with unphysical negative probabilities become part of the spectrum.

Now this creates a problem in d=10 string theory: how to get the d=4 world as we know it out of the theory.

So far there are two main proposals:

1. Roll up the extra dimensions into some very tiny but nonetheless interesting space of their own. This is called Kaluza Klein compactification.

2. Make the extra dimensions really big, but constrain all the matter and gravity to propagate in a three dimensional subspace called the three brane. (For an analogy, your computer screen could be said to be a two brane of three dimensional space.) These types of theories are called braneworlds.

APPENDIX

BASIC PHYSICS EQUATIONS AND FORMULAS

TABLE OF INFORMATION FOR 2002

CONSTANTS AND CONVERSION FACTORS

1 unified atomic mass unit,	$1\ u = 1.66 \times 10^{-27}$ kg
	$= 931\ MeV/c^2$
Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg
Magnitude of the electron charge,	$e = 1.60 \times 10^{-19}$ C
Avogadro's number,	$N_0 = 6.02 \times 10^{23}\ mol^{-1}$
Universal gas constant,	$R = 8.31\ J/(mol \cdot K)$
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K
Speed of light,	$c = 3.00 \times 10^8$ m/s
Planck's constant,	$h = 6.63 \times 10^{-34}\ J \cdot s$
	$= 4.14 \times 10^{-15}\ eV \cdot s$
	$hc = 1.99 \times 10^{-25}\ J \cdot m$
	$= 1.24 \times 10^3\ eV \cdot nm$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12}\ C^2/N \cdot m^2$
Coulomb's law constant,	$k = 1/4\pi\epsilon_0 = 9.0 \times 10^9\ N \cdot m^2/C^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}\ (T \cdot m)/A$
Magnetic constant,	$k' = \mu_0/4\pi = 10^{-7}\ (T \cdot m)/A$
Universal gravitational constant,	$G = 6.67 \times 10^{-11}\ m^3/kg \cdot s^2$
Acceleration due to gravity at the Earth's surface,	$g = 9.8\ m/s^2$
1 atmosphere pressure,	$1\ atm = 1.0 \times 10^5\ N/m^2$
	$= 1.0 \times 10^5$ Pa
1 electron volt,	$1\ eV = 1.60 \times 10^{-19}$ J

UNITS

Name	Symbol
meter	m
kilogram	kg
second	s
ampere	A
kelvin	K
mole	mol
hertz	Hz
newton	N
pascal	Pa
joule	J
watt	W
coulomb	C
volt	V
ohm	Ω
henry	H
farad	F
tesla	T
degree Celsius	°C
electron-volt	eV

PREFIXES

Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES

θ	sin θ	cos θ	tan θ
0°	0	1	0
30°	1/2	$\sqrt{3}/2$	$\sqrt{3}/3$
37°	3/5	4/5	3/4
45°	$\sqrt{2}/2$	$\sqrt{2}/2$	1
53°	4/5	3/5	4/3
60°	$\sqrt{3}/2$	1/2	$\sqrt{3}$
90°	1	0	∞

TABLE OF ENGLISH TENSES

tense	Affirmative/Negative/Question	Use	Signal Words
Simple Present	**A:** He speaks. **N:** He does not speak. **Q:** Does he speak?	action in the present taking place **once, never or several times** facts actions taking place one after another action set by a timetable or schedule	always, every …, never, normally, often, seldom, sometimes, usually if sentences type I (*If I **talk**, …*)
Present Progressive	**A:** He is speaking. **N:** He is not speaking. **Q:** Is he speaking?	**action taking place in the moment of speaking** action taking place only for a limited period of time action arranged for the future	at the moment, just, just now, Listen!, Look!, now, right now
Simple Past	**A:** He spoke. **N:** He did not speak. **Q:** Did he speak?	action in the past taking place **once, never or several times** actions taking place one after another action taking place in the middle of another action	yesterday, 2 minutes ago, in 1990, the other day, last Friday if sentence type II (*If I **talked**, …*)
Past Progressive	**A:** He was speaking. **N:** He was not speaking. **Q:** Was he speaking?	action **going on** at a certain time in the past actions taking place at the same time action in the past that is interrupted by another action	when, while, as long as
Present Perfect Simple	**A:** He has spoken. **N:** He has not spoken. **Q:** Has he spoken?	putting emphasis on the **result** action that is still going on action that stopped recently finished action that has an influence on the present action that has taken place once, never or several times before the moment of speaking	already, ever, just, never, not yet, so far, till now, up to now
Present Perfect Progressive	**A:** He has been speaking. **N:** He has not been speaking. **Q:** Has he been speaking?	putting emphasis on the **course or duration** (not the result) action that recently stopped or is still going on finished action that influenced the present	all day, for 4 years, since 1993, how long?, the whole week
Past Perfect Simple	**A:** He had spoken. **N:** He had not spoken. **Q:** Had he spoken?	action taking place before a certain time in the past sometimes interchangeable with	already, just, never, not yet, once, until that day

		past perfect progressive putting emphasis only on the **fact** (not the duration)	if sentence type III (*If I **had talked**, …*)
Past Perfect Progressive	**A:** He had been speaking. **N:** He had not been speaking. **Q:** Had he been speaking?	action taking place before a certain time in the past sometimes interchangeable with past perfect simple putting emphasis on the **duration or course** of an action	for, since, the whole day, all day
Future I Simple	**A:** He will speak. **N:** He will not speak. **Q:** Will he speak?	action in the future that cannot be influenced **spontaneous** decision assumption with regard to the future	in a year, next …, tomorrow If-Satz Typ I (*If you ask her, she **will help** you.*) *assumption*: I think, probably, we might …, perhaps
Future I Simple (going to)	**A:** He is going to speak. **N:** He is not going to speak. **Q:** Is he going to speak?	**decision** made for the future conclusion with regard to the future	in one year, next week, tomorrow
Future I Progressive	**A:** He will be speaking. **N:** He will not be speaking. **Q:** Will he be speaking?	action that is **going on** at a certain time in the future action that is sure to happen in the near future	in one year, next week, tomorrow
Future II Simple	**A:** He will have spoken. **N:** He will not have spoken. **Q:** Will he have spoken?	action that will be **finished** at a certain time in the future	by Monday, in a week
Future II Progressive	**A:** He will have been speaking. **N:** He will not have been speaking. **Q:** Will he have been speaking?	action taking place before a certain time in the future putting emphasis on the **course** of an action	for …, the last couple of hours, all day long
Conditional I Simple	**A:** He would speak. **N:** He would not speak. **Q:** Would he speak?	action that **might** take place	if sentences type II (*If I were you, I **would go** home.*)
Conditional I Progressive	**A:** He would be speaking. **N:** He would not be speaking. **Q:** Would he be speaking?	action that might take place putting emphasis on the **course** / **duration** of the action	
Conditional II Simple	**A:** He would have spoken. **N:** He would not have spoken. **Q:** Would he have spoken?	action that **might** have taken place in the past	if sentences type III (*If I had seen that, I **would have helped**.*)
Conditional II Progressive	**A:** He would have been speaking. **N:** He would not have been speaking. **Q:** Would he have been speaking?	action that might have taken place in the past puts emphasis on the **course** / **duration** of the action	

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