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Физический факультет
Кафедра английского языка

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Effective reading, speaking, writing

for senior science students

Учебное пособие
для учащихся магистратуры физического факультета

Москва
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Учебное пособие предназначено для учащихся магистратуры по направлению подготовки «Физика», продолжающих изучение английского языка на уровне B1–B2, и имеет целью дальнейшее развитие языковых и речевых компетенций в профессиональной сфере общения.

Основу пособия составляют аутентичные тексты, содержащие познавательную информацию о научных открытиях и изобретениях учёных, удостоенных Нобелевской премии по физике в 2000– 2014 годах.

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Contents

Предисловие

Настоящее учебное пособие предназначено для учащихся магистратуры физического факультета, чей уровень владения английским языком не ниже B-1, и основано на текстах, отражающих содержание научных открытий, удостоенных *Нобелевских премий по физике с 2000 по 2014 гг.* Целью пособия является развитие навыков чтения, устной и письменной речи на английском языке.

Материал включает в себя отрывки из автобиографий и интервью Нобелевских лауреатов, пресс-релизы, специализированные и общие тексты, разъясняющие достижения выдающихся ученых-физиков.

Благодаря использованию интервью ученых и текстов их выступлений на нобелевских банкетах (рубрика *Banquet Speech*), в пособии учитывается такой важный аспект работы с языковым материалом, как *аудирование*: учащимся предлагается прослушивать данные тексты, воспользовавшись ссылками на аудио- и видеозаписи, предоставленные на сайте Нобелевского комитета (*nobelprize.org*).

Пособие помогает учащимся закрепить навыки просмотрового, ознакомительного и изучающего *чтения*. Предлагаются разнообразные упражнения на извлечение информации из текстов различных жанров, построение плана текстов и отражение их содержания в форме конспекта. Понимание прочитанного материала проверяется на основе упражнений в форме вопросов, перевода, заполнения пробелов в контекстах. Также представлены задания, целью которых является устная передача основного содержания текста и подробный устный пересказ на изучаемом языке.

В спектр упражнений, входящих в пособие, включены задания, нацеленные на усвоение *терминологической и общенаучной лексики*, вырабатывание навыков активного использования лексических единиц и грамматических конструкций в собственной речи (как устной, так и письменной).

В пособии представлены упражнения на *перевод* терминов, словосочетаний, содержащих общенаучную лексику, и отрывков из текстов специализированного и более общего содержания (как с русского языка на английский, так и наоборот).

В ряде заданий предлагается устный перевод с листа (рубрика *Speed Read*); внимание также уделяется письменному переводу со словарем.

Настоящее пособие позволяет учащимся магистратуры развить и закрепить базовые знания *лексико-грамматического материала*, усвоенные на предыдущих этапах обучения по дисциплине «Иностранный язык», а также почерпнуть важную информацию, касающуюся основных достижений мирового уровня в области физики второй половины 20-го и начала 21-го века.

Unit 1

Physics and Information Technology. Heterostructures in Electronic Devices

The Nobel Prize in Physics 2000 — Popular Information

October 10, 2000

The Royal Swedish Academy of Sciences has awarded the Nobel Prize in Physics for 2000 *"for basic work on information and communication technology"*.

The prize is being awarded with one half jointly to **Zhores I. Alferov**, A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, and **Herbert Kroemer**, University of California at Santa Barbara, California, USA, *"for developing semiconductor heterostructures used in high-speed- and opto-electronics"* and one half to **Jack S. Kilby**, Texas Instruments, Dallas, Texas, USA, *"for his part in the invention of the integrated circuit"*.

Physics and Information Technology

Information technology, IT, which comprises electronic computer technology and telecommunications technology, has in a few decades changed our society radically. Behind this development lies a very advanced scientific and technical development originating largely from fundamental scientific inventions in physics.

The rapid development of *electronic computer technology* really started with the invention of the integrated circuit around 1960 and the microprocessor in the 1970s, when the number of components on a chip became sufficiently large to allow the creation of a complete microcomputer. The rapid increase in the number of components was formulated as a prediction in "Moore's law": the number of components on a chip will double every eighteen months. This has happened since the 1960s and today there are chips with millions of separate components, at prices that are largely unchanged.

Chip development has been matched by equally dynamic and powerful developments in *telecommunications technology.* Just as the integrated circuit has been and is a prime mover for electronic computer technology, ultra-rapid transistors and semiconductor lasers based on heterostructures of semiconductors are playing a decisive part in modern telecommunications.

Heterostructures in mobile telephones, CD-players, bar-code readers, brake-lights etc

Electronic components are commonly made of semiconductors, i.e. material that is something between a conductor and an insulator. A measure of whether a semiconductor most resembles a conductor or an insulator is given in the *band gap* — the amount of energy needed to produce moving charge-bearers in the form of electrons and "holes".

Most semiconductor components are made of silicon, but composite semiconductors of type gallium arsenide are growing in importance. A semiconductor, consisting of several thin layers with differing band gaps is termed a *heterostructured semiconductor.* The layers can have a thickness varying from a few atom layers to micrometres and may consist of gallium arsenide (GaAs) and aluminium gallium arsenide (AlGaAs). The layers are generally selected so that their crystal structures fit one another and the charge-bearers can move almost freely at the interface. It is this property of heterostructures that can be exploited in a number of different ways.

Heterostructures are very important in *technology.* Low-noise high-frequency amplifiers using heterotransistors are used in satellite communications and for improving the signal-to-noise ratio in mobile telephony. Semiconductor lasers based on heterostructures are used in fibre-optical communication, in optical data storage, as reading heads in CD players, as bar-code readers and laser markers, etc. Heterostructure-based light-emitting diodes are used in car brake-lights and other warning signals and may one day replace electric bulbs.

Heterostructures have also been of great importance for *scientific research.* Properties of what is called a two-dimensional electron gas formed in the interface layer between semiconductors was the starting point for the study of the quantised Hall effects (Nobel Prize in Physics 1985 to Klaus von Klitzing and 1998 to Robert B. Laughlin, Horst L. Störmer and Daniel C.Tsui). Quantised conductance has also been studied in one-dimensional channels and point contacts, artificial atoms and

molecules based on "quantum dots" with a limited number of free conduction electrons enclosed in very small spaces, one-electron components, etc.

The Heterotransistor

The first worked-out proposal for a heterostructure transistor was published in 1957 by **Herbert Kroemer**, then working at RCA (Radio Corporation of America) in Princeton, USA. His theoretical work showed that a heterotransistor can be superior to a conventional transistor, particularly for current amplification and high-frequency applications. A frequency as high as 600 GHz has been measured in a heterotransistor, i.e. about 100 times higher than the best ordinary transistors. In addition, the noise is low in amplifiers based on these components.

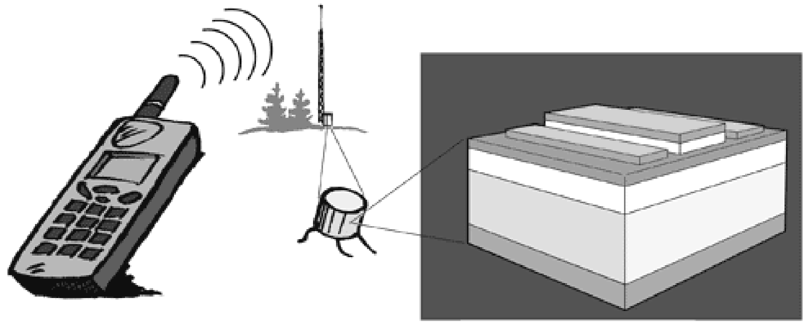


Fig. 1. In the fast transistors of the base stations of cell phones there are semiconductor heterostructures.

The heterostructure laser

Heterostructures have been crucially important for the development of semiconductor lasers. **Zhores I. Alferov** of the Ioffe Institute of the Russian Academy of Sciences in what was then Leningrad and **Herbert Kroemer** then at Varian in Palo Alto proposed in 1963, independently of each other, the principle for the heterostructure laser, an invention that is probably as significant as that of the heterotransistor.

Alferov was the first to succeed in producing a lattice-adapted heterostructure (AlGaAs/GaAs, 1969) with clear borders between the layers. Alferov's research team succeeded in rapidly developing many types of components built up of heterostructures, including the injection laser which Alferov patented in 1963. A technological breakthrough occurred around 1970 when heterostructure lasers became able to work continuously at room temperatures. These properties have, for example, made fibre-optic communications practically possible.

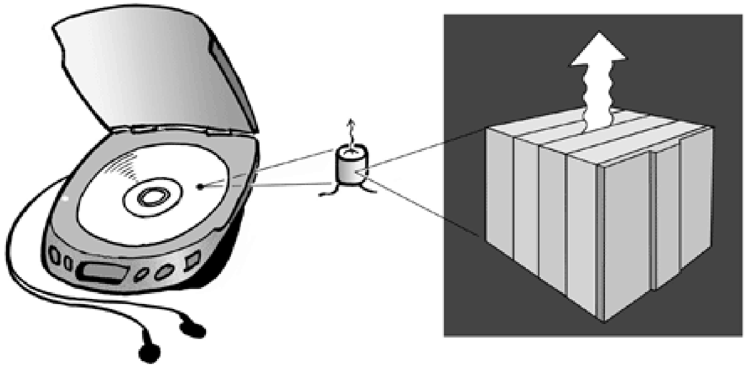


Fig.2. The laser diode of the CD player contains a semiconductor heterostructure.

The integrated circuit — the chip

The invention of the transistor just before Christmas 1947 is usually taken to mark the start of the development of modern semiconductor technology (Nobel Prize in Physics 1956 to William B. Shockley, John Bardeen and Walter H. Brattain). With the transistor there came a component that was considerably smaller, more reliable and less energy-consuming than the radio valve, which thus lost its importance. The increasing complexity of a system using more and more radio valves meant that a practical limit had been reached with around a thousand valves. By soldering individual transistors together on a printed-circuit board the system could be increased to over ten thousand transistors.

Even though the transistor permitted an increase in the complexity of a system of individual components soldered together it soon became clear that the number of transistors was the limiting factor in meeting the needs of the emerging computer industry. As early as the beginning of the 1950s there were ideas and thoughts about manufacturing transistors, resistors and condensers in a composite semiconductor block, an integrated circuit.

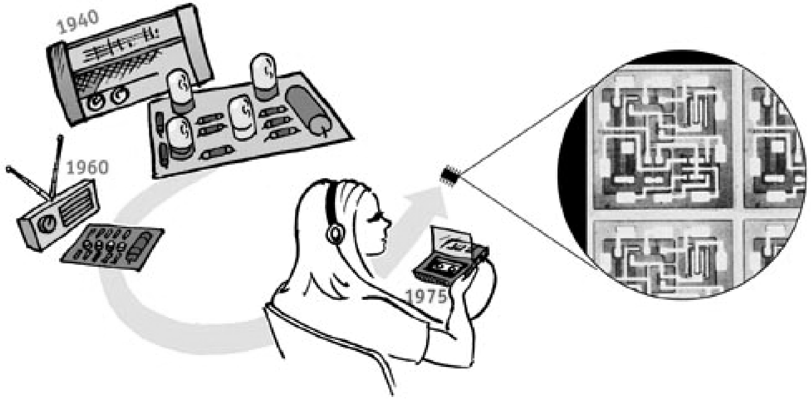


Fig 3. Development has gone from radio valves via transistors to integrated circuits, chips, now in all modern electronics.

The people who were to demonstrate the practical possibility of an integrated circuit were two young engineers, **Jack S. Kilby** and **Robert Noyce**, working independently of each other. Kilby, however, was first with his patent application and Noyce knew of this work when he filed his own application.

The integrated circuit is more of a technical invention than a discovery in physics. However it is evident that it embraces many physical issues. One example is the question of how aluminium and gold, which are part of an integrated circuit, differ regarding their adhesion to silicon. Another question is how to produce dense layers that are only a few atoms thick.

It is thus obvious that the development of the integrated circuit prompted enormous investment in research and development in solid-state physics. This has not only led to development in semiconductor technology but also to gigantic development of apparatus and instruments. Continual miniaturisation, moreover, has come up against a number of material-physical limitations and problems that have had to be solved.

The notion of an integrated circuit was there. But ten years were to pass from the invention of the transistor before the technology involved had matured sufficiently to allow the various elements to be fabricated in one and the same basic material and in one piece. The invention is one in a series of many that have made possible the great development of information technology. The integrated circuit is still, after 40 years, in a dynamic phase of development with no sign of flagging.

Jack S. Kilby and Robert Noyce are both considered as the inventors of the integrated circuit. Kilby was the one who built the first circuit. Noyce developed the circuit as it was later to be manufactured in practice with silicon and silicon dioxide as semiconductor and insulator and with aluminium as the electrically conductive element. Both have on a number of occasions received prizes and distinctions.

Robert Noyce died in 1990. He was then honoured as one of the most important founders of Silicon Valley and for the leading role his company had played in the development of information technology, with the integrated circuit as a cornerstone.

Jack S. Kilby has continued his career as an inventor, with some 60 patents. Among other things, he is co-inventor of the pocket calculator, one of the first applications of the integrated circuit. A market survey run before the start of planning for its manufacture showed that interest in a pocket calculator was negligible. After all, people had slide-rules!

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2000/public.html)

EXERCISES

1) Find terms in the text that have the following Russian equivalents.

интегральная схема, полупроводниковый лазер, ширина запрещенной зоны, высокочастотный малошумящий усилитель, коэффициент помех, электронная лампа, хранение оптических данных, светодиод, двумерный электронный газ, эффект квантования холловского сопротивления, квантовая проводимость, одномерный канал, точечно-контактный выпрямитель, квантовая точка, полупроводниковая гетероструктура, печатная плата, составной полупроводник, устройство считывания штрих-кода

2) The text contains many sentences connected with various technological discoveries and their importance. Fill in the gaps.

a) The rapid development of ____ really started with the invention of the ___around 1960 and the ___ in the 1970s.

b) ___ have been crucially important for the development of ___.

c) The invention of the ___ just before Christmas 1947 is usually taken to mark the start of the development of modern semiconductor technology.

d) The ___ is more of a technical invention than a discovery in physics.

e) The___ is still, after 40 years, in a dynamic phase of development with no sign of flagging.

f) Robert Noyce's company had played the leading role in the development of information technology, with the ___ as a cornerstone.

3) Answer the questions.

a) What does information technology comprise?

b) How did the rapid development of electronic computer technology begin?

c) What is "Moore's law"?

d) What inventions play a decisive part in modern telecommunications technology?

e) What is the band gap?

f) What is a heterostructured semiconductor? What specific property of a heterostructured semiconductor is exploited in a variety of devices? Enumerate these devices.

g) How have heterostructures been used in scientific research?

h) In what way is a heterotransistor superior to a conventional one?

i) What did Zhores I. Alferov succeed in producing? What did his discoveries and inventions lead to?

j) How did the transistor revolutionize the 20th century technology?

k) Who demonstrated the practical possibility of an integrated circuit?

l) Why did the development of the integrated circuit prompt enormous investment in research and development in solid state physics?

m) Which simple yet revolutionary technological gadget, among Jack S. Kilby's other inventions, received great success?

4) Translate the sentences into Russian.

a) It is this property of heterostructures that can be exploited in a number of different ways.

b) Alferov was the first to succeed in producing a lattice-adapted heterostructure with clear borders between the layers.

c) The invention of the transistor just before Christmas 1947 is usually taken to mark the start of the development of modern semiconductor technology.

d) As early as the beginning of the 1950s there were ideas and thoughts about manufacturing transistors, resistors and condensers in a composite semiconductor block, an integrated circuit.

e) Ten years were to pass from the invention of the transistor before the technology involved had matured sufficiently to allow the various elements to be fabricated in one and the same basic material and in one piece.

Zhores I. Alferov

Born: 15 March, 1930
Affiliation at the time of the award:
A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia

Field: Condensed matter physics, instrumentation

Read an excerpt from Zh.I. Alferov's autobiography and speak about the most important facts of his scientific career.

Autobiography

I remember my first attendance of the seminar on semiconductors at the Physico-Technical Institute in February 1953 as one of the most impressive events I have ever experienced. That was a brilliant report delivered by E.F. Gross about the discovery of the exciton. The sensation I experienced then could not be compared with anything else. I was stunned by the talk on the birth of a discovery in the area of science to which I myself had got an access.

Yet the main thing was everyday experimental work in the laboratory. Since that time I have been keeping, as a most precious thing, my laboratory daily report book that contains notes of mine about the creation of the first soviet p-n junction transistor on the 5th of March, 1953. And now, when recalling that time I cannot help feeling proud of what we had accomplished. We comprised a team of very young people. Under the guidance of V.M. Tuchkevich we succeeded in working out the principles of technology and metrics of transistor electronics. Below are the names of researchers who had been working in our small laboratory: A.A. Lebedev, a Leningrad University graduate — the growth and doping of perfect germanium single crystals; Zh.I. Alferov — the preparation of transistors, their parameters being at the level of the best world samples; A.I. Uvarov and S.M. Ruvkin - the creation of precise metrics of germanium single crystals and transistors; N.S. Yakovchuk, a graduate of the Faculty of Radio Engineering of Leningrad Electrical Technical Institute — designing transistor-based circuits.

As early as May 1953, the first Soviet transistor receivers were shown to the "top authorities". That work, the performers of which had been working with passion peculiar to their young hearts and with utmost sense of responsibility, exerted a great influence upon me. While quickly and effectively progressing as a scientist, I began to comprehend the significance of the technology not only for electronic devices, but for basic research work too, in regard to notorious "minor" details and sporadic results. And it is since then that I prefer to analyze experimental results proceeding from "simple" general laws prior to putting forward sophisticated explanations.

In subsequent years, our team of researchers at the Physico-Technical institute expanded considerably and in a very short time the first Soviet germanium power rectifiers were created alongside with germanium photodiodes and silicon rectifiers.

In May 1958, Anatolii Petrovic Alexandrov (later the President of the Academy of Sciences of the USSR) asked our team to work out a special semiconductor device for the first Soviet atomic submarine. That required a perfectly new technology and, in addition, another construction of germanium rectifiers, which had been made in a record short space of time. In the month of October, these devices were mounted on a submarine. I was a junior research associate at the Institute then, and was somewhat surprised by a telephone call from the first Vice-Chairman of the Government of the USSR, Dmitrii Fedorovich Ustinov, who asked me of a fortnight reduction of the term. There was no getting away from that: I directly moved to the laboratory premises and settled there but, of course, the request was fulfilled. Later I was decorated with my first State Order which I valued very much.

In 1961, I defended my candidate thesis that was mainly devoted to working out and investigating power germanium and partially silicon rectifiers. Soviet power semiconductor electronics became possible as a result of those works. Of great importance there, in the sense of a scientific, purely physical standpoint, was a conclusion drawn by me that in p-i-n, p-n-n semiconductor homostructures under working current densities (for most of semiconductor devices) the current was determined by recombination in heavily doped p- and n (n^+)-regions while the recombination contribution in the middle i(n)-region of a homostructure was not the determining one: so as soon as the first work on semiconductor lasers appeared, it was natural for me to consider the advantages of employing the double heterostructure of p-i-n (p-n-n^+, n-n-p^+) type in lasers. The idea was formulated by us shortly after the appearance of the first work of R. Hall with co-workers, which described a semiconductor laser based on a GaAs homo-p-n-structure.

To realize the principal advantages of heterostructures appeared to be possible only after obtaining $Al_xGa_{1-x}As$ heterostructures. We did that and it turned out that we had been only one month ahead of American researchers from IBM.

When we began investigating heterostructures, I used to convince my young colleagues, that we were not the only group of scientists in the world who understood the significance of the concept that semiconductor physics and electronics would be developing on the basis of HETERO-, rather than HOMO-structures. Indeed, in 1968 we entered an era of a strong competition with other laboratories in the world, the biggest being American companies: Bell Telephone, IBM and RCA.

In 1967, while on a short trip to the UK, I visited STL laboratories in Harlow. They were well equipped and the experimental base was excellent but English colleagues only discussed theoretical aspects of the heterostructures physics; they did not find experimental study of heterostructures to be promising then.

In 1968–1969, we virtually realized all the ideas of controlling the electron and light fluxes in classical heterostructures based on the arsenide gallium-arsenide aluminum system. Apart from fundamental results that were quite new and important such as efficient one-side injection, the "superinjection" effect, diagonal tunneling, electron and optical confinement in a double heterostructure (which in a short while became the main element in studying the low-dimensional electron gas in semiconductors), we succeeded in employing principal benefits of heterostructure applications in devices, i.e., lasers, LEDs, solar cells, dynistors and transistors. Of utmost importance was, beyond doubts, the making of low threshold room temperature operating lasers on a double heterostructure (DHS) that had been suggested by us as far back as 1963. The approach developed by M.B. Panish and I. Hayashi (Bell Telephone) as well as by H. Kressel (RCA) was different from that of ours since they offered to use a single p-AlGaAs-p-GaAs heterostructure in lasers, which made their approach rather limited. A possibility of obtaining an efficient injection in the heterojunction seemed doubtful to them in spite of the fact that potential advantages of DHS had been recognized.

In August 1969, I visited the USA for the first time; the paper that I read there at the International Conference on Luminescence in Newark (State of Delaware) was devoted to AlGaAs-based DHS low threshold room temperature lasers and produced an impression of an exploded bomb on American colleagues. Professor Ya. Pankov from RCA, who just shortly before my reading the paper had explained to me that they had not got a permission for me to visit their laboratory, the moment my speech was over told me that the permission had been received. I could not help enjoying my refusal explaining that I had already been invited by that moment to attend IBM and Bell Telephone Laboratories.

My seminar at Bell followed by a visit to the laboratories and discussions with researchers clearly revealed to me merits and demerits of our progress in my laboratory. I believe that worldwide recognition for being the first in getting the continuous wave operation of laser at room temperature was at that time a rare example of an open and friendly competition between laboratories belonging to the antagonistic Great Powers. We won the competition overtaking by a month Panish's group at Bell Telephone. The significance of obtaining the continuous wave regime had a connection first and foremost with working out an optical fiber with low losses as well as the creation of our DHS lasers, which resulted in appearance and rapid development of optical fiber communication.

In winter 1970–1971 and spring 1971, I spent six months in the USA working in the laboratory of semiconductor devices at the University of Illinois together with Prof. Nick Holonyak. We first met in 1967, when he visited my laboratory at the Physico-Technical Institute. Prof. Nick Holonyak, who is one of the founders of semiconductor optoelectronics, the inventor of the first visible semiconductor laser and LED, became my closest friend. Now for over 33 years we have been discussing all semiconductor physics and electronics problems, political and life aspects and our interaction (visits, letters, seminars, telephone conversations) has played a very important role in our work and life.

In 1971, I became a recipient of the USA Franklin's Institute gold medal for DHS laser works. Being my first international award, it was of particular value for me. There are Soviet physicists besides me who were given the Franklin's Institute gold medals too: Academician P.L. Kapitsa in 1944; Academician N.N. Bogolubov in 1974; Academician A.D. Sakharov in 1981. I consider it a big honour to belong to such a company!

An $Al_xGa_{1-x}As$ system of lattice-matched heterostructures, which in practice seemed to be a lucky exception, was infinitely expanded on the basis of multi-component solid solutions, first theoretically and later on experimentally (InGaAsP is the most convincing example).

Heterostructure-based solar cells were created by us as far back as 1970. And when American scientists published their early works, our solar batteries had already been mounted on the satellites (sputniks) and their industrial production was in full swing. The cells, when being employed in space, proved their efficiency. For many years they had been operating in the "MIR" skylab and in spite of the fact that forecasts of a substantial decrease of the value of one watt of the electrical power have not been justified so far, the most effective energy source in space is, nevertheless, a set of solar cells on heterostructures of III-V compounds.

In 1972, my colleagues and I were awarded the Lenin Prize — the highest scientific Prize in the USSR.

Studies of superlattices and quantum wells were rapidly promoted in the West and afterwards in this country soon resulted in coming into being of a new area of quantum physics of the solid: the physics of low-dimensional electron systems. In this regard, studies of zero-dimensional structures — so-called "quantum dots" — form the summit of the above mentioned works.

(http:/www./nobelprize.org/nobel_prizes/physics/laureates/2000/ alferov-bio.html)

EXERCISES

1) Give Russian equivalents for the following terms.

cathode oscilloscope operation, semiconductor photodetector, the photoconductivity of bismuth telluride compounds, germanium diodes and triodes (transistors) on p-n junctions, light isotope separation methods, gas dynamics of high velocities and high temperature protective coatings, kinetic theory of strength, exciton, growth and doping of perfect germanium single crystals, transistor-based circuit, germanium power rectifier, p-n-n semiconductor homostructures under working current densities, GaAs homo-p-n structure, electron and light fluxes in classical heterostructures based on the arsenide GaAsAl system, efficient one-side injection, the “superinjection” effect, diagonal tunneling, electron and optical confinement in a double heterostructure, LED, DHS, dynistor, AlGaAs-based DHS low threshold room temperature laser, optical fiber communication, lattice-matched heterostructure, multicomponent solid solution, superlattices and quantum wells, zero-dimensional structure, low-dimensional electron systems

2) Read an excerpt from the interview with academician Zh.I. Alferov and answer the questions.

a) What are Zh.I. Alferov's views on scientists' responsibility for their discoveries?

b) What major technological breakthroughs of the 20th century does Alferov mention?

c) What does he say about scientists who took part in atomic projects in the USA and Russia?

d) How did the scientific community react to the 2000 Nobel prize in physics being given for advances in technology?

В последнее время мне часто задавали вопрос об ответственности ученых за то, как используются научные открытия. Я обычно говорил, что ученый, в конечном счете, не может за это отвечать. Наша задача — добывать знания. Конечно, мы не могли не думать об их использовании, особенно в области полупроводников. Сфера применения наших исследований и открытий определилась быстро, и мы сами занимались внедрением. Но крупные решения по использованию научных открытий и у нас в стране, и за рубежом принимали и принимают, конечно, политики.

Я всегда говорю про три крупнейших технологических открытия XX века, которые, по сути, связаны с развитием квантовой физики. Это деление ядра, а стало быть, атомная бомба, атомная энергетика, и то, из чего выросли информационные технологии — открытия транзистора и лазерно-мазерного принципа.

И «Манхэттенский проект» в США, и наш атомный проект — события гигантские. В них принимали участие выдающиеся, крупнейшие ученые, многие из которых — нобелевские лауреаты. Их обуревали очень сложные чувства. С одной стороны, они работали — и с энтузиазмом — над созданием оружия, надеясь, что это сохранит мир на Земле, с другой стороны, они создали,

как когда-то сказал Ферми, «черт знает что, но какая замечательная физика!»

Когда объявили о присуждении Нобелевской премии по физике 2000 года, были разные отзывы, в том числе и упреки в адрес Нобелевского комитета за то, что он отошел от главного принципа — удостаивать премий очень глубокие фундаментальные физические открытия и вручил премию за технологию: физики в отмеченных работах не так уж много. Это неправильно, в случае с гетероструктурами и физики полно. Но в чем-то такое мнение справедливо.

В Нобелевском комитете несомненно долго взвешивали, прежде чем приняли решение, за что присудить последнюю в XX веке Нобелевскую премию по физике. Ведь отмеченные ею работы — это два ствола современных информационных технологий: интегральные схемы — вся современная микроэлектроника, а гетероструктуры — прежде всего телекоммуникации, связь, и выросли эти стволы из зерен — открытий транзистора и лазерно-мазерного принципа (в свое время также отмеченных нобелевскими премиями по физике). За интегральные схемы, вы знаете, премию 2000 года получил Джек Килби (на самом деле, Килби и Нойс — примерно в равной степени основатели современной микроэлектроники, но Нойс умер в 1990 году), а за гетероструктуры — Гербер Кремер и ваш покорный слуга (хорошо было бы, чтобы, кроме Кремера, и мой друг Ник Холоньяк оказался среди лауреатов).

Если Флеров, Курчатов, Ландау, Тамм, Зельдович, Сахаров, Сциллард, Ферми, Оппенгеймер сознательно работали над созданием страшного оружия, считая, что выполняют патриотический долг, то мы просто делали интересную физику, на основе которой получились замечательные вещи: те же компьютеры, тот же Интернет.

(Наука и жизнь №4, 2001 .С. 3-4)

Unit 2

Neutrinos from the Sun and Space

The Nobel Prize in Physics 2002 — Popular Information

October 8, 2002

This year's Nobel Prize in Physics is concerned with the discoveries and detection of cosmic particles and radiation, from which two new fields of research have emerged, neutrino astronomy and X-ray astronomy. The Prize is awarded with one half jointly to: **Raymond Davis Jr**, Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, USA, and **Masatoshi Koshiba**, International Center for Elementary Particle Physics, University of Tokyo, Japan, *"for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos",* and the second half to **Riccardo Giacconi**, Associated Universities, Inc., Washington, DC, USA, *"for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources"*. Here is a description of the scientists' award-winning achievements.

Two New Windows on the Universe

Why does the Sun shine?

In the 19th century there were lively discussions about the source of the Sun's energy. One theory was that this solar reaction was due to the release of gravitational energy when the Sun's material contracted. However, in this case, the calculated life expectancy of the Sun was, in our eyes, short. It was approximately 20 million years, compared with the age of the Earth, which we know today is approximately 5 billion years.

In 1920, an experiment showed that a helium atom has less mass than four hydrogen atoms. The British astrophysicist Sir Arthur Eddington realised that nuclear reactions in which hydrogen was transformed into helium might be the basis of the Sun's energy supply, using Albert Einstein's formula $E=m\cdot c^2$. The transformation of hydrogen into helium

in the Sun gives rise to two neutrinos for each helium nucleus that is formed by a series of reactions (explained by, among others, the Nobel Prize Laureate Hans Bethe). The dream of verifying this theory by detecting neutrinos was considered a practical impossibility by most scientists. However, in the 1950s the Nobel Prize Laureate Frederick Reines and his colleagues succeeded in showing that it was possible to prove the existence of neutrinos. In their experiment they used the reactions in a nuclear reactor, which generates a large flux of neutrinos.

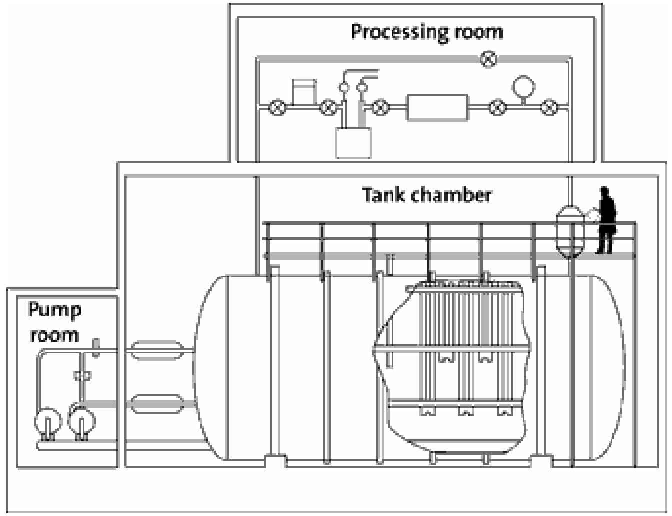


Fig. 1. Davis's detector, which for the first time in history proved the existence of solar neutrinos. The tank, which was placed in a gold mine, contained more than 600 tonnes of tetrachloroethylene and was 14.6 metres long, with a diameter of 6.1 metres.

The flux of neutrinos from the Sun was estimated to be very large: thousands of billions of solar neutrinos were reckoned to pass through our bodies every second without our noticing them. The reason is that these neutrinos react very weakly with matter, and only one of 1,000 billion solar neutrinos would be stopped on its way through the Earth.

In the late 1950s **Raymond Davis Jr** was the only scientist who dared to try to prove the existence of solar neutrinos, despite these poor odds. While most reactions in the Sun create neutrinos with energies so low that they are very difficult to detect, one rare reaction creates a high-energy neutrino. The Italian physicist Bruno Pontecorvo proposed that it ought to be possible to detect this neutrino after it had reacted with a nucleus of chlorine, forming a nucleus of argon and an electron. This argon nucleus is radioactive and has a life of about 50 days.

Particles captured in mines

In the 1960s Davis placed a tank filled with 615 tonnes of the common cleaning fluid tetrachloroethylene (Fig. 1) in a gold mine in South Dakota, USA. Altogether there were some $2 \cdot 10^{30}$ chlorine atoms in the tank. He calculated that every month approximately 20 neutrinos ought to react with the chlorine, or in other words that 20 argon atoms ought to be created. Davis's pioneering approach was the development of a method for extracting these argon atoms and measuring their number. He released helium gas through the chlorine fluid and the argon atoms attached themselves to it — an achievement considerably more difficult than finding a particular grain of sand in the whole of the Sahara desert!

This experiment gathered data until 1994 and all in all approximately 2,000 argon atoms were extracted. However, this was fewer than expected. By means of control experiments Davis was able to show that no argon atoms were left in the tank of chlorine, so it seemed as though our understanding of these processes in the Sun was incomplete or that some of the neutrinos had disappeared on their way to the Earth.

Neutrinos from space

While Davis's experiment was running, the Japanese physicist **Masatoshi Koshiba** and his team constructed another detector, which was given the name Kamiokande. It was placed in a mine in Japan and consisted of an enormous tank filled with water. When neutrinos pass through this tank, they may interact with atomic nuclei in the water. This reaction leads to the release of an electron, creating small flashes of light. The tank was surrounded by photomultipliers that can capture these flashes. By adjusting the sensitivity of the detectors the presence of neutrinos could be proved and Davis's result was confirmed. Decisive differences between Davis's and Koshiba's experiments were that the latter registered the time for events and was sensitive to direction. It was therefore possible for the first time to prove that neutrinos come from the Sun (Fig. 2 a).

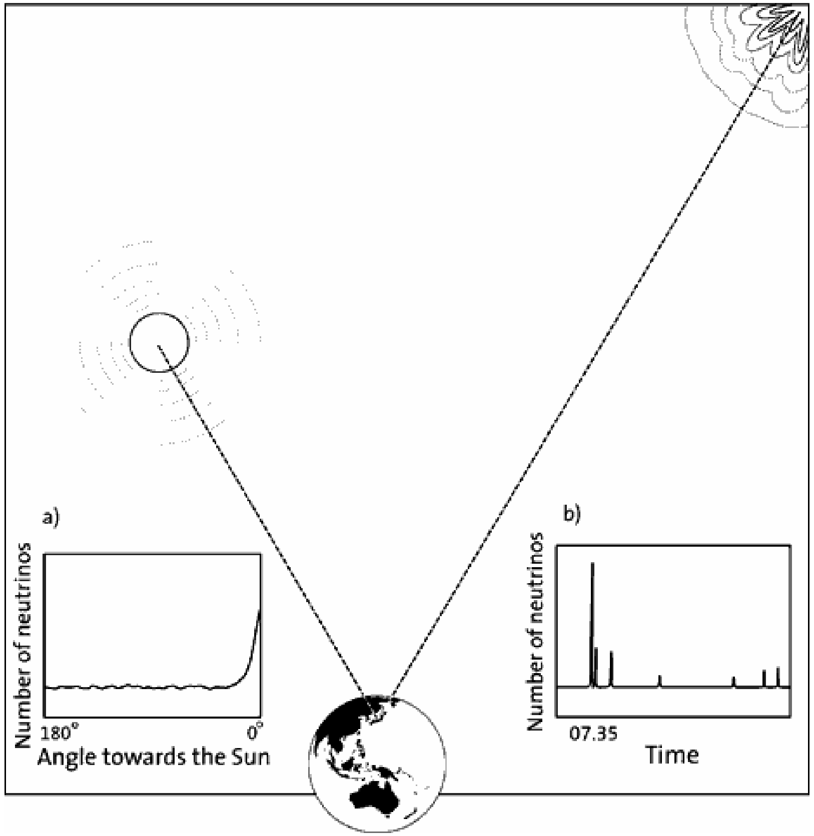


Fig. 2. a) Solar-neutrino observations in the Kamiokande experiment. A clear peak is visible at the angle corresponding to the direction of the Sun. The flat background comes from cosmic radiation and radioactivity around the detector. b) Observation of the burst of neutrinos from SN1987A. This figure shows the number of photomultipliers hit in a 17-minute interval beginning at 07.33 UT. The burst of neutrinos came at 07.35 UT on 23 February, 1987.

The Kamiokande detector was hit in February 1987 by a burst of neutrinos from a supernova explosion, named 1987A, in a neighbouring galaxy to the Milky Way called the Large Magellanic Cloud (Fig. 2 b). This lies at about 170,000 light years from the Earth (one light year corresponds to 10^{16} metres). If a neutron star is formed when a supernova explosion takes place, most of the enormous amount of energy released will be emitted as neutrinos. A total of about 10^{58} neutrinos is estimated to have been emitted from supernova 1987A, of which Koshiba's research group observed twelve of the approximately 10^{16} that passed through the detector. A similar experiment in the United States confirmed this discovery.

Do neutrinos change?

In order to increase sensitivity to cosmic neutrinos, Koshiba constructed a larger detector, Super Kamiokande, which came into operation in 1996. This experiment has recently observed effects of neutrinos produced within the atmosphere, indicating a completely new phenomenon, neutrino oscillations, in which one kind of neutrino can change to another type. This implies that neutrinos have a non-zero mass, which is of great significance for the Standard Model of elementary particles and also for the role that neutrinos play in the universe. It could also explain why Davis did not detect as many

Davis's and Koshiba's discoveries and their development of instruments have created the foundation for a new field, neutrino astronomy, which is of great importance for elementary particle physics, astrophysics and cosmology. The Standard Model for elementary particles will have to be modified if neutrinos have mass, and this mass can be highly significant for the collected mass of the universe. Studies designed to confirm or disprove the neutrino oscillation theory are in progress at many laboratories around the world.

An invisible firmament

The X-rays Wilhelm Röntgen discovered in 1895 were quickly put to use by physicists and doctors at laboratories and clinics all over the world. In contrast it took half a century for astronomers to study this type of radiation. The main reason was that X-ray radiation, which can so easily penetrate human tissue and other solid material, is almost entirely absorbed by the air in the Earth's thick atmosphere. It was not until the 1940s that rockets had been developed that could send instruments high enough up in the atmosphere.

The first X-ray radiation outside the Earth was recorded in 1949 by instruments placed on a rocket by the late Herbert Friedman and his colleagues. It was shown that this radiation came from areas on the surface of the Sun with sunspots and eruptions and from the surrounding corona, which has a temperature of several million degrees Celsius. But this type of radiation would have been very difficult to record if the Sun had been as far away as other stars in the Milky Way.

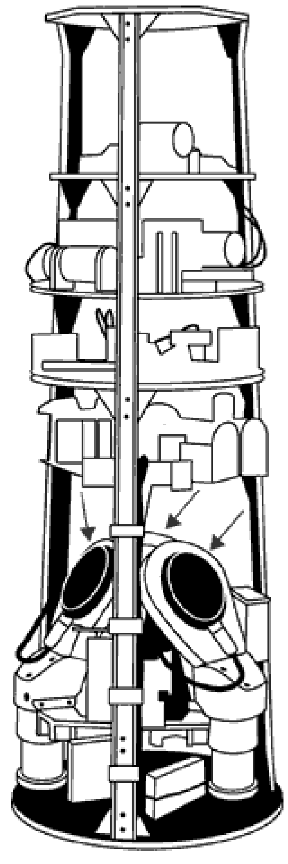


Fig. 3. The instrument in the nose of the Aerobee rocket that was launched in June 1962 by Giacconi and his group and which was the first to record a source of X-rays outside the solar system. The instrument, about one metre long, contained three Geiger counters (indicated by arrows), provided with windows of varying thickness so that the energy of the radiation could be determined.

In 1959 the then 28-year-old **Riccardo Giacconi** was recruited to build up a space-research program for a company that was to make it easier for young researchers to get commissions from e.g. NASA. Together with the man who took this initiative, the late Bruno Rossi, Giacconi worked out principles for how an X-ray telescope should be constructed. This construction collected radiation with cone-shaped, curved mirrors onto which the radiation falls very obliquely and is totally reflected. This is the same phenomenon as when a landscape is reflected in the air above an asphalt road on a hot summer day.

Giacconi and his newly-formed group also carried out rocket experiments to try to prove the presence of X-ray radiation from the universe, primarily to see whether the moon could emit X-ray radiation under the influence of the Sun. In one experiment a rocket flew at a high altitude for six minutes. No radiation from the moon could be detected, but a surprisingly strong source at a greater distance was recorded since the rocket was rotating and its detectors (Fig. 3) swept the sky. In addition, a background of X-ray radiation was discovered evenly distributed across the sky.

These unexpected discoveries gave an impetus to the development of X-ray astronomy. In time the way in which the direction of the radiation could be determined was improved and the sources could be identified with observations made in normal light. The source discovered in the first successful experiment was a distant ultraviolet star in the Scorpio constellation, Scorpius X-1 (X for X-ray, 1 for the first). Other important sources were stars in the Swan constellation (Cygnus X-1, X-2 and X-3). Most of the newly-discovered sources were double stars, in which one star circles in a narrow orbit around another object which is very compact — a neutron star or perhaps a black hole (Fig. 4). However, it was difficult to carry out these studies because the possible observation times from the balloons and rockets were too short.

X-ray satellites broadened our horizons

In order to extend observation times, Giacconi initiated the construction of a satellite to survey the sky for X-ray radiation. This satellite was launched in 1970 from a base in Kenya and was given the name UHURU ("freedom" in Swahili). It was ten times more sensitive than the rocket experiments and every week it was in orbit it produced more results than all the previous experiments put together.

However, so far no high-definition X-ray telescope had been sent into space that could provide sharp images. Giacconi constructed one, which was ready for use in 1978. It was called the Einstein X-ray Observatory and was able to provide relatively sharp images of the universe at X-ray wavelengths. Its sensitivity had been improved and objects a million times weaker than Scorpius X-1 (see above) could be recorded.

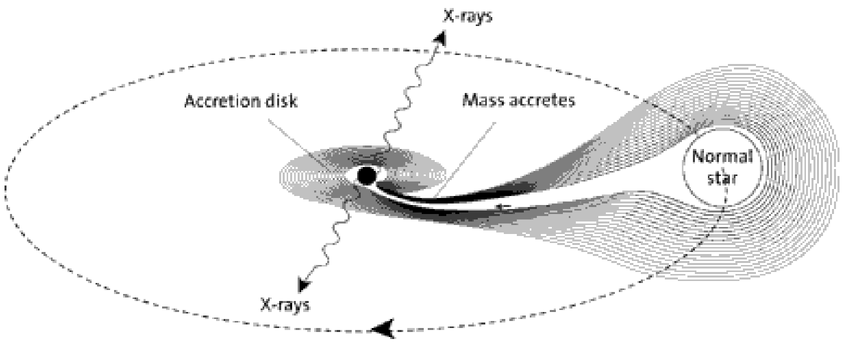


Fig. 4. A double star that generates X-rays. Gas streams out of the star down towards the compact object and accelerates in its strong gravitational field up to very high speeds. When the gas atoms collide with each other and are decelerated at the surface of the neutron star and by its magnetic field, intensive X-ray radiation is released.

This telescope made a large number of discoveries. Many X-ray double stars were studied in detail, not least a number of objects that were thought to contain black holes. More normal stars could also be studied for the first time in X-ray radiation. Remnants of supernovas were analysed, X-ray stars in galaxies outside the Milky Way were discovered and eruptions of X-ray radiation from distant active galaxies could be examined more closely. The X-ray radiation from the gas between galaxies in galaxy groups helped scientists draw conclusions about the dark matter content of the universe.

In 1976 Giacconi initiated the construction of an improved, even larger X-ray observatory. It was not launched until 1999, and was named Chandra after the astrophysicist and Nobel Prize Laureate Subrahmanyan Chandrasekhar. Chandra has provided extraordinarily detailed images of celestial bodies in X-ray radiation corresponding to those from the Hubble Space telescope or the new Earth-based telescopes using visible light.

New light thrown on black holes

Thanks to X-ray astronomy and its pioneers, in particular Giacconi, our picture of the universe has been changed in decisive ways. Fifty years ago our viewpoint was dominated by a picture of stars and star constellations in equilibrium, where any developments were very slow and gradual. Today we know that the universe is also the scene of extremely rapid developments in which enormous amounts of energy are released in processes lasting less than a second, in connection with objects that are not much larger than the Earth, but incredibly compact. Studies of processes at these objects and in the central parts of active galaxy cores are largely based on data from X-ray astronomy. A new, fantastic zoo of important and strange celestial bodies has been discovered and studied. Today the universe seems much more remarkable than we believed 50 years ago – in no small part thanks to X-ray astronomy.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2002/public.html)

EXERCISES

1) Translate the sentences into Russian.

a) The flux of neutrinos from the Sun was estimated to be very large: thousands of billions of solar neutrinos were reckoned to pass through our bodies every second without our noticing them.

b) The Italian physicist Bruno Pontecorvo proposed that it ought to be possible to detect this neutrino after it had reacted with a nucleus of chlorine, forming a nucleus of argon and an electron.

c) A total of about 10^{58} neutrinos is estimated to have been emitted from supernova 1987A, of which Koshiba's research group observed twelve of the approximately 10^{16} that passed through the detector.

d) The Standard Model for elementary particles will have to be modified if neutrinos have mass, and this mass can be highly significant for the collected mass of the universe.

e) It was not until the 1940s that rockets had been developed that could send instruments high enough up in the atmosphere.

f) This type of radiation would have been very difficult to record if the Sun had been as far away as other stars in the Milky Way.

g) Giacconi and his newly-formed group also carried out rocket experiments to try to prove the presence of X-ray radiation from the universe, primarily to see whether the moon could emit X-ray radiation under the influence of the Sun.

h) Chandra has provided extraordinarily detailed images of celestial bodies in X-ray radiation corresponding to those from the Hubble Space telescope or the new Earth-based telescopes using visible light.

2) Translate the sentences into English.

a) Опираясь на уравнение Эйнштейна $E=mc^2$, британский астрофизик сэр Артур Эддингтон предложил гипотезу, согласно которой ядерные реакции, отвечающие за превращение водорода в гелий, могут лежать в основе источника солнечной энергии. Трансформация водорода в гелий приводит к появлению двух нейтрино для каждого ядра гелия (что в числе других ученых удалось объяснить нобелевскому лауреату Гансу Бете).

b) Фредерик Рейнс и его коллеги сумели продемонстрировать, что существование нейтрино можно доказать в ходе реакций в ядерном реакторе, генерирующем мощный поток нейтрино. Построенный для регистрации солнечных нейтрино, детектор Дэвиса содержал более 600 тонн тетрахлорэтилена, составляя 14,6 м в длину и 6,1 м в диаметре.

c) Нейтрино очень слабо реагирует с материей, и лишь один из 1,000 миллиардов солнечных нейтрино может быть зарегистрирован на пути к Земле. Бруно Понтекорво предположил, что высокоэнергетичный нейтрино можно обнаружить после его вступления в реакцию с ядром хлора (при образовании ядра аргона и одного электрона). Новаторский подход Реймонда Дэвиса состоял в разработке метода выделения данных атомов аргона и их количественного измерения.

d) Масатоши Кошиба и его коллеги создали детектор нейтрино «Камиоканде», с помощью которого удалось измерить время появления нейтрино и установить направление их движения. Таким образом, впервые было доказано, что нейтрино поступают от Солнца.

e) В 1996 году был запущен детектор «Суперкамиоканде», при помощи которого стали возможны наблюдения эффектов, произведенных нейтрино в атмосфере и указывающих на новое явление – нейтринные осцилляции, т.е. превращения нейтрино в частицы другого типа, что подразумевает наличие у них ненулевой массы.

f) В 1949 году было впервые зафиксировано рентгеновское излучение за пределами Земли – с областей на поверхности Солнца, где наблюдались пятна и извержения, а также из прилегающих солнечных корон с температурой несколько миллионов градусов по Цельсию. Риккардо Джаккони и Бруно Росси разработали конструкцию телескопа, способного зарегистрировать излучение при помощи конусообразных изогнутых зеркал, полностью отражающих лучи.

g) В результате экспериментов, поставленных Джаккони и его исследовательской группой, было обнаружено, что большинство космических источников рентгеновского излучения составляли двойные звезды, в которых одно из тел вращается по узкой орбите вокруг нейтронной звезды или черной дыры. Запущенная в 1999 г. космическая рентгеновская обсерватория «Чандра» (названная в честь Субраманьяна Чандрасекара) предоставила необыкновенно детализированные изображения небесных тел в рентгеновском излучении.

h) Благодаря заслугам ученых, стоявших у истоков рентгеновской астрономии (в особенности, Джаккони), на данный момент известно, что во вселенной происходят необычайно быстрые изменения, в которых огромные объемы энергии высвобождаются в процессах, длящихся менее одной секунды, с участием объектов, чей размер сопоставим с Землей, но намного более компактных, чем наша планета.

3) Make an outline of the text and render its main content in English.

Unit 3
Superconductors and Superfluids

The Nobel Prize in Physics 2003 — Popular Information
October 7, 2003

The quantum physics that controls the micro-world has a wide range of spectacular effects that do not normally occur in our ordinary macro-world. There are, however, certain situations in which quantum phenomena are visible. This year's Nobel Prize in Physics is awarded for work concerning two of these situations: superconductivity and superfluidity. **Alexei Abrikosov** and **Vitaly Ginzburg** have developed theories for superconductivity and **Anthony Leggett** has explained one type of superfluidity. Both superconductivity and superfluidity occur at very low temperatures.

Flow without resistance

An unexpected cold effect

When investigations were first carried out into the nature of electricity in the 19th century, it was evident that metals and certain alloys conduct electricity by allowing electrons to move between the atoms. But the disorganised way in which the electrons move causes the atoms to vibrate, so heat is generated. If the current is too strong, the heat can be so great that the conductor melts. In addition it was found that an electric current through a conductor creates a magnetic field, which in turn generates current in the opposite direction. Electricity and magnetism interact and can thus counteract each other.

In 1911 the Dutch physicist Heike Kamerlingh Onnes made a remarkable discovery. He was particularly interested in the properties of substances at low temperatures and had succeeded in producing liquid helium, which has an extremely low temperature. When Onnes investigated the electric conductivity of mercury, he found that when the metal was cooled by means of liquid helium to a few degrees above absolute zero, its electric resistance vanished. He named this phenomenon *superconductiv-*

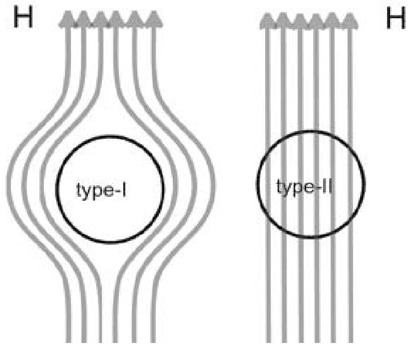
ity. Although no theoretical explanation could be found for this phenomenon, it was evident that it could have far-reaching significance in a modern society that was becoming more and more dependent on electricity. Onnes was awarded the Nobel Prize in Physics in 1913 for this work.

Superconductors of two types

Almost 50 years passed before the physicists John Bardeen, Leon Cooper and Robert Schrieffer (Nobel Prize in Physics, 1972) were able to present a theory (the BCS theory, named after the initials of their surnames) that explained the phenomenon. This theory shows that some of the negatively-charged electrons in a superconductor form pairs, called Cooper pairs. These pairs of electrons flow along attracting channels formed by the regular structure of the positively-charged metal atoms in the material. As a result of this combination and interaction the current can flow evenly and superconductivity occurs. The paired electrons are usually thought of as a condensate, similar to the drops of liquid that form in a cooled gas. Unlike an ordinary liquid this "electronic liquid" is superconductive.

These superconductors are called type-I. They are metals and are characterised by the Meissner effect, that is, in the superconductive state they actively counteract a surrounding magnetic field as long as its strength does not exceed a certain limit (fig. 1). If the surrounding magnetic field becomes too strong, the superconductive property disappears.

Fig. 1. Type-I superconductors repel a magnetic field (the Meissner effect). If the strength of the magnetic field increases, they lose their superconductivity. This does not happen with type-II superconductors, which accomodate strong magnetic fields by letting the magnetic field in.



But it is known that there are superconductors that lack or show only a partial Meissner effect. These are in general alloys of various metals or compounds consisting of non-metals and copper. These retain their

superconductive property even in a strong magnetic field. Experiments show that the properties of these so-called type-II superconductors cannot be described by the BCS theory.

Alexei Abrikosov, working at the Kapitsa Institute for Physical Problems in Moscow, succeeded in formulating a new theory to describe the phenomenon. His starting point was a description of superconductivity in which the density of the superconductive condensate is taken into account with the aid of an order parameter (a wave function). Abrikosov was able to show mathematically how the order parameter can describe vortices and how the external magnetic field can penetrate the material along the channels in these vortices (fig. 2).

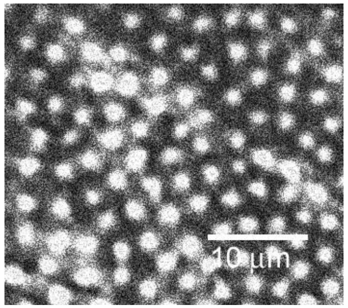


Fig. 2. This image is of an Abrikosov lattice of vortices in the electron fluid in a type-II superconductor. The magnetic field passes through these vortices.

Abrikosov was also able to predict in detail how the number of vortices can grow as the magnetic field increases in strength and how the superconductive property in the material is lost if the cores of the vortices overlap. This description was a breakthrough in the study of new superconducting materials and is still used in the development and analysis of new superconductors and magnets. His papers from the late 1950s have been quoted more and more frequently during the past ten years.

The theory Abrikosov's argument was based on was formulated in the early 1950s by **Vitaly Ginzburg** and Lev Landau (the latter was awarded the Nobel Prize in Physics in 1962 for other work, see below). This theory was intended to describe superconductivity and critical magnetic field strengths in the superconductors that were known at that time. Ginzburg and Landau realised that an order parameter (wave function) describing the density of the superconductive condensate in the material had to be introduced if the interaction between the superconductor and magnetism was to be explained. When this parameter was introduced, it was evident that there was a breakpoint when a characteristic value approximately 0.71 was reached and that in principle there were two types of superconductor. For mercury the value is approximately 0.16 and other superconductors known at the time have values close to this. There was therefore, at that time, no reason to consider values above the breakpoint. Abrikosov was able to tie up the theory by showing that type-II superconductors had precisely these values.

Our knowledge of superconductivity has led to revolutionary applications (fig. 3). New compounds with superconductive properties are being discovered all the time. In the past few decades a large number of high-temperature superconductors have been developed. The first one was produced by Georg Bednorz and Alex Müller, who were awarded the Nobel Prize in Physics in 1987. All high-temperature superconductors are type-II. Cooling is a critical factor for the utilisation of superconductors. An important limit is 77 K (-196°C), the boiling point of liquid nitrogen, which is cheaper and more manageable than liquid helium.

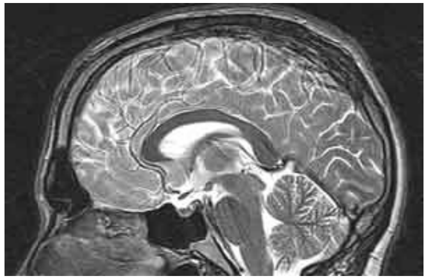


Fig. 3. An MRI image of a human brain. The resolution in the magnetic resonance camera is dependent partly on the strength of the magnetic field. Today strong superconducting magnets are used, all of them type-II.

Two fascinating superfluids

The lightest rare gas, helium, exists in nature in two forms, two isotopes. The usual form is represented as ^{4}He, where the figure 4 stands for the number of nucleons in the atomic nucleus (two protons and two neutrons). In the unusual form, ^{3}He, the atomic nucleus has only one neutron, so it is lighter. In helium that occurs naturally the heavier isotope is more frequent than the lighter one by a factor of about 10 million. That is why it is only in the last 50 years that it has been possible to produce large amounts of ^{3}He, at nuclear power stations, for example. At normal temperatures the gases of the two isotopes differ only in their atomic weights.

If helium gas is cooled to low temperatures, approximately 4 degrees above absolute zero (-273.15°C), the gas passes into liquid form, it condenses. This happens in the same way as when steam condenses into water. Provided the temperature is not too low, the liquids of the two isotopes have similar properties. Liquid helium is used widely as a coolant, in superconducting magnets, for example. In this case naturally-occurring helium is used, of course, that is, the usual and cheaper form of helium, ^{4}He.

If liquid helium is cooled to even lower temperatures, dramatic differences arise between the liquids of the two isotopes; quantum physical effects appear that cause the liquids to lose all their resistance to internal movement, they become superfluid. This occurs at quite different temperatures for the two superfluids and they exhibit a wide range of fascinating properties, such as flowing freely from openings in the vessel they are kept in. These effects can be explained only by means of quantum physics.

Historic discoveries

The fact that ^{4}He becomes superfluid was discovered by Pyotr Kapitsa, among others, already in the late 1930s. This phenomenon was explained almost immediately by the young theoretician Lev Landau, who was awarded the Nobel Prize in Physics in 1962 for this discovery. (Kapitsa was also awarded the Nobel Prize in Physics, but not until 1978.) The transformation from normal to superconducting liquid, which for ^{4}He occurs at approximately 2 degrees above absolute zero, is an example of Bose-Einstein condensation, a process that has also been observed more recently in gases (cf. the Nobel Prize in Physics awarded in 2001 to Eric Cornell, Wolfgang Ketterle and Carl Wieman).

For the ^{3}He isotope the transformation into the superfluid state was not discovered until the early 1970s by David Lee, Douglas Osheroff and Robert Richardson (Nobel Laureates in Physics in 1996). One reason why this discovery came so much later is that the transformation occurs at a very much lower temperature, approximately 1,000 times lower than for ^{4}He. Even though ^{3}He differs in quantum physical respects from ^{4}He and cannot directly undergo Bose-Einstein condensation, this discovery was not unexpected. Thanks to the microscopic theory of superconductivity presented in the 1950s (see above) by Bardeen, Cooper and Schrieffer, there was a mechanism, the formation of Cooper pairs, that ought to have been paralleled in ^{3}He (fig. 4).

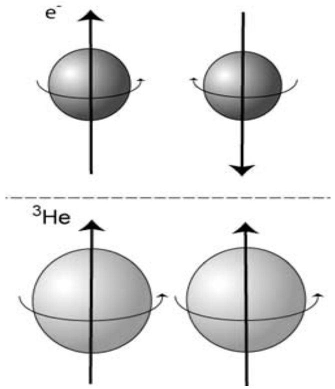


Fig. 4. The pair formation that occurs in superfluid ^{3}He differs from that which occurs between electrons in a superconductor (Cooper pairs). The magnetic properties of the helium atoms act together, whereas those of the electrons counteract each other.

The multifarious superfluid

The theoretician who first succeeded in explaining the properties of the new superfluid in a decisive way was **Anthony Leggett**, who in the 1970s was working at the University of Sussex in England. His theory helped experimentalists to interpret their results and provided a framework for a systematic explanation. Leggett's theory, which was first formulated for superfluidity in ^{3}He, has also proved useful in other fields of physics, e.g. particle physics and cosmology.

As superfluid, ^{3}He consists of pairs of atoms, its properties are much more complicated than those of the ^{4}He superfluid. In particular the pairs of atoms of the superfluid have magnetic properties, which means that the liquid is anisotropic, it has different properties in different directions. This fact was used in experiments in which studies were made of the liquid immediately after its discovery. By means of magnetic measurements it was revealed that the superfluid has very complex properties, exhibiting a mixture of three different phases. These three phases have different properties and the proportions in the mixture are dependent on temperature, pressure and external magnetic fields (fig. 5).

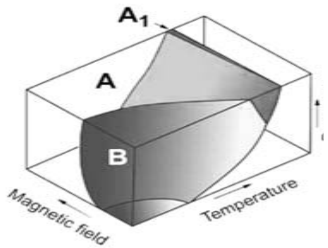


Fig. 5. Superfluid ^{3}He can exist in three phases called A, A_1, and B. The type of phase is determined by pressure, temperature and magnetic field according to the figure's phase diagram.

Superfluid ^{3}He is a tool that researchers can use in the laboratory to study other phenomena as well. In particular the formation of turbulence in the superfluid has recently been used to study how order can turn into chaos (fig. 6). This research may lead to a better understanding of the ways in which turbulence arises — one of the last unsolved problems of classical physics.

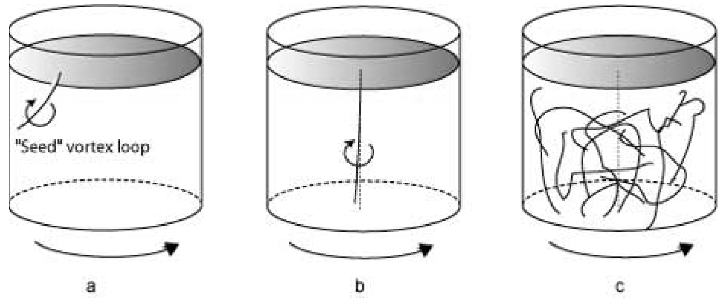


Fig. 6. It has recently been shown that if a vortex is created in a rotating vessel containing superfluid ^{3}He (a), the result can critically depend on the temperature. Above a critical temperature the vortex lines up along the axis of rotation (b). Below the critical temperature a confusion of vortices occurs (c).

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2003/public.html)

EXERCISES

1) ***The outline of the history of discoveries concerning superconductivity and superfluids contains a number of names. Can you remember what the achievements of these people are? Consult the text if necessary.***

Heike Kamerlingh Onnes, John Bardeen, Leon Cooper, Robert Schreiffer, Pyotr Kapitsa, Lev Landau, Georg Bednorz, Alex Müller, Eric Cornell, Wolfgang Ketterle, Carl Wieman, David Lee, Douglas Osheroff, Robert Richardson, Alexei Abrikosov, Vitaly Ginzburg, Anthony Leggett

2) ***Translate the terms into Russian and explain what they mean in English.***

type-I superconductors, type-II superconductors, BCS theory, Cooper pairs, the Meissner effect, order parameter, wave function, vortex core, strong superconducting magnet, Bose-Einstein condensation, microscopic theory of superconductivity, anisotropic liquid, external magnetic field, confusion of vortices

3) ***Answer the questions.***

a) What does the phenomenon of superconductivity imply?

b) What is the difference between type-I and type-II superconductors?

c) Can the BCS theory describe the specific properties of type-II superconductors?

d) What was Alexei Abrikosov's starting point in investigating superconductivity?

e) What breakthrough did Abrikosov make in his research in the late 1950s?

f) Why was it necessary to introduce an order parameter describing the density of the superconductive material?

g) What revolutionary applications has the knowledge of superconductivity led to?

h) What forms can helium take and what is the difference between them?

i) Why was it crucial to turn to quantum physical effects in explaining the properties of liquid helium?

j) How did Pyotr Kapitsa, Lev Landau and Richard Feynman contribute to the study of liquid helium?

k) What three different phases does the superfluid (^3He) exhibit?

l) How does turbulence form in the superfluid?

Banquet Speech

Listen as you read to the banquet speech of Anthony J. Leggett at http://www.nobelprize .org.
Do you find his pieces of advice useful?

Your Majesties, Your Royal Highnesses, Ladies and Gentlemen,

As a Nobel Laureate one gets asked many questions, some of them very peculiar indeed, but one frequent question that is quite *reasonable* is: What advice would you give to a student hoping to embark on a career in theoretical physics? Now I should make it clear that my only conceivable qualification, as a mere stripling, for giving this speech on behalf of all three of us physics laureates is that I happen to belong to that fortunate ten percent of the world's population who were born with English as their mother tongue, so I do not know whether my fellow laureates would agree with my answer. But for what it is worth, here it is:

First, if there's something in the conventional wisdom that you don't understand, worry away at it for as long as it takes and don't be deterred by the assurances of your fellow physicists that these questions are well understood.

Secondly, if you find a problem interesting, don't worry too much about whether it has been solved in the existing literature. You will have a lot more fun with it if you don't know, and you will learn a lot, even if what you come up with turns out not to be publishable.

Thirdly, remember that no piece of honestly conducted research is ever wasted, even if it seems so at the time. Put it away in a drawer, and ten, twenty or thirty years down the road, it will come back and help you in ways you never anticipated, and finally, take your teaching every bit as seriously as your research.

As I said, I don't know if my fellow physics laureates would agree with my answer. However, I am sure they will join me in expressing our gratitude, first to the late Alfred Nobel for his generosity in endowing these prizes, secondly to the members of the Nobel Physics Committee of the Royal Swedish Academy of Sciences — having served on several committees for the award of much less prestigious prizes, I can only imagine how much work they have to do and how difficult are the *decisions* they have to take — and finally to your Majesties and the Nobel Foundation for this sumptuous banquet to-night.

(http:www.nobelprize.org/nobel_prizes/physics/laureates/2003/ leggette-speech.html)

Questions

1) Would you like to embark on a career in theoretical physics?
2) What can deter you from studying a certain physics issue?

Unit 4

The Standard Model and the Four Forces. Quantum Chromodynamics

The Nobel Prize in Physics 2004 — Popular Information

October 5, 2004

The discovery which is awarded this year's Nobel Prize is of decisive importance for our understanding of how the theory of one of Nature's fundamental forces works, the force that ties together the smallest pieces of matter — the quarks. **David Gross**, **David Politzer** and **Frank Wilczek** have through their theoretical contributions made it possible to complete the Standard Model of Particle Physics, the model that describes the smallest objects in Nature and how they interact. At the same time it constitutes an important step in the endeavour to provide a unified description of all the forces of Nature, regardless of the spatial scale — from the tiniest distances within the atomic nucleus to the vast distances of the universe.

The strong force explained

The strong interaction — often called the *colour interaction* — is one of Nature's four basic forces. It acts between the quarks, the constituents that build protons, neutrons and the nuclei. Progress in particle physics or its relevance for our daily life can sometimes appear hard to grasp for anyone without a knowledge of physics. However, when analysing an everyday phenomenon like a coin spinning on a table, its movements are in fact determined by the fundamental forces between the basic building blocks — protons, neutrons, electrons. In fact, about 80% of the coin's weight is due to movements and processes in the interior of the protons and neutrons — the interaction be-

tween quarks. This year's Nobel Prize is about this interaction, the strong or colour force.

David Gross, **David Politzer** and **Frank Wilczek** discovered a property of the strong interaction which explains why quarks may behave almost as free particles only at high energies. The discovery laid the foundation for the theory for the colour interaction (a more complete name is *Quantum ChromoDynamics*, QCD). The theory has been tested in great detail, in particular during recent years at the European Laboratory for Particle Physics, CERN, in Geneva.

The Standard Model and the four forces of Nature

The first force that must have been evident to humans is gravity. This is the interaction that makes objects fall to the ground but also governs the movements of planets and galaxies. Gravity may seem strong — consider, for example, the large craters formed by comets hitting the earth, or the huge rockets that are required to lift a satellite into space. However, in the microcosmos, among particles like electrons and protons, the force of gravity is extremely weak (fig.1).

The three forces or interactions, as phycisists prefer to call them, that are applicable to the microcosmos are described by the *Standard Model*. They are the *electromagnetic interaction*, the *weak interaction* and the *strong interaction*. Through the contributions of several earlier Nobel Laureates the Standard Model has a very strong theoretical standing. This is because it is the only mathematical description which takes into account both Einstein's theory of relativity and quantum mechanics.

The Standard Model describes quarks, leptons and force-carrying particles. Quarks build, for instance, the protons and neutrons of the atomic nucleus. Electrons that form the outer casing for atoms are leptons and, as far as is known, are not constructed from any smaller constituents. The atoms join up to form molecules, the molecules build up structures and in this way the whole universe can finally be described.

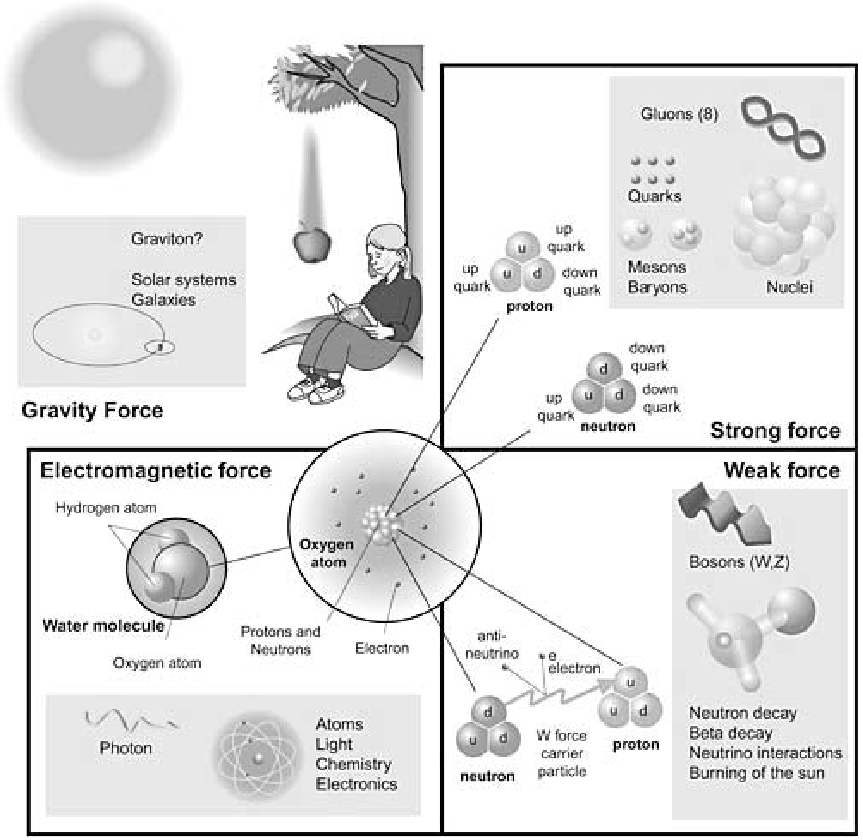


Fig. 1. The four forces (or interactions) of Nature, their force carrying particles and the phenomena or particles affected by them. The three interactions that govern the microcosmos are all much stronger than gravity and have been unified through the Standard Model.

The electromagnetic interaction provides light and cohesion

The electromagnetic interaction is responsible for a number of common phenomena in the world that surrounds us, such as friction, magnetism and the fact that neither we nor objects we lay aside fall through the floor.

The electromagnetic interaction that binds an electron and a proton in a hydrogen atom is the inconceivably large number of 10^{41} times stronger than gravity. Yet, in spite of the very large difference in

strength between the two interactions there are several similarities. The interaction strength decreases with the square of the distance and has a long range. Both the electromagnetic interaction and the gravitational interaction are mediated by *force carriers*, the graviton and the photon (the light particle). In contrast to the photon, the graviton still hasn't been found. Their long range can be shown to be due to the fact that they have no rest mass. The photons from the sun are necessary for life on earth. However, when the energy is produced from fusion at the centre of the sun the other two interactions in the Standard Model also play important roles. The photon has an important property; it is electrically neutral but couples with electrical charges. That is why photons do not interact with each other.

The electromagnetic interaction is described by the theory of quantum electrodynamics (QED), one of the most successful theories of physics. It agrees with the results of experiments with a precision that approaches one part in ten million. Sinitiro Tomonaga, Julian Schwinger and Richard Feynman were awarded the Nobel Prize for this in 1965. One of the reasons why it is so successful is that the equation contains a small constant, the so-called fine structure constant or coupling constant, a_{em}, with the value of 1/137, which is considerably smaller than 1. This makes it possible to calculate electromagnetic effects as a series expansion in the small constant, an elegant mathematical method called perturbation calculation that was much developed by Feynman.

One important property of quantum mechanics in the QED theory is that the fine structure constant could be shown to vary with energy; it increases with increasing energy. At today's accelerators, for example the CERN LEP accelerator, the value has been measured as 1/128 rather than 1/137 at energies corresponding to approximately 100 billion electronvolts. If the energy dependence for the fine structure constant is depicted in relation to the energy, the curve slopes slightly upwards. Theoretical physicists say that the derivate, or the beta function, is positive.

The weak interaction — radioactive decay

The weak interaction is carried by the bosons, $W^{\pm}$ and Z^0, particles that, unlike the photon and the graviton, have very large masses (approximately 100 proton masses!). That is why the interaction has a short range. It acts on both quarks and leptons and is responsible for some radioactive decays. It is closely related to the electromagnetic interaction and the two interactions are said to be united in the electroweak interaction, which was elucidated in the 1970s. Gerardus't Hooft and Martinus

Veltman received the 1999 Nobel Prize for the final formulation of this theory.

The strong interaction — charge and colour

It had been known since the 1960s that the proton (and the neutron) are composite and built up of quarks. However, strangely enough, it was not possible to produce free quarks. They are confined, a fundamental property of these building blocks. Only aggregates of quarks, two or three, can exist freely as, for example, the proton. Quarks have electric charges which are a fraction of the proton's, –1/3 or +2/3, a strange feature which has not yet been explained. Each quark, in addition to an electric charge, also has a special property which, like its electric charge, is quantised, that is, it can only take on certain values. This property is called *colour charge*, owing to its similarity to the concept of colour.

Quarks can carry the colour charges red, blue or green. For every quark there is an antiquark in the same way as the electron has an antiparticle, the positron. Antiquarks have the colour charges antired, antiblue or antigreen. Aggregates of quarks, which can exist freely, are *colour neutral*. The three quarks in the proton (u, u and d) have different colour charges so that the total colour charge is white (or neutral). In the same way as electrically neutral molecules can form bonds (through the attraction between their positive and negative parts) the exchange of force between protons and neutrons in the nucleus occurs through the colour forces that leak out from their quarks and force-carrying particles.

The force between quarks is carried by *gluons* (from the word 'glue'), which, like photons, lack mass. Gluons, however, in contrast to photons, also have the property of colour charge, consisting of a colour and an anticolour. This property is what makes the colour force so complex and different from the electromagnetic force.

A weaker coupling sets the particles free

For a long time physicists believed that it would be impossible to find a theory by which the effects of the strong interaction between quarks could be calculated in the same way as for the electromagnetic or the weak interaction. If, for example, the interaction between two protons in a nucleus is studied, quite good results can be obtained by describing it as an exchange of pi-mesons — an idea that gave Hideki Yukawa the Nobel Prize in 1949. A coupling constant larger than 1 is needed, however, which means that Feynman's perturbation calculations (see

above) cannot be used. Unfortunately, even today there is no satisfactory method for calculating such strong interaction effects.

The situation seemed to be even worse for higher energies; if the beta function is positive (the way the coupling constant changes with energy) the interaction will be even stronger and the calculations become increasingly absurd.

The German theoretical physicist, Kurt Symanzik (now deceased), realised that the only way to achieve a reasonable theory was to find one with a negative beta function. That would also explain why quarks could sometimes appear as free particles, grains, inside the proton — an effect that had been seen in scattering experiments between electrons and protons.

Unfortunately, Symanzik himself did not find such a theory, and although Gerardus't Hooft was very close to discovering it during the summer of 1972, physicists started to despair. "Evidence" was even presented that all realistic theories had a positive beta function. We now know it was incorrect because in June 1973 this year's Laureates entered the arena. In two publications back-to-back in the journal Physical Review Letters, one by Gross and Wilczek and one by Politzer, the amazing discovery was announced that the beta function can be negative. When their discovery was made, these physicists were quite young — Wilczek and Politzer were still graduate students, in fact.

According to their theories, the force carriers, the gluons, have a unique and highly unexpected property, namely that they interact not only with quarks but also with each other. This property means that the closer quarks come to each other, the weaker the quark colour charge and the weaker the interaction. Quarks come closer to each other when the energy increases, so the interaction strength decreases with energy. This property, called asymptotic freedom, means that the beta function is negative. On the other hand, the interaction strength increases with increasing distance, which means that a quark cannot be removed from an atomic nucleus. The theory confirmed the experiments: quarks are confined, in groups of three, inside the proton and the neutron but can be visualized as "grains" in suitable experiments.

Asymptotic freedom makes it possible to calculate the small distance interaction for quarks and gluons, assuming that they are free particles. By colliding the particles at very high energies it is possible to bring them close enough together. When asymptotic freedom had been discovered and a theory, Quantum ChromoDynamics, QCD, that was asymptotically free, had been formulated, calculations could be made for the first time that showed excellent agreement with experiments (fig. 2).

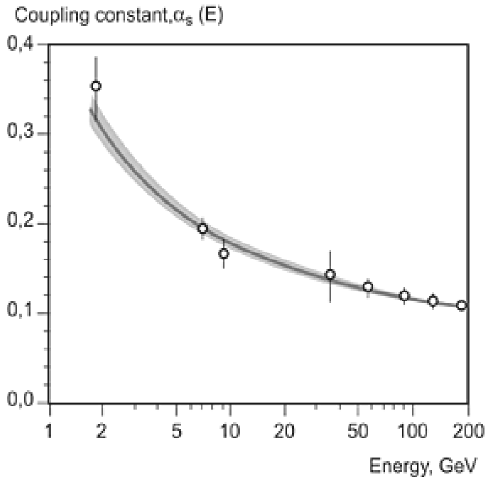


Fig. 2. The value of the "running" coupling constant, a_s, as a function of the energy scale E. The curve that slopes downwards (negative beta function) is a prediction of the asymptomatic freedom in QCD and, as can be seen, it agrees very closely with the measurements that have been made.

The showers of particles reveal the truth

An important proof of the QCD theory is provided by the collisions between electrons and their antiparticles, positrons, with very high kinetic energy, when they annihilate each other. According to Einstein's equation $E= mc^2$, kinetic energy can be transformed into new particles, for example, quarks with mass and kinetic energy. These quarks are created very deep within the process, very close to each other but moving away from each other at an extremely high speed. Thanks to the asymptotic freedom in QCD it is now possible to calculate this process.

Admittedly, when the quarks have moved away from each other, they are influenced by increasingly strong forces that eventually lead to the creation of new quark-antiquark particles, and a shower of particles arises in the direction of the original quarks and antiquarks respectively. But the process retains a "memory" of the first asymptomatically free part which can be calculated, giving a value for the probability of the occurrence of these two-shower events that agrees with observations.

Even more convincing, perhaps, are the three-shower occurrences discovered at the DESY accelerator in Hamburg in the late 1970s. These occurrences can be successfully interpreted as a gluon radiating away from a quark or an antiquark (fig. 3).

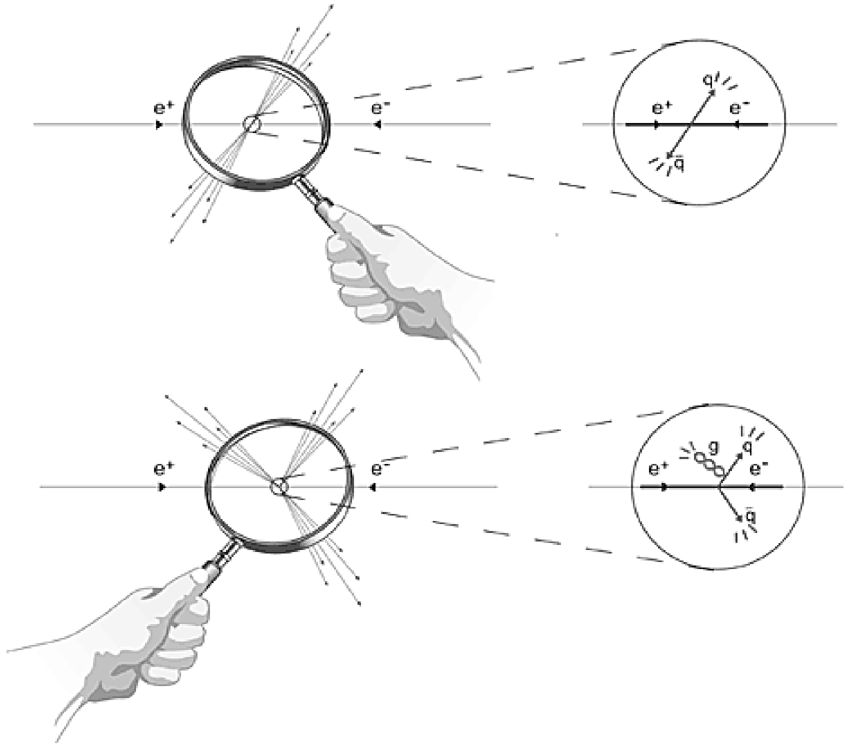


Fig. 3. Occurrences of two or three showers of particles observed in collisions between electrons and positrons. The enlarged portion displays the QCD interpretation, that also allows detailed calculations of the probability for these occurrences. These probabilities agree very well with measured data (e^-= electron, e^+= positron, q= quark, q with overscore= antiquark, g= gluon).

The QCD asymptotic freedom that this year's Laureates discovered also provided physicists with an explanation of a phenomenon that had been observed several years earlier at the Stanford accelerator (Friedman, Kendall and Taylor; Nobel Prize in 1990). The electrically-charged constituents of the proton behave as free particles when they are hit so hard that they get a high energy. By adding together the amount of the proton's momentum that comprised the charged constituents (the quarks) it also became evident that about half of the proton momentum was something else — gluons!

Can the forces of Nature be unified?

Perhaps the most tantalizing effect of QCD asymptotic freedom is that it opens up the possibility of a unified description of Nature's forces. When examining the energy dependence of the coupling constants for the electromagnetic, the weak and the strong interaction, it is evident that they almost, but not entirely, meet at one point and have the same value at a very high energy. If they do indeed meet at one point, it may be assumed that the three interactions are unified, an old dream of physicists, who would like to describe the laws of Nature in the simplest language possible (fig. 4).

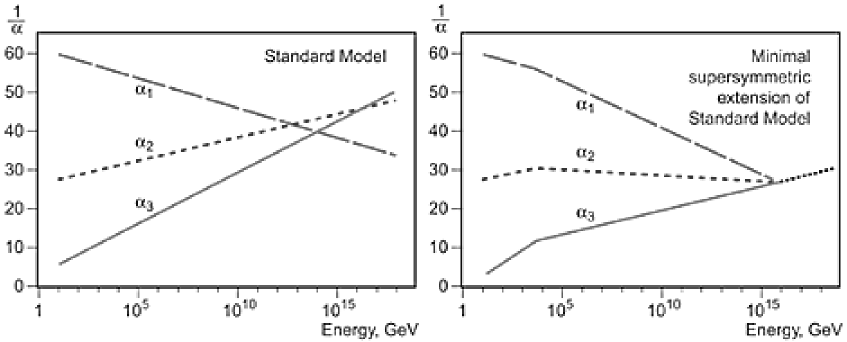


Fig. 4. Running coupling constants in the Standard Model (left) and with the introduction of supersymmetry (right). In the Standard Model the three lines, which show the inverse value of the coupling constant for the three fundamental forces, do not meet at one point, but with the introduction of supersymmetry, and assuming that the supersymmetric particles are not heavier than about 1 TeV/c^2, they do meet at one point. Is this an indication that supersymmetry will be discovered at the next accelerator at CERN, the Large Hadron Collider, or is it merely a coincidence?

However, the Standard Model needs some modification if the dream of the unification of the forces of Nature is to be realised. One possibility is to introduce a new set of particles, supersymmetric particles, that may have a small enough mass to be investigated at the LHC accelerator that is now being built at CERN in Geneva.

If supersymmetry is discovered, it will also imply strong support for string theories that may even unify gravitation with the other three interactions. The Standard Model also needs modification to incorporate the recently discovered properties of neutrinos — that they have a mass dif-

ferent from zero. In addition, perhaps this will lead to an explanation of a number of other cosmological enigmas such as the dark matter that seems to dominate space. Regardless of this development, it is clear that the fantastic and unexpected discovery of asymptotic freedom in QCD (fig. 5) has profoundly changed our understanding of the ways in which the basic forces of Nature in our world work.

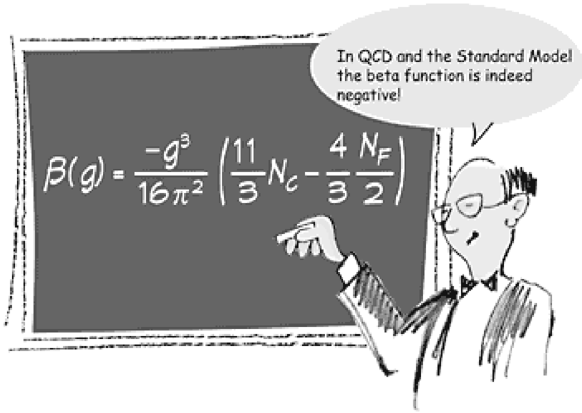


Fig. 5. The formula that describes the discovery. Here: g: coupling constant, N_c: number of colours (= 3 in QCD), N_F: number of quarks (= 6 in the Standard Model).

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2004/public.html)

EXERCISES

1) Give Russian equivalents for the terms and explain their meaning in English.

QCD asymptotic freedom, fine structure constant (coupling constant), perturbation calculation, force carrier, quark colour change, quark-antiquark particle, supersymmetric particles, string theories

2) Say what the main achievements of the following people are in describing the forces governing the microcosmos.

Sinitiro Tomonaga, Julian Schwinger, Richard Feynman, Gerardus't Hooft, Martinus Veltman, Hideki Yukawa, Kurt Sumanzik, David J. Gross, H. David Politzer, Frank A. Wilczek

3) Translate the sentences into English.

a) Адроны — это класс элементарных частиц, подверженных сильному взаимодействию. Адроны делятся на барионы, состоящие из трех кварков (в частности, к ним относятся протоны и нейтроны), и мезоны (пионы, каоны и др.), состоящие из кварка и антикварка.

b) Как выяснилось в 1960-е, элементарные частицы состоят из частиц, в настоящий момент рассматриваемых как истинно элементарные и называемых кварками. Кварк — фундаментальная частица Стандартной модели, имеющая элементарный заряд, кратный e/3, и не наблюдающаяся в свободном состоянии. Выдвигаются гипотезы, по которым кварки также состоят из более простых частиц (преонов). Однако данные гипотезы пока что не получили никакого подтверждения.

c) Бозоны и фермионы — частицы с целым (в случае бозона) или полуцелым (в случае фермиона) значением спина. К фермионам относятся кварки, электроны, мюоны, нейтрино и другие частицы.

d) Джордж Цвейг предложил гипотезу о существовании кварков в 1964 году. Он назвал кварки «тузами», поскольку предполагал, что существует всего четыре кварка. Марри Гелл-Ман постулировал кварковую модель элементарных частиц в 1964 году. Имя кваркам Гелл-Ман нашел в книге Джеймса Джойса «Поминки по Финнегану», где в одном из эпизодов говорится «Три кварка для мистера Марка!».

e) Бертон Рихтер отметил, что открытие J/ψмезона было делом случая. К середине 1970-х годов была уже построена общая теория субатомных частиц, имеющая в своем составе u-, d- и s-кварки. В ней не было места частицам, имеющим хоть один дополнительный кварк.

f) Открытие нового мезона было признано достижением революционного масштаба. Новая частица была столь массивной, что никак не могла состоять из «старых» кварков. Стало очевидно, что Стандартная модель нуждалась в расширении.

g) Сейчас известно, что J/ψ представляет собой мезон, связанное состояние c-кварка и его антикварка. Поскольку очарование c-кварка равно 1, а c-антикварка — 1, очарование мезона J/ψ равно 0. Его массу неоднократно уточняли в экспериментах и, по последним данным, она равна 3,0969 ГэВ (масса c-кварка составляет 1,29 ГэВ)[1].

h) Весомое доказательство в пользу теории квантовой электродинамики было предоставлено благодаря столкновениям электронов и их античастиц, позитронов, приводящим к их взаимной аннигиляции.

Banquet Speech

Read David J. Gross's speech at the Nobel Banquet and see the video at http://www.nobel prize.org.

Your Majesties, Your Royal Highnesses, Ladies and Gentlemen,

For more than 100 years the Nobel Foundation has handed out these generous prizes and hosted these magnificent banquets. All of this was made possible due to the generosity and vision of Alfred Nobel. But can it continue?

To continue having such splendid parties two things are required. First, an inexhaustible supply of money, but also, equally important, an inexhaustible supply of great scientific discoveries.

The first requirement seems to be guaranteed, since the Foundation spends only the interest and wisely invests the capital of Nobel's bequest.

The second requirement might appear harder to satisfy. As knowledge increases, could the pace of scientific discovery slow; as more and more problems are solved?

Fortunately Nature is as generous with its problems as Nobel with his fortune. The more we know, the more aware we are of what we

[1] Левин А. Квантовая хромодинамика. — «Наука в фокусе», октябрь 2014. С. 42–44.

know not. Indeed, the most important product of knowledge is ignorance.

The questions we ask today are more profound and more interesting than those asked years ago when I was a student. Many of those were answered. But back then we did not possess enough knowledge to be intelligently ignorant — and to ask the wonderful questions we ask today.

Some wonder whether some day we will arrive at a theory of everything, and run out of new problems to solve — much as the effort to explore the earth ran out of new continents to explore.

While this is conceivably possible, I am happy to report that there is no evidence that we are running out of our most important resource — ignorance.

How lucky for science.
How lucky for scientists.
And, how lucky for the Nobel Foundation.

(http:www.nobelprize.org/nobel_prizes/physics/laureates/2004/gross-speech.html)

QUESTIONS

1) ***Do you agree that ignorance can be the most important resource as D.J. Gross puts it?***
2) ***Do you believe humanity might one day run out of physics problems to solve?***

Unit 5
The Quantum Theory of Optical Coherence

The Nobel Prize in Physics 2005 — Press Release
October 4, 2005

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2005 with one half to **Roy J. Glauber**, Harvard University, Cambridge, MA, USA, *"for his contribution to the quantum theory of optical coherence" and one half jointly to* **John L. Hall**, JILA, University of Colorado and National Institute of Standards and Technology, Boulder, CO, USA, and **Theodor W. Hänsch**, Max-Planck-Institut für Quantenoptik, Garching and Ludwig-Maximilians-Universität, Munich, Germany, *"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique".*

Read the text and say in what way Roy J. Glauber, John L. Hall and Theodor W. Hänsch cast new light on optics.

New light on modern optics

As long as humans have populated the Earth, we have been fascinated by optical phenomena and gradually unravelled the nature of light. This year's Nobel Prize in Physics is awarded to three scientists in the field of optics. Roy Glauber is awarded half of the Prize for his theoretical description of the behaviour of light particles. John Hall and Theodor Hänsch share the other half of the Prize for their development of laser-based precision spectroscopy, that is, the determination of the colour of the light of atoms and molecules with extreme precision.

Just like radio waves, light is a form of electromagnetic radiation. Maxwell described this in the 1850s. His theory has been utilised in modern communication technology based on transmitters and receivers: mobile telephones, television and radio. If a receiver or a detector is to register light, it must be able to absorb the radiation energy and forward the signal. This energy occurs in packets called quanta and a hundred years ago Einstein was able to show how the absorption of a quantum (a photon) leads to the release of a photoelectron. It is these indirect photoelectrons that are registered in the apparatuses when photons are absorbed.

Thus light exhibits a double nature — it can be considered both as waves and as a stream of particles. Roy Glauber has established the basis of Quantum Optics, in which quantum theory encompasses the field of optics. He could explain the fundamental differences between hot sources of light such as light bulbs, with a mixture of frequencies and phases, and lasers which give a specific frequency and phase.

The important contributions by John Hall and Theodor Hänsch have made it possible to measure frequencies with an accuracy of fifteen digits. Lasers with extremely sharp colours can now be constructed and with the frequency comb technique precise readings can be made of light of all colours. This technique makes it possible to carry out studies of, for example, the stability of the constants of nature over time and to develop extremely accurate clocks and improved GPS technology.

Popular Information

Read the popular information on the 2005 Nobel Prize in Physics and match the paragraphs A-G with the headings: "The birth of Quantum Optics", "How long is a metre?", "Laser Based Precision Spectroscopy", "Future prospects", "The frequency comb — a new measuring stick", "Waves or particles?", "Organised and random light".

What limits the measurable?

A

We get most of our knowledge of the world around us through light, which is composed of electromagnetic waves. With the aid of light we can orient ourselves in our daily lives or observe the most distant galaxies of the universe. Optics has become the physicist's tool for dealing with light phenomena. But what is light and how do various kinds of light differ from each other? How does light emitted by a candle differ from the beam produced by a laser in a CD player?

According to Albert Einstein, the speed of light in empty space is constant. Is it possible to use light to measure time with greater precision

than with the atomic clocks of today? It is questions like these that have been answered by this year's Nobel Laureates in Physics.

In the late 19th century it was believed that the electromagnetic phenomena could be explained by means of the theory that the Scottish physicist James Clerk Maxwell had presented; he viewed light as waves. But an unexpected problem arose when one tried to understand the radiation from glowing matter like the sun, for example. The distribution of the strength of the colours did not agree at all with the theories that had been developed based on Maxwell's original work. There should be much more violet and ultraviolet radiation from the sun than had actually been observed.

This dilemma was solved in 1900 by Max Planck (Nobel Prize, 1918), who discovered a formula that matched the observed spectral distribution perfectly. Planck described the distribution as the result of the inner vibrational state of the heated matter. In one of his famous works a hundred years ago, in 1905, Einstein proposed that radiation energy, i.e. light, also occurs as individual energy packets, so-called quanta. When such an energy packet of this kind enters the surface of a metal, its energy is transferred to an electron, which is released and leaves the material — the photoelectric effect, which was included in Einstein's Nobel Prize in 1921.

Einstein's hypothesis means that a single energy packet, later called a photon, gives all its energy to just one electron. Thus we can count the quanta in the radiation by observing and counting the number of electrons, that is, the electric current that comes from the metal surface.

Almost all later light detectors are based on this effect. When the quantum theory was developed in the 1920s, it met with difficulties in the form of senseless, infinite expressions. This problem was not solved until after the Second World War, when quantum electrodynamics, QED, was developed (Nobel Prize in Physics 1965 to Tomonaga, Schwinger and Feynman). QED became the most precise theory in physics and was central to the development of particle physics. However, in the beginning it was judged unnecessary to apply QED to visible light. Instead it was to be treated as an ordinary wave motion with a number of random variations in intensity. A detailed quantum theoretical description was considered unnecessary.

B

Until the development of the laser and similar devices, most light phenomena could be understood by Maxwell's classical theory. A more realistic description is required when considering the light from a light bulb. Its light waves have different frequencies and wavelengths and are at the same time out of phase with each other. We see the source as affected by random noise. Thus, the incoherence makes the interference pattern less distinct.

Previously, most light sources were based on thermal radiation and special arrangements were required in order to observe the interference pattern. This changed when the laser, with its perfectly coherent light, was developed. Radiation with a well-defined phase and frequency was, of course, well known from radio technology. But somehow it seemed strange to see light from a thermal light source as a wave motion – it seemed easier to describe the disorder that stemmed from it as randomly distributed photons.

C

One half of this year's Nobel Prize in Physics is awarded to Roy J. Glauber for his pioneering work in applying quantum physics to optical phenomena. In 1963 he reported his results; he had developed a method for using electromagnetic quantization to understand optical observations. He carried out a consistent description of photoelectric detection with the aid of quantum field theory. Now he was able to show that the "bunching" that R. Hanbury Brown and R.Twiss had discovered was a natural consequence of the random nature of thermal radiation.

An ideal coherent laser beam does not display the same effect at all. But how can a stream of photons, independent particles, give rise to interference patterns? Here we have an example of the dual nature of light. Electromagnetic energy is transmitted in patterns determined by classical optics. Energy distributions of this kind form the landscape into which the photons can be distributed. These are separate individuals, but they have to follow the paths prescribed by optics. This explains the term Quantum Optics. For low light intensities, the state will be described by only a few photons. The individual particle observations will build the patterns of optics after a sufficient number of photoelectrons have been observed.

An essential feature of the theoretical quantum description of optical observations is that, when a photoelectron is observed, a photon has been absorbed and the state of the photon field has undergone a change. When several detectors are correlated, the system will become sensitive to quantum effects, which will be more evident if only a few photons are present in the field. Experiments involving several photo detectors have been carried out later, and they are all described by Glauber's theory.

Glauber's work in 1963 laid the foundations for future developments in the new field of Quantum Optics. It soon became evident that technical developments made it necessary to use the new quantum description of the phenomena.

An observable effect of the quantum nature of light is the opposite of the above-mentioned "bunching" that photons display. This is called "anti-bunching". The fact is that in some situations photons occur more infrequently in pairs than in a purely random signal. Such photons come from a quantum state that cannot in any way be described as classical waves.

This is because a quantum process can result in a state where photons are well separated, in contrast to the results of a purely random process. Quantum physics sets the ultimate limits and promises new applications. In technical applications, the quantum effects are often very small. The field state is chosen so that it can be assigned well-defined phase and amplitude properties. In laboratory measurements, too, the uncertainty of quantum physics seldom sets the limit. But the uncertainty that nevertheless exists appears as a random variation in the observations. This "quantum noise" sets the ultimate limit for the precision of optical observations. It is only the quantum nature of light that sets a limit for how precise our apparatuses can be.

Our knowledge about quantum states can also be utilised directly. We can get completely new technical applications of quantum phenomena, for example to enable safe encryption of messages within communication technology and information processing.

D

History teaches us that new phenomena and structures are discovered as a result of improved precision in measuring. A splendid example is atomic spectroscopy, which studies the structure of energy levels in atoms. Improved resolution has given us a deeper understanding of both the fine structure of atoms and the properties of the atomic nucleus. The other half of this year's Nobel Prize in Physics, awarded to John L. Hall and Theodor W. Hänsch, is for research and development within the field of laser-based precision spectroscopy, where the optical frequency comb technique is of special interest. The progress that has been made in this field of science can give us previously unthought of possibilities to investigate constants of nature, find out the difference between matter and antimatter and measure time with unsurpassed precision. Precision spectroscopy was developed when trying to solve some quite clear and straightforward problems as follows below.

E

The problem of determining the exact length of a metre illustrates one of the challenges offered by laser spectroscopy. The General Conference of Weights and Measures, which has had the right to decide on the exact definitions since 1889, abandoned the purely material measuring rod in 1960. This was kept under lock and key in Paris and its length could only with difficulty be distributed throughout the world.

By use of measurements of spectra, an atom-based definition was introduced: a metre was defined as a certain number of wavelengths of a certain spectral line in the inert gas krypton.

Some years later also an atom-based definition of a second was introduced: the time for a certain number of oscillations of the resonance frequency of a particular transition in cesium, which could be read off the cesium-based atomic clocks. These definitions made it possible to determine the speed of light as the product of wavelength and frequency.

John Hall was a leading figure in the efforts to measure the speed of light, using lasers with extremely high frequency stability. However, its accuracy was limited by the definition of the metre that was chosen. In 1983, therefore, the speed of light was defined as exactly 299,792,458 m/s, in agreement with the best measurements, but now with zero error! In consequence, a metre was the distance travelled by light in 1/299,792,458 s.

However, measuring optical frequencies in the range round 10^{15} Hz still proved to be extremely difficult due to the fact that the cesium clock had approximately 10^{5} times slower oscillations. A long chain of highly-stabilised lasers and microwave sources had to be used to overcome this problem. The practical utilisation of the new definition of a metre in the form of precise wavelengths remained problematic; there was an evident need for a simplified method for measuring frequency.

Parallel with these events came the rapid development of the laser as a general spectroscopic instrument. Also, methods for eliminating the Doppler effect were developed, which if not dealt with leads to broader and badly identifiable peaks in a spectrum. In 1981 N. Bloembergen and A.L. Schawlow were awarded the Nobel Prize in Physics for their contribution to the development of laser spectroscopy. This becomes especially interesting when an extreme level of precision can be attained, allowing fundamental questions concerning the nature of reality to be tackled. Hall and Hänsch have been instrumental in this process, through the development of extremely frequency-stable laser systems and advanced measurement techniques that can deepen our knowledge of the properties of matter, space and time.

F

Measuring frequencies with extremely high precision requires a laser which emits a large number of coherent frequency oscillations. If such oscillations of somewhat different frequency are connected together, the result will be extremely short pulses caused by interference. However, this only takes place if the different oscillations (modes) are locked to each other in what is called mode-locking. The more different oscillations that can be locked, the shorter the pulses. A 5 fs long pulse (a femtosecond, fs [10^{-15} s], is a millionth billionth of a second) locks about one million different frequencies, which need to cover a large part of the visible frequency range. Nowadays this can be attained in laser media such as dyes or titanium-doped sapphire crystals. A tiny “ball of light” bouncing between the mirrors in the laser arises because a large number of sharp and evenly distributed frequency modes are shining all the time! A little of the light is released as a train of laser pulses through the partially transparent mirror at one end. Since pulsed lasers also transmit sharp frequencies, they can be used for high-resolution laser spectroscopy. This was realised by Hänsch as early as in the late 1970s and he also succeeded in demonstrating it experimentally. V. P. Chebotayev, Novosibirsk, (d. 1992) also came to a similar conclusion.

However, a real breakthrough did not occur until around 1999, when Hänsch realised that the lasers with extremely short pulses that were available at that time could be used to measure optical frequencies directly with respect to the cesium clock. That is so because such lasers have a frequency comb embracing the whole of the visible range. Thus the optical frequency comb technique, as it came to be called, is based on a range of evenly distributed frequencies, more or less like the teeth of a comb or the marks on a ruler. An unknown frequency that is to be determined, can be related to one of the frequencies along the “measuring stick”.

Hänsch and his colleagues convincingly demonstrated that the frequency marks really were evenly distributed with extreme precision. One problem, however, was how to determine the absolute value of the frequency; even if the separation is very well-defined between the teeth of the comb, an unknown common frequency displacement occurs. This deviation must be determined exactly if an unknown frequency is to be measured. Hänsch developed a technique for this purpose in which the frequency also could be stabilised, but the problem was not solved practically and simply until Hall and his collaborators demonstrated a solution around the year 2000. If the frequency comb can be made so broad that the highest frequencies are more than twice as high as the lowest ones (an octave of oscillations), the frequency displacement can be calculated by simple subtraction involving the frequencies at the ends of the octave. It is possible to create pulses of this kind with a sufficiently broad frequency range in so-called photonic crystal fibres, in which the material is partially replaced by air filled channels. In these fibres a broad spectrum of frequencies can be generated by the light itself. Hänsch and Hall and their colleagues have subsequently, partly in collaborative work, refined these techniques into a simple instrument that has already gained wide use and is commercially available. An unknown sharp laser frequency can now be measured by observing the beat between this frequency and the nearest tooth in the frequency comb; this beat will be in an easily-managed radio frequency range. This is analogous to the fact that the beat between two tuning forks can be heard at a much lower frequency than the individual tones.

Quite recently frequency comb techniques have been extended to the extreme ultraviolet range, which can be attained by generating overtones from short pulses. This may mean that extreme precision can be achieved at very high frequencies, thereby leading to the possibility of creating even more accurate clocks at X-ray frequencies.

Another aspect of the frequency comb technique is that the control of the optical phase, that it permits, is also of the greatest importance in experiments with ultra short femtosecond pulses and in ultra-intense laser-matter interaction. The high overtones, evenly distributed infrequency, can be phase-locked to each other, whereby individual attosecond pulses approximately100 as long (1 as = 10^{-18} s) can be generated by interference in the same way as in the mode-locking described above. Thus the technique is of the greatest relevance for precision measurements in both frequency and time.

G

It now seems possible, with the frequency comb technique, to make frequency measurements in the future with a precision approaching one part in 10^{18}. This will soon lead to actualize the introduction of a new, optical standard clock. What phenomena and measuring problems can take advantage of this extreme precision?

The precision will make satellite-based navigation systems (GPS) more exact. Precision will be needed in, for example, navigation on long space journeys and for space-based telescope arrays that are looking for gravitational waves or making precision tests of the theory of relativity. Applications in telecommunication may also emerge.

This improved measurement precision can also be used in the study of the relation of antimatter to ordinary matter. Hydrogen is of special interest. When anti-hydrogen can be experimentally studied like ordinary hydrogen, it will become possible to compare their fundamental spectroscopic properties.

Finally, greater precision in fundamental measurements can be used to test possible changes in the constants of nature over time. Such measurements have already begun to be made, but so far no deviations have been registered. However, improved precision will make it possible to draw increasingly definite conclusions concerning this fundamental issue.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2005/public.html)

EXERCISES

1) Answer the questions.

a) What dilemma did Max Planck manage to solve?

b) What is the photoelectric effect?

c) Can you define a quantum?

d) What are the applications of quantum electrodynamics?

e) What does Roy J. Glauber's pioneering work in physics consist in?

f) Which essential feature does the quantum description of optical observations possess?

g) What is "anti-bunching"?

h) What is John L. Hall's and Theodor W. Hänsch's contribution to developing laser spectroscopy?

i) Can you describe the optical frequency comb technique?

j) What prospects of using the frequency comb technique are mentioned in the text?

2) Fill in the gaps with the following words: quantization, spectroscopic, energy packet, inner vibrational state, interference pattern, spectral distribution, amplitude, phase-locked, krypton.

a) Planck described the distribution as the result of the ____ of the heated matter. His formula matched the observed ____ perfectly.

b) Einstein's hypothesis means that a single ____, later called a photon, gives all its energy to just one electron.

c) Previously, most light sources were based on thermal radiation and special arrangements were required in order to observe the ____.

d) In 1963 Roy J. Glauber reported his results; he had developed a method for using electromagnetic ____ to understand optical observations.

e) In technical applications, the quantum effects are often very small. The field state is chosen so that it can be assigned well-defined phase and ____ properties.

f) A metre was defined as a certain number of wavelengths of a certain spectral line in the inert gas ____.

g) The high overtones, evenly distributed in frequency, can be ____ to each other, whereby individual attosecond pulses approximately 100 as long (1 as = 10^{-18} s) can be generated by interference in the same way as in the mode-locking described above.

h) When anti-hydrogen can be experimentally studied like ordinary hydrogen, it will become possible to compare their fundamental ____ properties.

3) Translate the sentences into Russian.

a) It is only the quantum nature of light that sets a limit for how precise our apparatuses can be.

b) Improved resolution has given us a deeper understanding of both the fine structure of atoms and the properties of the atomic nucleus.

c) However, measuring optical frequencies in the range round 10^{15} Hz still proved to be extremely difficult due to the fact that the cesium clock had approximately 10^{5} times slower oscillations.

d) Measuring frequencies with extremely high precision requires a laser which emits a large number of coherent frequency oscillations.

e) However, a real breakthrough did not occur until around 1999, when Hänsch realised that the lasers with extremely short pulses that were available at that time could be used to measure optical frequencies directly with respect to the cesium clock.

Award Ceremony Speech

Read the award ceremony speech made by Professor Stig Stenholm.

Your Majesties, Your Royal Highnesses, Ladies and Gentlemen,

We live in a world of light. We experience our surroundings by sight. Likewise, light from the most distant galaxies gives us knowledge about the Universe. This year's Prize is concerned with light.

Light displays a characteristic dual nature: it appears both as a wave motion but also as a stream of discrete particles of light, as photons. When a photon hits a material, it can emit one and only one electron.

Light may be described by classical optics, but observing it is always based on the absorption of one quantum of energy.

Optics has been an important part of physics for a long time, and we live with its technical applications every day. Hence, physicists were slow in recognizing the need for a quantum theory of optics. The emergence of the laser, however, made it essential to distinguish its special light from the more disordered radiation emitted by hot bodies. This induced Roy Glauber to utilize the quantum theory to describe the properties of light and how these can be observed. His work laid the foundations for the field of research today called Quantum Optics. This makes it possible to test our conception of the fundamental features of reality.

These results are based on utilization of the quantum character of light. At the same time, light is a wave motion, where a precise colour corresponds to a precise distance between the crests of the waves. Because the velocity of light is constant, the distance between two crests always corresponds to a definite time interval; they occur with a definite frequency. Physicists have long struggled to measure time with extreme accuracy. We need good references for time. A good reference has to be available to everybody, and hence it is chosen from the world of atoms; we have so-called atomic clocks. But a reference is not sufficient; one must also be able to establish the measure of an unknown period of time as compared with the reference. We need a measuring rod to compare two intervals of time.

John Hall and Theodor Hänsch have worked on ever-improved standard references for frequency measurements. In order to compare an unknown period of light with the reference, they have developed the frequency comb technique. This gives a sequence of exactly separated frequencies and a method to set this measuring rod against an unknown frequency. Thus one obtains an extremely accurate number for the unknown period. This allows spectroscopic measurements with extremely high precision. Today this technique is as exact as the methods developed for this purpose during earlier decades, but it promises many times improved accuracy.

The history of physics shows that, when the accuracy of measurements is improved, new physics may be discovered and explored. The work honored today facilitates tests of our basic theories in physics. The character of time and space may be clarified, and the limitations of the laws of physics may be established.

This year's Nobel Prize explores two of the ultimate modes of behavior of light. Its lumpy quanta determine the smallest packet of energy that can be utilized in measurements. At the other extreme, its role as a perfect wave motion may act as a reference for time periods.

Professor Glauber has shown how to apply quantum considerations to all light sources. Thus he initiated the field of Quantum Optics, which today offers both challenging tasks for the scientists and promising techniques for future quantum engineering.

Professor Hall and Professor Hänsch have developed highly precise methods for spectroscopy and provided the measuring rod to compare optical signals, the frequency comb. Thus the determination of the frequency of an unknown light becomes both simpler and more exact. The present state of the art is highly precise, but future developments promise progress far beyond the achievements of today.

Professor Glauber, Professor Hall and Professor Hänsch, you have been awarded the 2005 Nobel Prize in Physics for your research into the properties of light, extending our knowledge and technology into the extremes of its dual nature. On behalf of the Royal Swedish Academy of Sciences, I convey to you the warmest congratulations. I now ask you to step forward to receive your Nobel Prizes from the hands of His Majesty the King.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2005/presentation-speech.html)

EXERCISES

1) Comment on the main points of the speech using the following word combinations.

to be concerned with smth, to live with the technical applications of light every day, to be slow in recognizing smth, to make smth essential, to distinguish smth from smth, to induce smb to do smth, to lay the foundations for a field of research, the fundamental features of reality, to test a conception of smth, to measure smth with extreme accuracy, limitations of the laws of physics, to offer challenging tasks for smb, the present state of the art

2) The contributions made by Roy J. Glauber, John L. Hall and Theodor Hänsch were preceded by centuries of scientific enquiry into the nature of light. Match the names of the scientists listed on the right with their achievements in the left column.

a) development of a system of electric power generation and distribution	Joseph Swan
b) invention of the incandescent light bulb	Thomas Alva Edison
c) introducing the concept of quantization of radiation	Max Planck
d) discovery and identification of the electron	J.J. Thomson
e) establishing the wave theory of light	Thomas Young
f) pioneering work in photographic studies of motion and motion-picture projection	Eadweard Muybridge
g) pioneering work in developing the modern atomic theory and research into color blindness	John Dalton
h) bringing together electricity, magnetism and light as manifestations of the same phenomenon	James Clerk Maxwell

Unit 6

Cosmic Microwave Background Radiation

The Nobel Prize in Physics 2006 — Press Release

October 3, 2006

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2006 jointly to **John C. Mather** NASA Goddard Space Flight Center, Greenbelt, MD, USA, and **George F. Smoot** University of California, Berkeley, CA, USA, *"for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"*.

Pictures of a newborn Universe

This year the Physics Prize is awarded for work that looks back into the infancy of the Universe and attempts to gain some understanding of the origin of galaxies and stars. It is based on measurements made with the help of the COBE satellite launched by NASA in 1989.

The COBE results provided increased support for the Big Bang scenario for the origin of the Universe, as this is the only scenario that predicts the kind of cosmic microwave background radiation measured by COBE. These measurements also marked the inception of cosmology as a precise science. It was not long before it was followed up, for instance by the WMAP satellite, which yielded even clearer images of the background radiation. Very soon the European Planck satellite will be launched in order to study the radiation in even greater detail.

According to the Big Bang scenario, the cosmic microwave background radiation is a relic of the earliest phase of the Universe. Immediately after the big bang itself, the Universe can be compared to a glowing body emitting radiation in which the distribution across different wavelengths depends solely on its temperature. The shape of the spectrum of this kind of radiation has a special form known as blackbody radiation. When it was emitted the temperature of the Universe was almost 3,000 degrees Centigrade. Since then, according to the Big Bang scenario, the radiation has gradually cooled as the Universe has expanded. The background radiation we can measure today corresponds to a temperature that is barely 2.7 degrees above absolute zero. The Laureates were able to calculate this temperature thanks to the blackbody spectrum revealed by the COBE measurements.

COBE also had the task of seeking small variations of temperature in different directions (which is what the term 'anisotropy' refers to). Extremely small differences of this kind in the temperature of the cosmic background radiation — in the range of a hundred-thousandth of a degree — offer an important clue to how the galaxies came into being. The variations in temperature show us how the matter in the Universe began to "aggregate". This was necessary if the galaxies, stars and ultimately life like us were to be able to develop. Without this mechanism matter would have taken a completely different form, spread evenly throughout the Universe.

COBE was launched using its own rocket on 18 November 1989. The first results were received after nine minutes of observations: COBE had registered a perfect blackbody spectrum. When the curve was later shown at an astronomy conference the results received a standing ovation.

The success of COBE was the outcome of prodigious team work involving more than 1,000 researchers, engineers and other participants. **John Mather** coordinated the entire process and also had primary responsibility for the experiment that revealed the blackbody form of the microwave background radiation measured by COBE. **George Smoot** had main responsibility for measuring the small variations in the temperature of the radiation.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2006/press.html)

EXERCISES

1) ***Find English equivalents for the following word combinations in “Pictures of a newborn Universe”.***

излучение черного тела; попытки понять происхождение галактик и звезд; быть основанным на измерениях; предоставить значительную поддержку теории большого взрыва; возникновение космологии как точной науки; дать еще более четкие изображения; реликт наиболее ранней стадии существования вселенной; суметь измерить температуру; предоставить важную подсказку о том, как появились галактики; принять совершенно иную форму; равномерно распространиться по вселенной; результат удивительной командной работы, включавшей более 1000 исследователей, инженеров и других участников; координировать весь процесс; нести основную ответственность за что-либо

2) ***Sum up the main ideas of the text.***

George F. Smoot — Interview

Listen as you read. Highlight the most important issues in writing.

"In human terms ... it's like looking at an embryo that's a few hours old"

Telephone interview with Professor George F. Smoot immediately following the announcement of the 2006 Nobel Prize in Physics, October 3, 2006. The interviewer is Adam Smith, Editor-in-Chief of Nobelprize.org.

[George Smoot] – Hello.
[Adam Smith] – Good morning, I'm sorry to call so early, may I speak to Professor Smoot please?
[GS] – Speaking.
[AS] – Oh, hello, my name's Adam Smith. I'm calling from the official website of the Nobel Foundation. We have ...
[GS] – The which?
[AS] – The official website of the Nobel Foundation.
[GS] – Oh, I see, OK.
[AS] – We have a tradition of recording brief telephone interviews with Laureates shortly after they've won. Well, first of all, many, many congratulations. Presumably you were asleep when they called you, since you're in California?
[GS] – Yes, because it was still before three o'clock in the morning.
[AS] – So, did you manage to get back to bed or have you been up since then?
[GS] – Unfortunately I've been up since then because people have been calling ever since.

[AS] – I'm sure, you must be exhausted. So just a few questions. You've been awarded the prize particularly for your painstaking work revealing that the cosmic background radiation ...
[GS] – Right, co-awarded it with John Mather.
[AS] – Exactly, and indeed we spoke to Professor Mather a little earlier. But your part was particularly revealing that the background radiation contains these minute variations which are the whispers of earlier galaxies – of the earliest galaxies.
[GS] – Right, and actually galaxies and also clusters of galaxies and even larger scale structures.
[AS] – And what time are we looking back to when we observe these?
[GS] – We're looking back to a time which is between 300,000 and 400,000 years after the Big Bang, which seems like a long time, but we're, you know, 15 billion years, 14 billion years after the Big Bang now. So, in human terms the analogy I usually give is that it's like looking at an embryo that's a few hours old. That's how far back we're looking, in terms of – you know, putting the universe in human terms.
[AS] – It's a very vivid analogy, yes. They were predicted to exist, these variations or anisotropies?
[GS] – Actually they were predicted to exist. They were predicted to exist at a level — in the percent level, and then at the tenth of a percent level, and then at the hundredth of a percent level, and they had to exist by the part in ten thousand that we found them. Because otherwise we'd have to have a whole new model of how the universe was put together, which was always possible, but did not turn out to be the case.
[AS] – Right. And you just needed to get up into space to actually be able to observe them?
[GS] – Right. We not only had to wait to get into space, we actually had to improve — we had a delay because of the shuttle disaster and during that time I was able to convince NASA headquarters to give us additional time and funds to improve the receiver quality so that we could actually detect it.
[AS] – So the delay worked in one's favour a little bit. And I once heard that you offered a plane ticket to anywhere in the world for anyone who could find a mistake in your data. Is that true, and was it just a clever strategy to get rid of annoying people?
[GS] – No, that was a strategy — the problem was that once we discovered it, you know, your job as a scientist and my job as the leader of the team was to make sure that there wasn't some mistake or something

wrong. And so it was for the members of my team to try and really probe; instead of taking that we've just made the discovery, look at it really carefully and make sure that we haven't made a mistake because a part in ten thousand is very tiny, and even a small mistake could cause that effect.
[AS] – And as a result of these observations, the Big Bang theory is now pretty much accepted as proven. Is that correct?
[GS] – Well, the Big Bang theory is the accepted theory of cosmology. You never prove anything completely, but it's the accepted theory of cosmology. And we continue on, in my group, we continue on with balloon observations, and then there's the WMAP and now we're getting the Max Planck surveyor satellite ready with the European Space Agency, who is sponsoring that. So there's a whole sequence. What it was, was that was the opening shot and saying OK, there's some gold to be discovered in the hills, go looking for it.
[AS] – So the cosmic microwave background radiation contains yet more, unrevealed information which you're now looking for?
[GS] – We don't know if there's more unrevealed information. The better we measure the more precisely we're going to know the general parameters of the universe.
[AS] – Presumably it also contains the signatures of more recent cataclysmic events? Is it just that the strength of the signal from the early universe is so strong that it masks what happened later?
[GS] – It's the strength from the early universe that we're really interested in, so we choose the places where we look and the frequencies that we look at in order to emphasize the early universe. Clearly you can see the imprints from clusters of galaxies and from other things in that, but they're generally on different energy scales and in particular places in the sky, and so you try and either average over them, or avoid those regions, including our own galactic plane.
[AS] – Right. I've kept you for long enough but I just wanted to ask whether you've had any time to think about how you're planning to celebrate today, you and your team?
[GS] – My problem is I have to finish making my breakfast (which I'm doing right now) and then I have to rush in because we've scheduled a press conference for 10. And then I've got to get my — I have a midterm exam to give tomorrow and I've got to get that finished, and ready for my students.

[AS] – Life goes on. Well, we were very lucky to catch you for these few minutes. Thank you very much and we speak at greater length when you come to Stockholm in December so I hope we can continue ....
[GS] – OK. Well, I look forward to that. I've got to figure out how to schedule my final exam so I can come.
[AS] – I'm sure your students will be as helpful as they can be.
[GS] – Be understanding? I don't think so!
[AS] – It's not the nature of students.
[GS] – I've got 170 students. I bet only a few of them will understand.
[AS] – I'm sure they will be very proud though. Anyway, once again, congratulations, and thank you for talking to us.
[GS] – Thank you very much.
[AS] – Bye, bye.
[GS] – Bye.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2006/smoot-interview.html)

John C. Mather — Interview

Listen as you read. Sum up the most important information.

"I think of it as the accumulated trace of everything"

Telephone interview with Dr. John C. Mather immediately following the announcement of the 2006 Nobel Prize in Physics, October 3, 2006. The interviewer is Adam Smith, Editor-in-Chief of Nobelprize.org.

[John Mather] – Good morning.
[Adam Smith] – Good morning, may I speak to Professor Mather please?
[JM] – This is John Mather, yes.
[AS] – Hello, my name is Adam Smith and I'm calling from the official website of the Nobel Foundation.
[JM] – Oh, yes.
[AS] – I know you've just been on the phone to the Royal Academy of Sciences but we have a tradition of recording very brief telephone interviews with Nobel Laureates immediately after they have been informed, so would you mind if I asked you a few, quick questions.
[JM] – No, please do, that's fine.

[AS] – Thank you. It's pretty early there, what were you doing when you actually heard the news?
[JM] – Well, I was asleep. I'm just barely waking up. So ...
[AS] – I can imagine ...
[JM] – I did receive a phone call from the Academy this morning.
[AS] – Must have been quite a surprise.
[JM] – Yes.
[AS] – You and George Smoot have been awarded the prize for your discovery, or rather for the satellite measurements of faint signatures of the early universe left behind in the form of background radiation. Why is it so important to observe this background radiation from space?
[JM] – Well, it really is very difficult to observe it well from the ground. The atmosphere of the earth absorbs the radiation somewhat, and even at wavelengths where the radiation does come through, the atmosphere emits its own radiation, which confuses matters quite a lot. So it really was important to get up into space where it's cold and quiet.
[AS] – And I gather it took many, many years of work to get up into space with the COBE satellite?
[JM] – Yes, 15 years from proposal to launch and then we operated the satellite for 4 more years, and kept on analyzing data for another several years after that.
[AS] – So you need some considerable patience before you reach your Eureka moment?
[JM] – Yes. Well one suspects, in the beginning, but one doesn't know, and so extreme care is required, especially for these kinds of things because there's basically no other way to tell if the equipment got the right answer.
[AS] – And once the data did start flooding in the first key finding was that the cosmic background radiation did indeed display a perfect blackbody radiation spectrum. What does that tell us?
[JM] – Well, it says that the radiation really did come from the big bang. There really is not a good alternative explanation for having such a perfect blackbody spectrum. Many people looked, but no good explanation was found, and so the big bang theory is confirmed by that spectrum.
[AS] – Right. Now what are we actually seeing in the CMB? Is it a snapshot of a particular moment, or rather the accumulated trace of hundreds of thousands of years?
[JM] – Well, I think of it as the accumulated trace of everything. The history is roughly this; the early universe, in the first submicroseconds, was extremely [word inaudible] and all of the cosmic particles, protons,

electrons, unstable nuclear particles, neutrinos and photons and background radiation were all hot and were all together. Then, as the universe expanded, progressively each kind either disappeared, because it was unstable, or annihilated some other kind of particle, or did not. But in any case they all cooled down and so the cosmic microwave background radiation is actually a remnant that traces back to those very earliest moments. But we see features of it that were finally set later. For instance, the spectrum that we observed to test the big bang theory could have been modified as late as, say a year after the big bang. And even in most recent times of course things in our own galaxy, and other galaxies, can emit small amounts of radiation that would confuse the measurements.

[AS] – Quite. So presumably all hot bodies are leaving their own, small background signatures?

[JM] – Absolutely. And similarly the spatial distribution, the map that we obtained, that shows the hot and cold spots, that shows the universe as it was approximately 389,000 years after the big bang.

[AS] – That's very precise. And is there further information hidden in the CMB?

[JM] – Yes, we certainly think so. One of the continuing investigations is to get the polarization of this radiation. The polarization (is expected and some has been measured) tells us already that the first luminous objects after the big bang were quite early, when the universe was less than a 20th of its present size. So that's already been measured with the WMAP satellite, and much more is thought to be lurking there in the radiation if we could measure even better. Traces from the gravitational waves of the earliest universe, for instance.

[AS] – Right. So increasing precision will yield more data.

[JM] – Yeah.

[AS] – What's the main challenge to getting that increased precision?

[JM] – Well, it's extremely carefully done because the signature is extremely faint. The radiation itself is called ‘faint', but it's not so faint; it's about a microwatt per square meter coming to us, you can actually say that. But the spectrum measurement was made to a part in a hundred thousand accuracy and the hot and cold spots are about a part in a hundred thousand. Now this polarization is maybe a hundredth of that, so we're getting down to signals that are measured in nanoKelvins.

[AS] – And COBE was a NASA project. Is it becoming more of an international effort as time goes on?

[JM] – Well, the European Space Agency is about to launch the Planck mission and maybe they will even make some progress with this polarization question. They certainly will have sensitivity to finer scale features on this guy.

[AS] – I suppose the last question that I wanted to ask was how you intend to celebrate the award of the prize with your team, which I know is very large?

[JM] – Good question. I think I will need to talk to them.

[AS] – That's fair enough. OK, well many, many congratulations on the award and thank you very much for sparing the time to speak to us.

[JM] – Thank you.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2006/mather-interview.html)

Banquet Speech

Look through John C. Mather's banquet speech and then watch a video clip at http://www.nobelprize.org. What is the leitmotif of the speech?

Your Majesties, Your Royal Highnesses, Your Excellencies, Honored Guests, Ladies and Gentlemen,

It is a great honor for George Smoot and me to accept the Prize in Physics this year for our work on the very first light, the incredibly intense heat radiation that filled the universe when it was young, and still shines down on us with a microwatt per square meter even now. We are here with the members of the Cosmic Background Explorer science team who did this work with us, and with a few of the 1600 other professionals at NASA's Goddard Space Flight Center and Ball Aerospace, who found a way to build what had never been built before, to find out what had never been known before. I am here with my wife Jane, who has shared in this project from the beginning, as have all our families, and we are so happy we could burst. We always knew our work was important, and now you know and everyone knows.

You might ask, why is light so important, that it is the subject of 14 previous Nobel Prizes, including one for the discovery of this very same primeval radiation? That is like asking, why is there a universe to explore, or what was there before the Big Bang? Everybody asks that question, but I don't have an answer. When, or if, we do have an answer, I am pretty sure that the Nobel committee will consider it an important discovery. Light gives us life through photosynthesis, it fills one of our only five senses, it lets us see back in time towards that cosmic big bang, and it helps us communicate with the other sentient beings here on earth, and maybe in outer space, though the odds of finding those other beings are small. Christer Fuglesang, Sweden's first astronaut, is helping us start our trip into the solar system, and we use radio, which is a form of light, to talk to him. Einstein studied light to develop the theory of relativity, believing that the laws of nature that give us light must surely be true no matter how fast we are moving. And now we know that even electrons and protons behave a lot like waves of light, in ways that continue to astonish us. They give us the basic laws of chemistry and lead to the complexity of biology and eventually to that incomprehensible consciousness that brings us together here tonight.

And now we are here, in this beautiful northern city, at a time of year when the light from the Sun is hidden from us so much, we enjoy the fruits of science and engineering, we turn on the light wherever we go, and marvel at the sweet mystery of life. George and I and the whole COBE team thank the Nobel Foundation for recognizing our work, and we are happy to say, that by giving the Nobel Prizes, Sweden achieves far greater honor than we do. For all of us who worked on the COBE project, and all our families, we thank you with all our hearts.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2006/mather-speech.html)

Translate into English.

КАК УВИДЕТЬ РАННЮЮ ВСЕЛЕННУЮ

Нобелевская премия по физике 2006 года вручена американским исследователям Джону Мазеру (Mather) и Джорджу Смуту (Smoot) "за работу, позволяющую проследить развитие Вселенной и понять процесс возникновения космического пространства, звезд и галактик" — сказано в заявлении Шведской королевской академии наук.

В начале 1960-х годов американские исследователи Арно Пензиас и Роберт Вилсон обнаружили слабое электромагнитное излучение, приходящее из космического пространства. Это излучение известный российский астрофизик И.С. Шкловский очень метко назвал реликтовым, ибо его флуктуации (отклонения от средней величины) отражают то распределение плотности вещества во Вселенной, которое было много миллиардов лет назад.

Сценарий Большого взрыва предполагает, что на первой стадии развития Вселенной она была заполнена нагретыми до сотен тысяч градусов ионизованными газами — водородом и гелием, которые не пропускали излучения. Примерно через полмиллиона лет температура упала до 3000 градусов, газ стал нейтральным и прозрачным. Излучение стало распространяться во все стороны, неся информацию о распределении плотности вещества. За прошедшее с этого момента время температура излучения упала до 2,725 К, а средняя величина его флуктуаций составляет 10^{-5} К. Спектр реликтового излучения соответствует спектру абсолютно черного тела.

Измерить столь малые перепады температуры удалось при помощи спутника КОБЕ (COBE — Cosmic Background Explorer), запущенного НАСА в 1989 году, и системы отечественных спутников "Реликт" и "Реликт-1", которые выводились на орбиту в эти же годы. Обработка результатов, полученных с орбитальной аппаратуры, позволила подтвердить справедливость гипотезы Большого взрыва и получить карту первичного распределения вещества в ранней Вселенной, из которого впоследствии образовались звезды, галактики и их скопления.

(Наука и жизнь №11,2006 г.)

Unit 7

Giant Magnetoresistance

The Nobel Prize in Physics 2007 — Press Release

October 9, 2007

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2007 jointly to **Albert Fert**, Unité Mixte de Physique CNRS/THALES, Université Paris-Sud, Orsay, France, and **Peter Grünberg**, Forschungszentrum Jülich, Germany, *"for the discovery of Giant Magnetoresistance"*.

Nanotechnology gives sensitive read-out heads for compact hard disks

This year's physics prize is awarded for the technology that is used to read data on hard disks. It is thanks to this technology that it has been possible to miniaturize hard disks so radically in recent years. Sensitive read-out heads are needed to be able to read data from the compact hard disks used in laptops and some music players, for instance.

In 1988 the Frenchman **Albert Fert** and the German **Peter Grünberg** each independently discovered a totally new physical effect — Giant Magnetoresistance or GMR. Very weak magnetic changes give rise to major differences in electrical resistance in a GMR system. A system of this kind is the perfect tool for reading data from hard disks when information registered magnetically has to be converted to electric current. Soon researchers and engineers began work to enable use of the effect in read-out heads. In 1997 the first read-out head based on the GMR effect was launched and this soon became the standard technology. Even the most recent read-out techniques of today are further developments of GMR.

A hard disk stores information, such as music, in the form of microscopically small areas magnetized in different directions. The information is retrieved by a read-out head that scans the disk and registers the

magnetic changes. The smaller and more compact the hard disk, the smaller and weaker the individual magnetic areas. More sensitive read-out heads are therefore required if information has to be packed more densely on a hard disk. A read-out head based on the GMR effect can convert very small magnetic changes into differences in electrical resistance and therefore into changes in the current emitted by the read-out head. The current is the signal from the read-out head and its different strengths represent ones and zeros.

The GMR effect was discovered thanks to new techniques developed during the 1970s to produce very thin layers of different materials. If GMR is to work, structures consisting of layers that are only a few atoms thick have to be produced. For this reason GMR can also be considered one of the first real applications of the promising field of nanotechnology.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2007/press.html)

EXERCISES

1) Answer the questions using the following word combinations and phrases from the text.

to read data, it is thanks to this technology that…, to miniaturize hard disks, to discover smth independently, to give rise to major differences, the perfect tool for reading data, to be converted to electric current, to become the standard technology, further developments of GMR, to retrieve information, to pack information more densely on a hard disk, to convert very small magnetic changes into differences in electric resistance, one of the first real applications of nanotechnology

a) What has Giant Magnetoresistance made possible?

b) Who discovered this effect?

c) What does a GMR system consist of?

d) How does it work? What is the future of GMR?

2) Translate the text in writing.

Speed Read

Translate at sight.

The Giant within Small Devices

Lying at the heart of the computer which you are using to read this article is a memory retrieval system based on the discoveries for which the 2007 Nobel Prize in Physics was awarded to Albert Fert and Peter Grünberg. They discov-ered, quite independently, a new way of using magnetism to control the flow of electrical current through sandwiches of metals built at the nanotechnology scale.

150 years ago, William Thomson observed very small changes in the electrical properties of metals when they were placed in a magnetic field, a phenomenon he named 'Magnetoresistance'. In due course, his finding found application, magnetically-induced current fluctuations becoming the underlying principle for reading computer memories. Then, in 1988, Fert and Grünberg, working with specially-constructed stacks made from alternating layers of very thinly-spread iron and chromium, unexpectedly discovered that they could use magnetic fields to evoke much greater increases in electrical resistance than Thomson, or anyone since, had observed. Recognizing the novelty of the effect, Fert named it 'Giant magnetoresistance', and it was only a few years before the improvements, and the miniaturization, it offered led to its adoption in favour of classical magnetoresistance.

Giant magnetoresistance is essentially a quantum mechanical effect depending on the property of electron spin. Using an applied magnetic field to cause the electrons belonging to atoms in alternate metal layers to adopt opposite spins results in a reduction in the passage of electric current, in a similar fashion to the way that crossed polarizing filters block the passage of sunlight. When, however, magnetic fields are used to align the electron spins in different layers, current passes more easily, just as light passes through polarizers aligned in the same direction.

The application of this discovery has been rapid and wide-ranging, dramatically improving information storage capacity in many devices, from computers to car brakes. And while quietly pervading the technol-

ogy behind our daily lives, the principles of giant magnetoresistance are now being used to tackle problems in wider fields, for instance, in the selective separation of genetic material.

(by Adam Smith, Editor-in-Chief, Nobelprize.org)

Advanced Information

The phenomenon called magnetoresistance (MR) is the change of resistance of a conductor when it is placed in an external magnetic field. For ferromagnets like iron, cobalt and nickel this property will also depend on the direction of the external field relative to the direction of the current through the magnet. Exactly 150 years ago W. Thomson (Lord Kelvin) measured the behaviour of the resistance of iron and nickel in the presence of a magnetic field. He wrote "I found that iron, when subjected to a magnetic force, acquires an increase of resistance to the conduction of electricity along, and a diminution of resistance to the conduction of electricity across, the lines of magnetization". This difference in resistance between the parallel and perpendicular case is called anisotropic magnetoresistance (AMR). It is now known that this property originates from the electron spin-orbit coupling. In general magnetoresistance effects are very small, at most of the order of a few per cent.

The MR effect has been of substantial importance technologically, especially in connection with readout heads for magnetic disks and as sensors of magnetic fields. The most useful material has been an alloy between iron and nickel, $Fe_{20}Ni_{80}$ (permalloy). In general, however, there was hardly any improvement of the performance of magnetoresistive materials since the work of Kelvin. The general consensus in the 1980s was that it was not possible to significantly improve on the performance of magnetic sensors based on magnetoresistance.

Therefore it was a great surprise when in 1988 two research groups independently discovered materials showing a very large magneto resistance, now known as giant magnetoresistance (GMR). These materials are so called magnetic multilayers, where layers of ferromagnetic and non-magnetic metals are stacked on each other. The widths of the individual layers are of nanometre size — i.e. only a few atomic layers thick. In the original experiments leading to the discovery of GMR one group, led by Peter Grünberg, used a trilayer system Fe/Cr/Fe, while the other group, led by Albert Fert, used multilayers of the form $(Fe/Cr)_n$ where n could be as high as 60. Grünberg also reported low temperature magnetoresistance measurements for a system with three iron layers separated by two chromium layers and found a resistance decrease of 10%.

Not only did Fert and Grünberg measure strongly enhanced magnetoresistivities, but they also identified these observations as a new phenomenon, where the origin of the magnetoresistance was of a totally new type. The title of the original paper from Fert's group already referred to the observed effect as "Giant Magnetoresistance". Grünberg also realized at once the new possibilities for technical applications and patented the discovery. From this very moment the area of thin film magnetism research completely changed direction into magnetoelectronics. /…/

The resistance of a GMR device can be understood from the following somewhat simplified way. A plot of the magnetic configuration for the FM/NM/FM (ferromagnetic/non-magnetic/ferromagnetic) multilayer is made together with the corresponding electron density of state for the two ferromagnetic sides (FM). In the absence of a magnetic field the two FM layers are separated from each other in such a way that they have opposite magnetization directions. In the presence of a magnetic field the magnetizations of the two FM layers will be parallel. An electrical current is sent through the system for both configurations. As already mentioned above the current through the FM layer is composed of two types — one spin up current and one spin down current — and the resistance for these two currents will differ. When an electron leaves the first iron layer and enters the non-magnetic metal there will be additional scattering processes giving rise to extra resistance. Since the spin up and spin down particles have different density of states at the Fermi level (or rather, they originate from energy levels having different character), the resistance not only within the FM layers, but also that originating from the FM/NM interface will be different for the two spins.

Inside the NM layer the up and down spins will experience the same resistance, but generally this is low compared to those in the FM layers and FM/NM interfaces and can here be neglected. When the electrons enter the second iron layer they will again experience spin dependent scattering at the NM/FM interface. Finally the spin up and spin down electrons go through the second iron layer with the same resistance as in the first iron layer, which still of course differs for the two spins. For simplicity the resistance for the spin up (down) electrons through the FM layer and the scattering at the interface to the NM layer will be called $R\uparrow$ ($R\downarrow$). Thus when the two layers have parallel spin polarizations (magnetizations), i.e. in the presence of an external magnetic field (H), the resistance for the spin up channel is $2\,R\uparrow$ and for the spin down channel it is $2\,R\downarrow$. Standard addition of resistances for a parallel current configuration gives the following total resistance, RH, in the presence of an external magnetic field; $R_H = 2R\uparrow R\downarrow/(R\uparrow + R\downarrow)$./…/

Since magnetoresistance deals with electrical conductivity it is obvious that it is the behaviour of the electrons at the Femi surface (defined by the Fermi energy) which is of primary interest. The more spin-polarized the density of states (DOS) at the Fermi energy, i.e., the more $N\uparrow(E_F)$ deviates from $N\downarrow(E_F)$, the more pronounced one expects the efficiency of the magnetoelectronic effects to be. In this respect a very interesting class of materials consists of what are called half-metals, a concept introduced by de Groot and co-workers. Such a property was then predicted theoretically for CrO_2 by Schwarz in 1986. The name half-metal originates from the particular feature that the spin down band is metallic while the spin up band is an insulator. It is clear that there is a 100% spin polarization at the Fermi level. The theoretical prediction for CrO_2 was later confirmed by experiment./…/

Another variation of multilayers in the present context is to grow layered materials with an alternation between metallic and insulating layers. Here the insulating material should be only a few atomic layers thick so that there is a significant probability that electrons can quantum mechanically tunnel through the insulating barrier. In this manner a current can be sent through the multilayer. The first publication on such a system was made by Julliere. This work was done for a trilayer junction with the following structure Fe/amorphous Ge/Co. The experiments were done at low temperature and an effect of about 14% was reported. /…/

The discovery by Albert Fert and Peter Grünberg of giant magnetoresistance (GMR) was very rapidly recognized by the scientific community. Research in magnetism became fashionable with a rich variety of new scientific and technological possibilities. GMR is a good example of how an unexpected fundamental scientific discovery can quickly give rise to new technologies and commercial products. The discovery of GMR opened the door to a new field of science, magnetoelectronics (or spintronics), where two fundamental properties of the electron, namely its charge and its spin, are manipulated simultaneously. Emerging nanotechnology was an original prerequisite for the discovery of GMR, now magnetoelectronics is in its turn a driving force for new applications of nanotechnology. In this field, demanding and exciting scientific and technological challenges become intertwined, strongly reinforcing progress.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2007/advanced.html)

EXERCISES

1) Translate the terms into Russian.

AMR, GMR, electron spin-orbit coupling, electron density, Fermi level, parallel spin polarization, scattering process, energy level, magnetic multilayer

2) Answer the questions.

a) How did W. Thomson (Lord Kelvin) contribute to studying the phenomenon of magnetoresistance?

b) Can you define anisotropic magnetoresistance (AMR) and giant magnetoresistance (GMR)?

c) What metals did the groups led by Peter Grünberg and Albert Fert use in their groundbreaking experiments in the 1980s? What did they achieve?

d) Can you describe the resistance of a GMR device?

e) What are half-metals?

f) What is tunneling magnetoresistance?

g) What new field of science did the discovery of GMR lead to?

h) Which new technological possibilities did GMR reveal?

3) Translate the sentences into Russian.

a) Not only did Fert and Grünberg measure strongly enhanced magnetoresistivities, but they also identified these observations as a new phenomenon, where the origin of the magnetoresistance was of a totally new type.

b) Since magnetoresistance deals with electrical conductivity it is obvious that it is the behaviour of the electrons at the Femi surface (defined by the Fermi energy) which is of primary interest.

c) Here the insulating material should be only a few atomic layers thick so that there is a significant probability that electrons can quantum mechanically tunnel through the insulating barrier.

Translate the text into English in writing.

ВКЛАД АЛЬБЕРА ФЕРА И ПЕТЕРА ГРЮНБЕРГА

Альбер Фер с коллегами исследовал систему из нескольких десятков чередующихся слоев железа и хрома. Чтобы получить должный эффект, ученые проводили эксперименты в условиях почти полного вакуума при низкой температуре. Группа Петера Грюнберга работала с более простой системой, состоящей из двух или трех слоев железа, проложенных слоем хрома.

Фер обнаружил, что электрическое сопротивление пленок уменьшается на 50%, когда относительная намагниченность ферромагнитных слоев изменяется от антипараллельной до параллельной конфигурации при наложении внешнего магнитного поля в условиях низких температур. У Грюнберга показатели меньше – всего 1,5%, но при комнатной температуре (эта цифра выросла до 10% при температуре 5К). Физическая природа эффекта, который наблюдали независимо обе группы ученых, оказалась одинаковой. Ученые констатировали, что наблюдали совершенно новое явление. Альбер Фер был одним из тех, кто предложил теоретическое объяснение гигантского магнетосопротивления и в своей первой публикации 1988 года указал, что открытие может иметь большое значение для практики. Петер Грюнберг также отметил практический потенциал явления и одновременно с публикацией своих научных исследований в 1989 году предусмотрительно оформил патенты в Германии, Европе и США.

Но для широкого применения новой технологии требовалось разработать промышленный процесс получения тончайших слоев. Метод, который использовали и Грюнберг, и Фер, был достаточно сложным и дорогим. Он больше подходил для лабораторных исследований, а не для крупномасштабных промышленных разработок. Воплотить фундаментальные разработки в жизнь помогли работы англичанина Стюарта Паркина (Stuart Parkin). Он показал, что для изготовления тонкослойных магнитных “сэндвичей” можно использовать технологию магнетронного распыления, причем при комнатной температуре. И с 1997 года началось производство GMR-головок, которые позволили многократно увеличить емкость жестких дисков.

(Наука и жизнь № 11, 2007 г.)

Unit 8

Spontaneous Broken Symmetry in Subatomic Physics

The Nobel Prize in Physics 2008 — Press Release

October 7, 2008

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2008 with one half to **Yoichiro Nambu** Enrico Fermi Institute, University of Chicago, IL, USA, *"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"* and the other half jointly to **Makoto Kobayashi**, High Energy Accelerator Research Organization (KEK), Tsukuba, Japan and **Toshihide Maskawa**, Yukawa Institute for Theoretical Physics (YITP), Kyoto University, and Kyoto Sangyo University, Japan, *"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"*.

Passion for symmetry

The fact that our world does not behave perfectly symmetrically is due to deviations from symmetry at the microscopic level.

As early as 1960, **Yoichiro Nambu** formulated his mathematical description of spontaneous broken symmetry in elementary particle physics. Spontaneous broken symmetry conceals nature's order under an apparently jumbled surface. It has proved to be extremely useful, and Nambu's theories permeate the Standard Model of elementary particle physics. The Model unifies the smallest building blocks of all matter and three of nature's four forces in one single theory.

The spontaneous broken symmetries that Nambu studied, differ from the broken symmetries described by **Makoto Kobayashi** and **Toshihide Maskawa**. These spontaneous occurrences seem to have existed in nature since the very beginning of the universe and came as a complete surprise when they first appeared in particle experiments in 1964. It is only in recent years that scientists have come to fully confirm the

explanations that Kobayashi and Maskawa made in 1972. It is for this work that they are now awarded the Nobel Prize in Physics. They explained broken symmetry within the framework of the Standard Model, but required that the Model be extended to three families of quarks. These predicted, hypothetical new quarks have recently appeared in physics experiments. As late as 2001, the two particle detectors BaBar at Stanford, USA and Belle at Tsukuba, Japan, both detected broken symmetries independently of each other. The results were exactly as Kobayashi and Maskawa had predicted almost three decades earlier.

A hitherto unexplained broken symmetry of the same kind lies behind the very origin of the cosmos in the Big Bang some 14 billion years ago. If equal amounts of matter and antimatter were created, they ought to have annihilated each other. But this did not happen, there was a tiny deviation of one extra particle of matter for every 10 billion antimatter particles. It is this broken symmetry that seems to have caused our cosmos to survive. The question of how this exactly happened still remains unanswered. Perhaps the new particle accelerator LHC at CERN in Geneva will unravel some of the mysteries that continue to puzzle us.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2008/press.html)

EXERCISES

1) ***Sum up the main ideas of the text using the following vocabulary.***

deviations from symmetry at the microscopic level, to be extremely useful, to permeate the Standard Model, spontaneous occurrences, to come as a complete surprise, to fully confirm the explanations, to explain broken symmetry within the framework of the Standard Model, to extend the model, to detect broken symmetry independently of each other, to lie behind the very origin of the cosmos, to remain unanswered, to unravel new mysteries

2) ***Translate the text in writing.***

Popular Information

Unravelling the hidden symmetries of nature

Nature’s laws of symmetry are at the heart of this subject: or rather, broken symmetries, both those that seem to have existed in our universe from the very beginning and those that have spontaneously lost their original symmetry somewhere along the road.

In fact, we are all the children of broken symmetry. It must have occurred immediately after the Big Bang some 14 billion years ago when as much antimatter as matter was created. The meeting between the two is fatal for both; they annihilate each other and all that is left is radiation. Evidently, however, matter won against antimatter, otherwise we would not be here. But we are here, and just a tiny deviation from perfect symmetry seems to have been enough — one extraparticle of matter for every ten billion particles of antimatter was enough to make our world survive. This excess of matter was the seed of our whole universe, which filled with galaxies, stars and planets — and eventually life. But what lies behind this symmetry violation in the cosmos is still a major mystery and an active field of research.

Through the looking glass

For many years physics has focused on finding the natural laws that are hidden deep within the wide range of phenomena we see around us. Natural laws should be perfectly symmetrical and absolute; they should be valid throughout the whole of the universe. This approach seems true for most situations, but not always. That is why broken symmetries became the subject of physics research as much as symmetries themselves, which is not so remarkable considering our lopsided world where perfect symmetry is a rare ideal.

Various types of symmetries and broken symmetries are part of our everyday life; the letter A does not change when we look at it in a mirror, while the letter Z breaks this symmetry. On the other hand, Z looks the same when you turn it upside down, but if you do the same with the letter A, the symmetry will be broken.

The basic theory for elementary particles describes three different principles of symmetry: mirror symmetry, charge symmetry and time symmetry (in the language of physics, mirror symmetry is called P, from parity, C stands for charge symmetry and T for time symmetry).

In mirror symmetry, all events should occur in exactly the same way whether they are seen directly or in a mirror. There should not be any difference between left and right and nobody should be able to decide whether they are in their own world or in a looking glass world. Charge symmetry states that particles should behave exactly like their alter egos, antiparticles, which have exactly the same properties but the opposite charge. And according to time symmetry, physical events at the microlevel should be equally independent whether they occur forwards or backwards in time.

Symmetries do not just have an aesthetic value in physics. They simplify many awkward calculations and therefore play a decisive role for the mathematical description of the microworld. An even more important fact is that these symmetries implicate a large number of conservation laws at the particle level. For example, there is a law that energy cannot be lost in collisions between elementary particles, it must remain the same before and after the collision, which is evident in the symmetry of equations that describe particle collisions. Or there is the law of the conservation of electrical charges that is related to symmetry in electromagnetic theory.

The pattern emerges more clearly

It was around the middle of the 20th century that broken symmetry first appeared in studies of the basic principles of matter. At this time physics was thoroughly involved in achieving its greatest dream – to unite all nature's smallest building blocks and all forces in one unified theory. But to begin with, particle physics only became more and more complicated. New accelerators built after the Second World War produced a constant stream of particles that had never been seen before. Most of them did not fit into the models physicists had at that time, that matter consisted of atoms with neutrons and protons in the nucleus and electrons round it. Deeper investigations into the innermost regions of matter revealed that protons and neutrons each concealed a trio of quarks. The particles that had already been discovered also were shown to consist of quarks.

Now, almost all the pieces of the puzzle have fallen into place; a Standard Model for the indivisible parts of matter comprises three families of particles. These families resemble each other, but only the particles in the first and lightest family are sufficiently stable to build up the cosmos. The particles in the two heavier families live under very unstable conditions and disintegrate immediately into lighter kinds of particles.

Everything is controlled by forces. The Standard Model, at least for the time being, includes three of nature's four fundamental forces along with their messengers, particles that convey the interaction between the elementary particles. The messenger of the electromagnetic force is the photon with zero mass; the weak force that accounts for radioactive disintegration and causes the sun and the stars to shine is carried by the heavy W and Z boson particles; while the strong force is carried by gluon particles, which see to it that the atom nuclei hold together. Gravity, the fourth force, which makes sure we keep our feet on the ground, has not yet been incorporated into the model and poses a colossal challenge for physicists today.

The mirror is shattered

The Standard Model is a synthesis of all the insights into the innermost parts of matter that physics has gathered during the last century. It stands firmly on a theoretical base consisting of the symmetry principles of quantum physics and the theory of relativity and has stood up to countless tests. But before the pattern was quite clear, a number of crises occurred that threatened this well-balanced construction. These crises related to the fact that physicists had assumed that the laws of symmetry applied to the Lilliputian world of elementary particles. But this, it turned out, was not entirely the case.

The first surprise came in 1956 when two Chinese-American theoreticians, Tsung Dao Lee and Chen Ning Yang (awarded the Nobel Prize the following year in 1957) challenged mirror symmetry (P symmetry) in the weak force. That nature respected mirror symmetry, the symmetry concerning left and right, was considered, like other symmetry principles, to be a well-established fact.

We need to re-evaluate old principles in the quantum world, where the elementary particles exist, claimed Lee and Yang. They proposed a series of experiments to test this mirror symmetry. And sure enough, only a few months later the decay of the atom nucleus in the radioactive element cobalt 60 revealed that it did not follow the principles of mirror symmetry. The symmetry was broken when the electrons that left the cobalt nucleus preferred one direction to another. It was as if you were standing in front of the Stockholm Central station and saw most of the people turning left out from the station.

Inherent asymmetry determines our fate

It may well be that charge and mirror symmetries are broken separately, but both of them, the so called CP-symmetry, are certainly not broken at the same time. The physicist community consoled itself with the idea that this symmetry remains unbroken. The laws of nature, they believed, would not change if you stepped into a mirror world where all matter was replaced with antimatter.

This also means that if you met an extraterrestrial being, there should not be any way of deciding whether the alien came from our world or from the antiworld. A welcoming hug could then have disastrous consequences. Only a puff of energy would be left when matter and antimatter annihilated each other on first contact.

So it was perhaps just as well that the weak force came back into the limelight in 1964. A new violation of the symmetry laws emerged in the radioactive decay of a strange particle, called a kaon (Nobel Prize awarded to James Cronin and Val Fitch in 1980). A small fraction of the kaons did not follow the current mirror and charge symmetries; they broke the double CP-symmetry and challenged the whole structure of the theory.

Thinking about meeting extraterrestrial beings, this discovery offers a salvation. It might be enough to ask an extraterrestrial before it hugs you to first look carefully at the kaon decay at home and check whether it is made of the same matter as us or antimatter.

The first person to point out the decisive importance of broken symmetry for the genesis of the cosmos was the Russian physicist and Nobel Peace Prize Laureate Andrei Sakharov. In 1967, he set up three conditions for creating a world like ours, empty of antimatter. Firstly, that the laws of physics distinguish between matter and antimatter, which in fact was discovered with the broken CP-symmetry; secondly, that the cosmos originated in the heat of the Big Bang; and thirdly, that the protons in every atom nucleus disintegrate. The last condition might lead to the end of the world, since it implies that all matter can eventually disappear. But so far that has not happened; and experiments have shown that protons remain stable for 10^{33} years, a comfortable10 trillion times longer than the age of the universe, which is slightly more than 10^{10} years. And still there is no one who knows how Sakharov’s chain of events took place in the early universe.

Solving the mystery of the broken symmetry

It may well be that Sakharov’s conditions will eventually be incorporated into the Standard Model of physics. Then the surplus of matter created at the birth of the universe will be explained. That, however, requires a much greater symmetry violation than the doubly broken symmetry, that Fitch and Cronin found in their experiment.

However, even a considerably smaller broken symmetry that the kaons were guilty of needed an interpretation; otherwise the whole Standard Model would be threatened. The question of why the symmetries were broken remained a mystery until 1972, when two young researchers from the University of Kyoto, Makoto Kobayashi and Toshihide Maskawa, who were well acquainted with quantum physics calculations, found the solution in a 3 x 3 matrix.

How does this double broken symmetry take place? Each kaon particle consists of a combination of a quark and an antiquark. The weak force makes them switch identities time and time again: the quark becomes an antiquark while the antiquark becomes a quark, thus transforming the kaon into its antikaon. In this way the kaon particle flips between itself and its antiself. But if the right conditions are met, the symmetry between matter and antimatter will be broken. Kobayashi and Maskawa's calculation matrix contains probabilities for describing how the transformation of the quarks will take place.

It turned out that the quarks and antiquarks swapped identity with each other within their own family. If this exchange of identity with double broken symmetry was to take place between matter and antimatter, a further quark family was needed in addition to the other two. This was a bold concept, and the Standard Model received these speculative new quarks, which appeared as predicted in later experiments. The charm quark was discovered as early as 1974, the bottom quark in 1977 and the last one, the top quark, as late as 1994.

Meson factories provide the answer

It may well be that the explanation of broken CP-symmetry also provides a raison d'être for the second and third particle families. These resemble the first family in many respects, but are so short-lived that they cannot form anything lasting in our world. One possibility is that these capricious particles fulfilled their most important function at the beginning of time when their presence guaranteed the broken symmetry that made matter win against antimatter. How nature solved this problem is, as mentioned before, something we do not yet know in detail. The broken symmetry needs to be reproduced many, many times to create all the matter that gives us our star-scattered sky.

Kobayashi and Maskawa's theory also indicated that it should be possible to study a major violation of symmetry in B-meson particles, which are ten times heavier than their cousins, the kaons. However, broken symmetry occurs extremely rarely in B-mesons, so immense quantities of these particles are needed to find just a few that break the symmetry. Two gigantic constructions housing the BaBar particle detectors at the SLAC accelerator at Stanford, California and Belle at the KEK accelerator at Tsukuba in Japan produced more than one million B-mesons a day in order to follow their decay in detail. As early as 2001, both independent experiments confirmed the symmetry violation of the B-

mesons, exactly as Kobayashi and Maskawa's model had predicted almost 30 years earlier.

This meant the completion of the Standard Model, which has worked well for many years. Almost all the missing pieces of the puzzle have fallen into place in accordance with the boldest of predictions. All the same, the physicists are still not content.

Symmetry lies hidden under spontaneous violations

As already explained, the Standard Model comprises all of the known elementary particles and three of the four fundamental forces. But why are these forces so different? And why do the particles have such different masses? The heaviest one, the top quark, is more than three hundred thousand times heavier than the electron. Why do they have any mass at all? The weak force stands out in this respect again: its messenger particles, W and Z, are much heavier, while its ally, the photon, which conveys the electromagnetic force, lacks mass at all.

Most physicists believe that another spontaneous broken symmetry, called the Higgs mechanism, destroyed the original symmetry between forces and gave the particles their masses in the very earliest stages of the universe.

The road to this discovery was mapped out by Yoichiro Nambu when, in 1960, he was the first to introduce spontaneous symmetry violation into elementary particle physics. It is for this discovery that he is now awarded the Nobel Prize in Physics. To begin with, Nambu worked on theoretical calculations of another remarkable phenomenon in physics, superconductivity, when electric currents suddenly flow without any resistance. Spontaneous symmetry violation that described superconductivity was later translated by Nambu into the world of elementary particles, and his mathematical tools now permeate all theories concerning the Standard Model.

We can witness more banal spontaneous symmetry violations in everyday life. A pencil standing on its point leads a completely symmetrical existence in which all directions are equal. But this symmetry is lost when it falls over — now only one direction counts. On the other hand, its condition has become more stable, the pencil cannot fall any further, it has reached its lowest level of energy.

A vacuum has the lowest possible energy level in the cosmos. In fact, a vacuum in physics is precisely a state with the lowest possible energy. But it is not empty by any means. Since the arrival of quantum physics, a vacuum is defined as full of a bubbling soup of particles that pop up, only to immediately disappear again in ubiquitously present but invisible quantum fields. We are surrounded by many different quantum fields across space; the four fundamental forces of nature are also described as fields. One of them, the gravitational field, is known to us all. It is the one that keeps us down on earth and determines what is up and what is down.

Nambu realised at an early date that the properties of a vacuum are of interest for studies of spontaneous broken symmetry. A vacuum, that is, the lowest state of energy, does not correspond to the most symmetrical state. As with the fallen pencil, the symmetry of the quantum field has been broken and only one of many possible field directions has been chosen. In recent decades, Nambu's methods of treating spontaneous symmetry violation in the Standard Model have been refined; they are frequently used today to calculate the effects of the strong force.

Higgs provides mass

The question of the mass of elementary particles has also been answered by spontaneous broken symmetry of the hypothetical Higgs field. It is thought that at the Big Bang the field was perfectly symmetrical and all the particles had zero mass. But the Higgs field, like the pencil standing on its point, was not stable, so when the universe cooled down, the field dropped to its lowest energy level, its own vacuum according to the quantum definition. Its symmetry disappeared and the Higgs field became a sort of syrup for elementary particles; they absorbed different amounts of the field and got different masses. Some, like the photons, were not attracted and remained without mass; but why the electrons acquired mass at all is quite a different question that no one has answered yet.

Like other quantum fields, the Higgs field has its own representative, the Higgs particle. Physicists are eager to find this particle soon in the world's most powerful particle accelerator, the brand new LHC at Cern in Geneva. It is possible that several different Higgs particles will be detected — or none at all. Physicists are prepared, a so-called supersymmetric theory is the favourite among many to extend the Standard Model. Other theories exist, some more exotic, some less so. In any case, they are likely to be symmetrical, even though the symmetry may not be evident at first. But it is there, keeping itself hidden in the seemingly messy appearance.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2008/public.html)

EXERCISES

1) Give Russian equivalents for the following terms and explain what they mean in English.

broken symmetry, mirror symmetry, charge symmetry, time symmetry, conservation laws, the double CP-symmetry, quarks, B-mesons, spontaneous symmetry violation, the Higgs particle, the Standard Model

2) Make up sentences using the following word combinations.

Nature's laws of symmetry, excess of matter, a tiny deviation from perfect symmetry, to simplify awkward calculations, to play a decisive role, the mathematical description of the microworld, to produce a constant stream of particles, indivisible parts of matter, to pose a challenge, insights into the innermost parts of matter, to stand firmly on a theoretical base, to stand up to countless tests, to challenge mirror symmetry, to reevaluate old principles, to break the double CP-symmetry, to point out the importance of broken symmetry, to set up conditions for smth, to distinguish between matter and antimatter, to originate in the heat of the Big Bang, the transformation of the quarks, to confirm the symmetry violation of the B-mesons, to be in accordance with the boldest predictions, to introduce spontaneous symmetry violation into elementary particle physics, to extend the Standard Model

3) Answer the questions.

a) What role did a tiny deviation from perfect symmetry play in the period immediately following the Big Bang?

b) What are three different principles of symmetry? Why are they so important?

c) What discovery became feasible due to deeper investigations into the world of elementary particles in the middle of the 20th century? How did it contribute to the creation of a unified theory of matter?

d) What forces and their messenger particles are incorporated into the Standard Model? Why do you think gravity poses a challenge for physicists?

e) Who challenged mirror symmetry? What experiment was carried out to test mirror symmetry and with what result?

f) What experiment are James Cronin and Val Fitch famous for?

g) What conditions for creating a world like ours did Andrei Sakharov set up?

h) How was the mystery of the broken symmetry solved?

i) What experiments confirmed the symmetry violation of the B-mesons predicted by Kobayashi and Maskawa's model?

j) What does Yoichiro Nambu's contribution to elementary particle physics consist in?

k) What further progress has been achieved in extending the Standard Model?

4) Sum up the information from the text about the symmetries of nature in 15–18 sentences in writing.

Speed Read

Translate at sight.

The Importance of Asymmetry

Luckily for us, the Universe is not symmetrical, at least at the subatomic level. If it was, the newly formed matter at the Universe's birth would have been annihilated by an equal and opposite amount of antimatter, and nothingness would have resulted. Instead, a small imbalance, or asymmetry, in the amount of matter and antimatter created led to a slight excess of matter, from which we are all eventually formed. Such 'broken symmetry' is one key to our existence.

Understanding symmetry, or the lack of it, is an ongoing task, and the 2008 Nobel Prize in Physics rewarded two discoveries concerning symmetry violation in the field of particle physics. In the 1960s Yoichiro

Nambu, who had been working on asymmetries underlying superconductivity, was the first to model how broken symmetry can occur spontaneously at the subatomic level. The mathematical descriptions he formulated helped refine the standard model of particle physics, the current working theory that best explains much, but not all, of the way that fundamental particles and the forces that govern their behaviour interact to create the known Universe.

In the early 1970s, Kobayashi and Maskawa formulated a model that explained certain symmetry violations that had recently surprised observers in particle physics experiments. Their model suggested that the collection of subatomic particles known at the time were insufficient to explain the observed behaviours, and predicted the existence of as yet undiscovered elementary particles. It did not, however, specify precisely what form these particles should take. Kobayashi and Maskawa hypothesized the existence of a third family of quarks, which are some of the building blocks from which all matter and antimatter is formed. They then had to wait almost three decades for the experimental results that would verify their hypothesis. The existence of all three families was finally confirmed when the last member was observed in the mid -1990s.

(by Adam Smith, Editor-in-Chief, Nobelprize.org)

Unit 9

Telecommunications Revolution. The Charge-Coupled Device (CCD)

The Nobel Prize in Physics 2009 — Popular Information

The masters of light

*The 2009 Nobel Prize in Physics honors three scientists, who have had important roles in shaping modern information technology, with one half to **Charles Kuen Kao** and with **Willard Sterling Boyle** and **George Elwood Smith** sharing the other half. Kao's discoveries have paved the way for optical fiber technology, which today is used for almost all telephony and data communication. Boyle and Smith have invented a digital image sensor — CCD, or charge-coupled device — which today has become an electronic eye in almost all areas of photography.*

When the Nobel Prize in Physics is announced in Stockholm, a large part of the world receives the message almost instantly. At almost the speed of light, the highest of speeds, the message is spread around the world. Text, images, speech and video are shuffled around in optical fibers and through space, and are received instantly in small and convenient devices. It is something that many people have already come to take for granted. The optical fiber has been a prerequisite for this extremely rapid development in the field of communications, a development that Charles Kao predicted over 40 years ago.

Just a few years later, Willard Boyle and George Smith radically altered the conditions for the field of photography, because film is no longer needed in cameras where the images can be captured electronically with an image sensor. The electronic eye, the CCD, became the first truly successful technology for the digital transfer of images. It opened the door to a daily stream of images, which is filling up the optical fiber cables. Only optical fiber is capable of transferring such large quantities of data that electronic image sensor technology yields.

The arrival of light

It is via sunlight that we see the world. However, it would take a long time before humans acquired the skills to control light and direct it into a waveguide. In this way coded messages could be transmitted to many people simultaneously.

This development required numerous inventions, big and small, which form the foundations for the modern information society. The optical fiber required modern glass technology in order to be developed and manufactured. A reliable source of light was also needed and this was provided by semiconductor technology. Finally, an ingenious network needed to be assembled and extended, consisting of transistors, amplifiers, switches, transmitters and receivers, as well as other units, all working together. The telecommunications revolution was made possible by the work of thousands of scientists and inventors from all around the world.

Playing with light

The 1889 World Exhibition in Paris celebrated the centenary of the French revolution. The Eiffel tower was to become one of the most well-known monuments of this exhibition. However, a remarkable play of lights proved a less memorable spectacle. It was performed with water fountains filled with colorful beams of light. This show was made possible with electricity. A source of inspiration was also provided by earlier attempts, in the middle of the 19th century, to create beams of light guided by water. Those trials had shown that when a beam of water is exposed to sunlight, the light travels through the beam and follows its curving shape. Of course, the effects of light in glass or water had been discovered much earlier than that. Already 4 500 years ago, glass was manufactured in Mesopotamia and Egypt. The Venetian glass masters could not have been ignorant of the beautiful play of light that occurred in their swirling decorations. Cut glass was used in candelabras and crystal chandeliers, and the elusive mystery of the rainbow challenged the imagination of many men and women long before the laws of optics provided the answer in the 17th century. However, it was only about 100 years ago that these ideas surfaced and people tried to make use of captured beams of light.

Capturing light

A ray of sunlight that falls into water bends when it hits the surface, because the so-called refractive index of water is higher than the refractive index of air. If the direction of the light beam is inverted, travelling from water into air, it is possible that it will not enter the air at all, and instead will be reflected back into the water. This phenomenon forms the basis for optical waveguide technology where light is captured inside a fiber with a higher refractive index than its surrounding environment. A ray of light that is directed into a fiber, bounces against the glass wall and moves forward since the refractive index of glass is higher than the surrounding air.

The medical profession has used short and simple optical fibers since the 1930s. With a bundle of thin glass rods, they could peek inside the stomachs of patients or highlight teeth during operations. However, when the fibers touched each other they leaked light, and they also easily became worn out. Coating the bare fiber in a glass cladding with a lower refractive index led to considerable improvements, which in the 1960s paved the way for industrial manufacturing of instruments for gastroscopy and other medical uses.

For long distance communication, however, these glass fibers were useless. Furthermore, few were really interested in optical light; these were the days of electronics and radio technology. In 1956, the first transatlantic cable was deployed, and it had a capacity for 36 simultaneous phone calls. Soon satellites would begin to cover the growing communication needs — telephony increased dramatically and television broadcasting required ever higher transfer capacities. Compared to radio waves, infrared or visible light carries tens of thousands times more information, so the potential of optical light waves could not be disregarded any longer.

Transmitting light

The invention of the laser at the beginning of the 1960s was a decisive step forward for fiber optics. The laser was a stable source of light that emitted an intensive and highly focused beam of light, and could be pumped into a thin optical fiber. The first lasers emitted infrared light and required cooling. Around 1970 more practical lasers were developed which could work continuously at room temperature. This was a technological breakthrough that facilitated optical communication.

All information could now be coded into an extremely fast flashing light, representing digital ones and zeros. However, how such signals could be transmitted over longer distances was still not known — after

just 20 meters, only 1 percent of the light that had entered the glass fiber remained.

Reducing this loss of light became a challenge for a visionary like Charles Kuen Kao. Born in 1933 in Shanghai, he had moved to Hong Kong together with his family in 1948. Educated as an electronics engineer, he defended his Ph.D.-thesis in 1965 in London. By that time he was already employed at the Standard Telecommunication Laboratories, where he meticulously studied glass fibers together with his young colleague George A. Hockham. Their goal was that at least 1 percent of the light that entered a glass fiber would remain after it had travelled 1 kilometer.

In January 1966, Kao presented his conclusions. It was not imperfections in the fiber thread that was the main problem, instead it was the glass that had to be purified. He admitted that this would be feasible but very difficult. The goal was to manufacture glass of a transparency that had never been attained before. Kao's enthusiasm inspired other researchers to share his vision of the future potential of fiber optics.

Glass is manufactured from quartz, the most abundant mineral on Earth. During its production, different additives such as soda and lime are used in order to simplify the process. However, in order to produce the purest glass in the world, Kao pointed out that fused quartz, fused silica, could be used. It melts at almost 2 000 °C, a heat difficult to control but from which one would draw out ultra-thin threads of fiber. After four years, in 1971, scientists at the Corning Glass Works in the USA, a glass manufacturer with over 100 years experience, produced a 1 kilometer long optical fiber using chemical processes.

Filled with light

Ultra-thin fibers made out of glass may seem very fragile. However, when glass is correctly drawn out in a long thread, its properties change. It becomes strong, light and flexible, which is a prerequisite if the fiber is to be buried, drawn under water or bent around corners. Unlike copper cables, glass fiber is not sensitive to lightning, and unlike radio communication, it is not affected by bad weather.

It took a fair share of time to coil the Earth in fiber. In 1988, the first optical cable was laid out along the bottom of the Atlantic Ocean between the United States and Europe. It was 6 000 km long. Today, telephone and data communication flows in a network of optical glass fiber, the length of which totals over 1 billion km. If that amount of optical fiber was wrapped around the globe it would span the world more than 25 000 times — and the amount of fiber is increasing every hour.

Even in a high purity glass fiber, the signal is slightly reduced along the way and has to be reinforced when it is transmitted over longer distances. This task, which previously required electronics, is today performed by optical amplifiers. This has brought an end to unnecessary losses that occur when light is transformed to and from electronic signals.

Today 95 percent of the light remains after having been transmitted a full kilometer, a number that should be compared to Kao's ambition of having 1 percent left after that same distance. Furthermore, it is not possible to speak of only one single kind of fiber. Choosing which fiber to use is subject to many different technical considerations, communication needs and costs.

The fibers consist of a sophisticated interplay between size, material properties, and wavelengths of light. Semiconductor lasers and light diodes the size of a grain of sand fill networks of optical fibers with light which carries almost all of the telephone and data communication around the world. Infrared light with a wavelength of 1.55 micrometers, is nowadays used for all long distance communication where the losses are lowest.

The capacity of optical cable networks is still growing at an amazing speed – transferring thousands of gigabits per second is no longer a dream. Technological development is heading in the direction of more and more interactive communication, where optical fiber cables are designed to reach all the way into the homes of each and every one of us. The technology already exists. What we do with it is an altogether different question.

Electronic eye

Sometimes inventions appear totally unanticipated. The image sensor, CCD, or charge-coupled device, is such an invention. Without the CCD, the development of digital cameras would have taken a slower course. Without CCD we would not have seen the astonishing images of space taken by the Hubble space telescope, or the images of the red desert on our neighboring planet Mars.

This was not what the inventors of the CCD, Willard Boyle and George Smith, had imagined when they began their work. One day in September 1969, they outlined the basis of an image sensor on a blackboard

in Boyle's office. At that time they did not have photographic images in mind. Their aim with the CCD was to create a better electronic memory. As a memory device it is now forgotten. However, they did come up with an indispensable part of modern imaging technology. The CCD is yet another success story of our electronic era.

Images become digital

Just like many other devices in the electronics industry, a digital image sensor, CCD, is made out of silicon. The size of a stamp, the silicon plate holds millions of photocells sensitive to light. The imaging technique makes use of the photoelectric effect which was first theorized by Albert Einstein and earned him 1921's Nobel Prize. The effect occurs when light hits the silicon plate and knocks out electrons in the photocells. The liberated electrons are gathered in the cells which become small wells for them. The larger the amount of light, the larger the number of electrons that fill these wells.

When voltage is applied to the CCD array, the content of the wells can be progressively read out; row by row, the electrons slide off the array onto a kind of a conveyor belt. So for example, an array of 10 x 10 image points is transformed into a 100 points long chain. In this manner the CCD transforms the optical image into electric signals that are subsequently translated into digital ones and zeros. Each cell can then be recreated as an image point, a pixel. When the width of a CCD, expressed in pixels, is multiplied with its height, the image capacity of the sensor is obtained. Thus a CCD with 1280 x 1024 pixels yields a capacity of 1.3 megapixels (1.3 million pixels).

The CCD renders an image in black and white, so various filters have to be used in order to obtain the colors of light. One kind of filter that contains one of the base colors red, green or blue, is placed over every cell in the image sensor. Owing to the sensitivity of the human eye, the number of green pixels needs to be twice that of the blue or red pixels. For more advanced imaging, a number of filters may be used.

Challenges at work

The fact that Boyle and Smith got the idea for the CCD during their short brainstorming session 40 years ago can be attributed to the internal politics of their employer. Their boss at Bell Labs outside New York, encouraged them to take on the challenge and enter a competition regarding the development of a better bubble memory, another one of the Bell Labs' inventions. When the basic design for the CCD was finished, it would only take a week before technicians assembled the first prototype. As a memory it is long forgotten, but the CCD has become the center of many digital imaging techniques.

The American George Smith was hired at Bell Labs in 1959, and took out 30 patents during his time at the company. When he retired in 1986, he could at last dedicate himself fully to his life-long passion — sailing on the great seas, which has brought him around the globe many times.

By 1969, Willard Boyle had made many important discoveries, for instance in relation with the development of the world's first continuous red light laser. Boyle was born in a distant part of Nova Scotia in Canada, and was educated at home by his mother until the age of 15. He began to work at Bell Labs in 1953, and in the 1960s he joined the 400 000 scientists in the USA whose efforts were to put the first man on the moon on 20 July 1969.

A photographic camera for everyone

The advantages of the electronic image sensor quickly became evident. In 1970, just about a year after the invention, Smith and Boyle could demonstrate a CCD in their video camera for the first time. In 1972, the American company Fairchild constructed the first image sensor with 100 x 100 pixels, which entered production a few years later. In 1975, Boyle and Smith themselves constructed a digital video camera of a sufficiently high resolution to manage television broadcasts.

It would not be until 1981 before the first camera with built-in CCD appeared on the market. Notwithstanding its bulky and primitive characteristics, when compared to contemporary cameras, it initiated a more commercially oriented digitalization in the field of photography. Five years later in 1986, the first 1.4 megapixel image sensor (1.4 million pixels) arrived, and a further nine years on in 1995, the world's first fully digital photographic camera appeared. Camera manufacturers around the world quickly caught on, and soon the market was flooded with ever smaller and cheaper products.

With cameras equipped with image sensors instead of film, an era in the history of photography had ended. It had begun in 1839 when Louis Daguerre presented his invention of photographic film before the French Académie des Sciences.

When it comes to everyday photography, digital cameras have turned out to be a commercial success. Lately the CCD has been challenged by another technology, CMOS, or Complementary Metal Oxide

Semiconductor; a technology that was invented at about the same time as CCD. Both make use of the photoeffect, but while the electrons gathered in a CCD march in line in order to be read out, every photocell in a CMOS is read out on site.

CMOS consumes less energy so batteries last longer, and for a long time it has also been cheaper. However, one also has to take into account its higher noise levels and the loss of image quality, and consequently CMOS is not sufficiently sensitive for many advanced applications. CMOS is currently often used for everyday cell phone photography, and for other kinds of photography. Both technologies, however, are constantly being developed and for many applications they are interchangeable.

Three years ago, CCD breached the limit of 100 megapixels, and although the image quality is not only dependent on the number of pixels, surpassing this limit is seen to have brought digital photography a further step into the future. There are those that predict that the future belongs to CMOS rather than to CCD. Others still, maintain that the two technologies will continue to supplement each other for a long time.

Light-sensitive pixels

Initially, no one predicted that CCD would become indispensable to the field of astronomy. However, it is precisely thanks to digital technology that the wide-angle camera on the Hubble space telescope can send the most astonishing images back to Earth. The camera's sensor initially consisted of only 0.64 megapixels. However, as four sensors were interconnected, they provided a total of 2.56 megapixels. This was a big thing in the 1980s when the space telescope was designed. Today the Kepler satellite has been equipped with a mosaic sensor of 95 megapixels, and the hope is that it will discover Earth-like planets around stars other than the sun.

Early on, astronomers realized the advantages of the digital image sensor. It spans the entire light spectrum, from X-ray to infrared. It is a thousand times more sensitive than photographic film. Out of 100 incoming light particles a CCD catches up to 90, whereas a photographic plate or the human eye will only catch one. In a few seconds, light from distant objects is gathered – a process that previously would have taken several hours. The effect is also directly proportional to the intensity of the light — the larger the amount of light, the higher the number of electrons.

In 1974 the first image sensor had already been used to take photographs of the moon – the first astronomical images ever to be taken with a digital camera. With lightning speed, astronomers adopted this new technology; in 1979 a digital camera with a resolution of 320 x 512 pixels was mounted on one of the telescopes at Kitt Peak in Arizona, USA.

Today whenever photo, video or television is used, digital image sensors are usually involved in the process. They are useful for surveillance purposes both on Earth and in space. Furthermore, CCD technology is used in a host of medical applications, e.g. imaging the inside of the human body, both for diagnostics and for surgical operations. The digital image sensor has become a widely used instrument at the service of science both at the bottom of the oceans and in space. It can reveal fine details in very distant and in extremely small objects. In this way, technological and scientific breakthroughs intertwine.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2008/public.html)

Exercises

1) ***What are the Russian equivalents of the following terms? Explain their meaning in English.***

charge-coupled device (CCD), optical amplifier, optical waveguide technology, pixel, infrared light, bubble memory, Complementary Metal Oxide Semiconductor (CMOS), continuous red light laser

2) ***Find English equivalents for the following word combinations in the text.***

a) сформировать современные информационные технологии, цифровой датчик изображения, мгновенно получать информацию, принимать что-то как должное, необходимое условие необычайно быстрого развития в области коммуникаций, изменить условия в области фотографирования, зафиксировать изображение в электронной форме при помощи датчика изображения, цифровая передача изображений, способный передавать большие объемы информации, требовать многочисленных изобретений (Introduction);

b) бросить вызов воображению многих мужчин и женщин, предоставить ответ, коэффициент преломления, наметить путь промышленного производства медицинских инструментов, системы дальней связи, удовлетворять растущие потребности в коммуникации, не принимать во внимание потенциал оптического света (Playing with light and Capturing light);
c) решительный шаг вперед к волоконной оптике, стабильный источник света, испускать интенсивный и строго направленный луч света, облегчить оптическую коммуникацию, скрупулезно изучать что-либо, представить свои заключения, упростить процесс; осуществимый, но крайне трудный (Transmitting light);
d) занять достаточно длительное время, передаваться на большие расстояния, покончить с лишними тратами, подвергнуть что-либо рассмотрению с технической точки зрения; сложная взаимосвязь между размером, свойствами материала и длиной световых волн; совершенно другой вопрос (Filled with light);
e) оказаться абсолютно неожиданным, снизить скорость развития, придумать незаменимую часть современной технологии формирования изображений (Electronic eye);
f) превращать оптические изображения в электрические сигналы, придумать идею во время коллективного обсуждения, полностью посвятить себя чему-либо, собрать прототип (Images become digital and Challenges at work);
g) появиться на рынке, достаточно высокое разрешение, оказаться коммерчески успешным, принимать во внимание более высокий уровень шума и потерю качества изображения, превзойти уровень чего-либо, постоянно развиваемый, покрывать весь световой спектр, стать незаменимым в области астрономии, камера широкого диапазона (A photographic camera for everyone and Light-sensitive pixels)

3) Fill in the gaps.

a) It [glass] becomes strong, light and flexible, which is a ___ if the fiber is to be buried, drawn under water or bent around corners.
b) When ___ is applied to the CCD array, the content of the wells can be progressively read out.
c) /…/ CCD ___ the limit of 100 megapixels, and although the image quality is not dependent on the number of pixels, ___ this limit is seen to have brought digital photography a further step into the future.
d) The electronic eye, the CCD, became the first truly successful technology for the ___.
e) During the production of glass, different additives such as ___ and ___are used to simplify the process.
f) ___its bulky and primitive characteristics, when compared to contemporary cameras, it initiated a more commercially oriented digitalization in the field of photography.

4) Say whether the following statements are true or false.

a) In 1975, Boyle and Smith themselves constructed a digital video camera of a sufficiently high resolution to manage television broadcasts.
b) The Kepler satellite was equipped with a mosaic sensor of 45 megapixels.
c) The photoelectric effect occurs when light hits the silver plate and knocks out electrons in the photocells.
d) In 1969 Boyle and Smith were aiming to create an image sensor and had photographic images in mind.
e) Charles Kuen Kao never believed in the future potential of fiber optics.
f) The photoelectric effect forms the basis for optical waveguide technology.
g) Optical lasers that could work continuously at room temperature facilitated optical communication.

Speed Read

Translate at sight.

Illuminating information sharing

If you're reading this online, and if you have just been surveying portraits of the new Nobel Laureates, then it's safe to say that you're benefitting directly from the two achievements rewarded with the 2009 Nobel Prize in Physics. The optical fibers along which this Speed Read is travelling, and the digital imaging which underlies practically all modern photography, are the direct consequences of that work, done 40 years ago.

Optical fiber communication is now ubiquitous, but when Charles Kao first suggested that glass fibers could be used for long range information transfer, his ideas were met with scepticism. It had long been understood that glass fibers could act as waveguides for light, allowing, for instance, the development of short range optical fibers for probing the inner recesses of our bodies. But such fibers were thought to be far too inefficient for any long range use, light transmission falling to negligible levels after just a few meters. In a 1966 paper, Kao and his colleague George Hockham put forward the radical suggestion that impurities in the glass were responsible for this inefficiency, and that truly pure glass would give vastly improved light transmission. When, four years later, optical fibers of pure glass were at last fabricated, Kao and Hockham's prediction was found to be correct, paving the way for the development of today's ubiquitous, efficient, energy-saving optical cable networks.

Digital image capture, now so much a part of everyday life, got its start from an afternoon's brainstorming between Willard Boyle and George Smith, colleagues at the famous Bell Laboratories. Working in the semiconductor division, in 1969 they were asked by their boss to come up with a novel technology for information storage. The device they sketched on the board that afternoon was an image sensor based on Albert Einstein's photoelectric effect, in which arrays of photocells would emit electrons in amounts proportional to the intensity of incoming light. The electron content of each photocell could then be read out, transforming an optical image into a digital one. Their charge-coupled device (CCD), as they named it, proved not to have a future in memory storage, but rather gave rise to an explosion in digital imaging, with the first CCD-based video cameras appearing in the early 1970s. Although

CCDs are to some extent now supplemented by competing technologies, their use in applications ranging from digital cameras to the Hubble space telescope has completely transformed image processing.

(by Adam Smith, Editor-in-Chief,Nobelprize.org)

Willard S. Boyle — Interview

Listen as you read. Highlight the most interesting facts.

"When we made the CCD, it worked immediately and it was amazing! We never had that kind of luck before"

Telephone interview with Willard S. Boyle recorded on 7 October 2009, the day following the announcement of the 2009 Nobel Prize in Physics. The interviewer is Adam Smith, Editor-in-Chief of Nobelprize.org.

[Willard Boyle] And a good morning to you, sir!

[Adam Smith] Good morning to you! And, of course, congratulations.

[WB] Well, thank you very much.

[AS] It's been ...

[WB] I gather you were talking to George Smith?

[AS] Yes, yesterday.

[WB] That's good. Oh yesterday even?

[AS] In fact, there was a slight mix-up and he didn't receive the call from the Royal Swedish Academy of Science because he missed it, he woke up but didn't actually get to the telephone. So, when I spoke to him, he hadn't actually heard the news yet!

[WB] Oh my gosh! When was that?

[AS] Well, pretty close to the announcement time, just a few minutes after the public announcement in Stockholm.

[WB] Oh, so he did hear about it, though, yesterday morning.

[AS] Yes, yes, exactly, just within ... it was just maybe five minutes after the public announcement so ...

[WB] Oh, well, then that's no problem.

[AS] No, but ...

[WB] I haven't spoken to him, you see. I haven't spoken to him for a long time. And so I was a little curious how's he doing?

[AS] Well, he sounded well. I asked him whether he was still sailing around the world and he said, no, he'd stopped that now and the sailing vessel was docked out at the end of the garden.

[WB] Sure.

[AS] You two used to sail together, I gather?

[WB] Yes, I've sailed with him over in Numea. In the South Pacific for a couple of weeks.

[AS] Goodness. And, we're calling you now at home in Nova Scotia, which is where you were brought up, I gather?

[WB] That is correct, yes. So, yes, mostly my primary education was in Nova Scotia.

[AS] And, indeed, high school was the first school you attended. Until then you were home schooled, is that right?

[WB] That is correct, yes. My mother taught me and she did, I guess, a fairly good job.

[AS] Apparently so! I wanted to ask you how the last 24 hours have been, actually, since the news arrived?

[WB] The last 24 hours have been busy! The likes of which I've never experienced before.

[AS] Are you enjoying the experience?

[WB] A little bit more, yes. But there are little things that have to be tidied up. And I think I've done my series of interviews with the press. And you run out of a certain number of things to talk about with them.

[AS] Oh dear, well, at the risk of exploring some of the same ground, here goes! May I ask you a little bit about your time at Bell Labs because so many have said what a special atmosphere it was.

[WB] Absolutely.

[AS] And, of course, you know, it's now finished. But something about it was right. Can you describe what that was?

[WB] Yes, I think the atmosphere set up by the management was very conducive to people being creative. In other words, it's become fashionable here in North America, for example, to demand that one has a plan, some kind of a financial plan when they're given a grant for doing research work here; 'Now you must develop a plan and tell us what you're going to do in the first year, and the second year, and the third year and so on of this grant of yours. And what your goal is, specifically in the way of profits and losses, and so on.' And, you can't possibly do that when you're trying to do research of the kind of work that was going on in Bell Labs, because as you know ... Have you counted up the number of Nobels from Bell Labs?

[AS] I never have but it's a considerable number for sure. Do you know the number?

[WB] Well, it depends how you count it. There were people, you know, partially at the university, partially at Bell Labs. That was their secret of success, I think. But at least it was eight, and it could be two more than that even. Which is, you know, pretty good for an industrial research lab! So, I guess the other part that was very conducive to wanting to work there and enjoy it and so on, was that the management itself, they were not bureaucratic, they were not money bureaucrats, but rather they were scientists themselves. Now, Baker for example, maybe you've never heard of Baker? He was a chemist, and he was extremely bright and he was head of all research. And, he knew what was going on in every lab! And he'd pop around every now and then and maybe have lunch with you and so on and, 'how are things going?' So, he knew intimately all the people in research that mattered at all.

[AS] Yes, I've heard that approach described as 'management by walking around' ...

[WB] Yes.

[AS] ... being part of it all, yes.

[WB] And no ... no yearly plans and things like that, 'what are you going to achieve this year?' You know, you can't possibly describe that and it's a waste of time.

[AS] And freedom to get involved in different things? You were seconded to the Apollo program for a while?

[WB] Oh yes, for two years.

[AS] And Bell Labs was happy to let you go off and do that?

[WB] Well, yes. At the end of two years, I quit and went back to my research lab. So, yes ... and that was dreadfully trying and I had the utmost respect for the people that were working there. Very long hours and tremendous pressures to get things done and so on, and they were all very successful.

[AS] But a rather different environment, yes. And, this famous afternoon brainstorming meeting in which the CCD was conceived by you and

George Smith; what led to it? Was it simply that you thought that you would sit down and have a brainstorm? Or were you under a directive to come up with something?

[WB] No directive. No directive, no. I was a laboratory director and George was the department head and so there were levels between us but we worked together regardless. And so there was ... We had total freedom to do what we wanted to do. And we had done, and worked in many different areas. And we changed from one area to another, and ...

[AS] I mean it was originally conceived as device that afternoon for increased memory storage but very quickly it became an imaging technology. When did the imaging application occur to you?

[WB] I guess at the same time. But, you know the first model that we made — that was another thing that was just so wonderful at Bell Labs: we could make models, semiconductor devices, and see whether they'd work or not. And we did that on various occasions. This was ... when we made the CCD, it worked immediately and it was amazing! We never had that kind of luck before. And, actually, I think in the first paper it shows a photograph of an image made by a CCD. I think that you probably have the first paper.

[AS] And then, having developed it, did you stay with it for quite a while or was it something that you passed on to others and then went back to ...

[WB] I guess I passed it on totally. And George was also heading up a group and I think his group continued and made more models and increased in complexity and diversity. And there was a one bit sensor and then it was increased and started to look quite interesting. So much so, as a matter of fact, that, well, we said, "Well, we've got something here that's pretty good, we had better call it something." And we tried various names for it even and finally settled on the CCD. We had other names and dismissed those, but that one seemed to stick and it did, it did stick. And we did that, I guess, very early, you know. As far as I know it was within a month or so of the first one that worked. But I don't, you know, you don't know these times exactly.

[AS] No, of course. It's hard to piece it together in retrospect. So this was all forty years ago. Perhaps an obvious question, but were you surprised to receive the call yesterday after so long?

[WB] Very much so! Very much so. Doubly surprised, really, because we had, from time to time, just because so many people around us had been winning Nobel Prizes, well, we sort of said, 'well, our stuff is reasonable. It's possible, you know, we'll get something here, I don't know!' And, hoped for the best, but nothing had happened and so we'd pretty well dismissed it. And then, I guess, it was just before lights out last night with my wife, I said, "Well, you know, medicine was announced a couple of days ago, we'll probably hear about physics and so, who knows, you know?" And she said, "Well, we know for sure because we're not going to win because they always tell you at least a week ahead of time." So, I ... so we went to sleep feeling totally comfortable that we don't have to worry about it; we'll sleep in tomorrow morning a little bit. And, of course, the phone rang at five o'clock. And then she answered the phone. And all she did is, she came over and gave me a little whack, and she said, "Stockholm is calling!" And I said, "Oh, I suppose it's that same old joker." You know, somebody, at one time, actually had called us up I think, or at least we made this up, wouldn't it be terrible if somebody called you? And so I knew it was real, however, because after a moment or two we heard this lovely voice and it's from Stockholm. And there was this woman with a magnificent Swedish accent! And I suddenly thought, well, nobody is going to have gone to all that trouble just to fool us at five o'clock in the morning!

[AS] What a marvelous story. Perfect.

[WB] It's absolutely true!

[AS] Lovely. It's nice that the secret is still so well kept, that there was no leak at all.

[WB] Yes, totally. I have no idea how they just keep it so secret! I presume you get nominations from other winners of the Nobel Prize?

[AS] Yes, previous Nobel Laureates are entitled to nominate, that's right.

[WB] Yeah, I suspect ... I do know a couple of other winners, several as a matter of fact just because they were at Bell Labs, I guess. And, maybe they put in a good word for us, I don't know. I don't want to know.

[AS] No, it all stays secret for fifty years but one thing ...

[WB] Good!

[AS] One thing one does know is one has to be nominated in the year of the award.

[WB] I see.

[AS] So, even if you've been nominated for twenty years previously, but you're not nominated this year, you can't be awarded the prize this year.

So, after forty years, we know that somebody was still nominating for sure.

[WB] Isn't that great? That's surprising, you know, sort of, after all that time because some of the people, I'm sure that we knew so well, they've probably passed along.

[AS] Well, it's been an enormous pleasure speaking to you.

[WB] Likewise.

[AS] And, I hope that you have an enjoyable rest of day.

[WB] I think we will.

[AS] Excellent, thank you very much indeed.

[WB] Nice talking to you.

[AS] OK, nice to talk to you, bye, bye.

[WB] Bye, bye.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2009/ boyle-interview.html)

Unit 10
Graphene

The Nobel Prize in Physics 2010

The Nobel Prize in Physics 2010 was awarded to **Andre Geim** and **Konstantin Novoselov** *"for groundbreaking experiments regarding the two dimensional material graphene"*.

Autobiography

1) Read some excerpts from Andre Geim's Nobel autobiography and answer the questions.

a) How did Geim's physics tutor help him in learning to deal with physics problems? Did that approach influence his research style in later years?

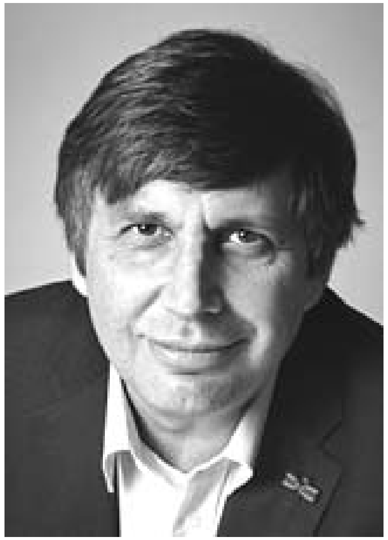
b) What did the scientist dream of investigating as a would-be physics student?

c) What difficult problem was Geim asked to solve at the entrance interview?

d) What is the author's general opinion on the quality of higher education he acquired? How does Geim describe the examination style he got accustomed to at Phystech?

e) Was studying at university a struggle for Geim?

f) What was the topic of Geim's Master's project?



Andre Geim

Born: 21 October 1958, Sochi, Russia
Affiliation at the time of the award:
University of Manchester, Manchester, United Kingdom

Field: Condensed matter physics, materials physics

I was born on October 21, 1958 in the small Black Sea resort of Sochi, the second son of Nina Bayer and Konstantin Geim. /…/ At the age of seven, it was time to go to school and, reluctantly, I had to leave Sochi and go to live with my parents and my elder brother Vladislav in the city of Nalchik where they worked. /…/ For the next ten years I spent my school time there but returned to Sochi every year to stay with my grandmother during the summer months.

At the age of 16, I graduated from school with a gold medal, a distinction given to those who achieved the perfect score in all subjects (typically, the top 5%). My parents encouraged me to go to the best possible university and my sights were set on a couple of elite universities in Moscow. At school I was doing well in all exact sciences, including physics and chemistry, but my strongest subject was maths. However, my parents persuaded me that pure maths would not offer good career prospects. Hence, my decision was to study physics. /…/

My parents were supportive and /…/ paid for tutoring in maths, physics and Russian literature./…/ My tutor was a physics professor from Nalchik's University, Valery Petrosian. I thoroughly enjoyed every lesson. We solved many problems from old exam papers either from Phystech or, even harder, from international Olympiads. But even more helpful was the way he taught me to deal with physics problems: it is much easier to solve a problem if you first guess possible answers. Most problems at Phystech level require understanding of more than one area of physics and usually involve several logical steps. For example, in the case of a five-step solution, the possibilities for dealing with the problem quickly diverge and it may take many attempts before you get to the final answer. If, however, you try to solve the same problem from both ends, guessing two or three plausible answers, the space of possibilities and logical steps is much reduced. This is the way I learned to think then and I am still using it in my research every day, trying to build all the logical steps between what I have and what I think may be the end result of a particular project. /…/

I /…/ applied to Phystech. My examination marks were comfortably above the threshold required for admission, even though I got only one 'excellent' mark out of four exams, with the rest 'good'. Like many would-be students of that age, I dreamed of doing astrophysics or particle physics and aspired to solve 'the greatest mysteries of the universe'. But there was a rumour among Phystech candidates that saying so was considered to be very naïve by interviewers. I remembered that but did not want to cheat. So, when asked about my aspirations, I said that I wanted to study neutron stars (true) because I wanted to understand how matter behaved at extremely high densities (an excuse, not to sound so naïve). A prompt reply /…/ was 'Good, you can then study high-pressure physics at our Institute [of Solid State Physics].'

Another memory of that interview is being asked to estimate the weight of the earth's atmosphere (it was customary to give candidates some tricky mental problems to solve). I spent most of my three minutes multiplying the numbers in my head (atmospheric pressure multiplied by the surface area of the earth divided by gravity, all in SI units) and when I gave an answer in trillions of trillions of kg, everyone was surprised because I was only expected to give a general answer, not a specific number.

Phystech is quite an exceptional university, not only by Russian standards /…/. As Phystech students we were forced to think and find logic in everything we studied, as opposed to just memorising facts and formulas. This was largely due to Phystech's examination style: when it came to specialised subjects, many of the exams we took every year were open-book. This meant that there was no need to remember formulas, as long as one knew where to find them. Instead, the problems

were challenging, requiring combinations of different subject areas and thus teaching us to really understand science rather than merely to memorise it.

From the moment of its establishment, Phystech was led by prominent Soviet scientists such as Kapitsa, Landau and many others. Among my own lecturers and examiners were many eminent scientists such as Emmanuel Rashba, Vladimir Pokrovski, Viktor Lidskii, Spartak Belyaev, Lev Pitaevskii, Isaak Khalatnikov and Lev Gorkov, to name but a few /…/.

For me personally, only the first half year at Phystech was a struggle. I came from a provincial town, while some of my classmates were graduates of elite Moscow schools specialising in physics and maths. Quite a few were winners of international Olympiads in physics or mathematics. The first few months were essentially designed to bring everyone to the level of those guys; they were nearly a year ahead of the rest of us in formal topics, especially maths. Only after I got all the highest marks in the first set of mid-year exams did I start feeling confident enough in this wunderkind environment and was able to relax somewhat. Despite all the pressure and grilling, every single one of us who managed to graduate from Phystech have great memories of those hard years and are most proud of our alma mater /…/.

My attitude of doing all right to reach a goal but not doing my utmost persisted through all the university and PhD years. I only started to really enjoy physics and do my absolute best, for its own sake, much later when I became an independent researcher.

The topic of my Master's project was electronic properties of metals, which I studied by exciting electromagnetic waves (so-called helicons) in spherical samples of ultrapure indium. From the helicon resonances I could extract information about the resistivity of those samples. The competitive edge of this research was the extreme purity of the indium I was working with, such that at low temperatures electrons could shoot over distances comparable with the sample diameter (~1 cm). After graduating I started working towards my PhD in the same laboratory, as was customary for many Phystech graduates.

http://www.nobelprize.org/nobel_prizes/physics/laureates/2010/ geim-bio.html)

1) Find additional information about Andre Geim's scientific career after he defended his PhD thesis (you can find this information in Geim's Nobel lecture: http://www.nobelprize.org/nobel_prizes/physics/laureates/2010/geim-lecture.html)

2) Describe your university years using word combinations and phrases from the text.

to bring everyone to a particular level, to feel confident enough, to get all the highest marks, despite the pressure, to graduate from the university, to be proud of one's alma mater, to do one's utmost, to become an independent researcher, to extract information about smth, prominent scientists, to be quite an exceptional university, challenging problems, to really understand science rather than merely memorize it, to thoroughly enjoy smth, to require understanding of more than one area of physics

Advanced Information

Read the text about graphene and answer the questions.

1) What is graphene and what is its electronic structure like?
2) Which of graphene's properties make it indispensable in a great number of applications?
3) Were Andre Geim and Konstantin Novoselov the first to study graphene? In what way did their research turn out to be a breakthrough?

Two-dimensional (2D) crystalline materials have recently been identified and analyzed. The first material in this new class is graphene, a single atomic layer of carbon. This new material has a number of unique properties, which makes it interesting for both fundamental studies and future applications.

The electronic properties of this 2D-material lead to, for instance, an unusual quantum Hall effect. It is a transparent conductor which is one atom thin. It also gives rise to analogies with particle physics, including an exotic type of tunneling which was predicted by the Swedish physicist Oscar Klein.

In addition, graphene has a number of remarkable mechanical and electrical properties. It is substantially stronger than steel, and it is very

stretchable. The thermal and electrical conductivity is very high and it can be used as a flexible conductor. /…/

Graphene is a single layer of carbon packed in a hexagonal (honeycomb) lattice, with a carbon-carbon distance of 0.142 nm. It is the first truly two-dimensional crystalline material and it is representative of a whole class of 2D materials including for example single layers of Boron-Nitride (BN) and Molybdenum-disulphide (MoS_2), which have both been produced after 2004.

The electronic structure of graphene is rather different from usual three-dimensional materials. Its Fermi surface is characterized by six double cones. In intrinsic (undoped) graphene the Fermi level is situated at the connection points of the cones. Since the density of states of the material is zero at that point, the electrical conductivity of intrinsic graphene is quite low and is of the order of the conductance quantum $\sigma \sim e^2/h$; the exact prefactor is still debated. The Fermi level can however be changed by an electric field so that the material becomes either n-doped (with electrons) or p-doped (with holes) depending on the polarity of the applied field. Graphene can also be doped by adsorbing, for example, water or ammonia on its surface. The electrical conductivity for doped graphene is potentially quite high, at room temperature it may even be higher than that of copper.

Close to the Fermi level the dispersion relation for electrons and holes is linear. Since the effective masses are given by the curvature of the energy bands, this corresponds to zero effective mass. The equation describing the excitations in graphene is formally identical to the Dirac equation for massless fermions which travel at a constant speed. The connection points of the cones are therefore called Dirac points. This gives rise to interesting analogies between graphene and particle physics, which are valid for energies up to approximately 1eV, where the dispersion relation starts to be nonlinear. One result of this special dispersion relation, is that the quantum Hall effect becomes unusual in graphene.

Graphene is practically transparent. In the optical region it absorbs only 2.3% of the light. This number is in fact given by $\pi\ \alpha$, where α is the fine structure constant that sets the strength of the electromagnetic force. In contrast to low temperature 2D systems based on semiconductors, graphene maintains its 2D properties at room temperature. Graphene also has several other interesting properties, which it shares with carbon nanotubes. It is substantially stronger than steel, very stretchable and can be used as a flexible conductor. Its thermal conductivity is much higher than that of silver.

Graphene had already been studied theoretically in 1947 by P.R. Wallace as a text book example for calculations in solid state physics. He predicted the electronic structure and noted the linear dispersion relation. The wave equation for excitations was written down by J.W. McClure already in 1956, and the similarity to the Dirac equation was discussed by G.W. Semenoff in 1984.

It came as a surprise to the physics community when Andre Geim, Konstantin Novoselov and their collaborators from the University of Manchester (UK), and the Institute for Microelectronics Technology in Chernogolovka (Russia), presented their results on graphene structures. They published their results in October of 2004 in Science. In this paper they described the fabrication, identification and Atomic Force Microscopy (AFM) characterization of graphene. They used a simple but effective mechanical exfoliation method for extracting thin layers of graphite from a graphite crystal with Scotch tape and then transferred these layers to a silicon substrate. This method was first suggested and tried by R. Ruoff's group who were, however, not able to identify any monolayers. The Manchester group succeeded by using an optical method with which they were able to identify fragments made up of only a few layers./…/

Graphene has a number of properties which makes it interesting for several different applications. It is an ultimately thin, mechanically very strong, transparent and flexible conductor. Its conductivity can be modified over a large range either by chemical doping or by an electric field. The mobility of graphene is very high which makes the material very interesting for electronic high frequency applications. Recently it has become possible to fabricate large sheets of graphene. Using near-industrial methods, sheets with a width of 70cm have been produced. Since graphene is a transparent conductor it can be used in applications such as touch screens, light panels and solar cells, where it can replace the rather fragile and expensive Indium-Tin-Oxide (ITO). Flexible electronics and gas sensors are other potential applications. The quantum Hall effect in graphene could also possibly contribute to an even more accurate resistance standard in metrology. New types of composite materials based on graphene with great strength and low weight could also become interesting for use in satellites and aircraft.

The development of this new material, opens new exiting possibilities. It is the first crystalline 2D-material and it has unique properties, which makes it interesting both for fundamental science and for future

applications. The breakthrough was done by Geim, Novoselov and their co-workers; it was their paper from 2004 which ignited the development. For this they are awarded the Nobel Prize in Physics 2010.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2010/advanced.html)

Speed Read

Translate at sight.

A Chip Off the Old Block[2]

Sometimes the old gives rise to the new in wonderfully unexpected ways. Such was the case with graphene: an entirely new form of carbon, the world's first 2-dimensional material and the subject of the 2010 Nobel Prize in Physics. This novel wonder material, which offers possibilities ranging from faster computers to new insights into quantum physics, was produced from plain, familiar old graphite, the stuff that fills your pencils. Pencils work because graphite is made from layer upon layer of carbon atoms arranged in sheets a single atom thick; every time you move the pencil across the paper, clumps of these sheets shear off (срезать, скалывать) and are left on the paper. Graphene, which consists of just one of these sheets, can, it turned out, also be sheared off a lump of graphite.

Andre Geim and Konstantin Novoselov, this year's Nobel Laureates, actually isolated Graphene in 2004 in one of their 'Friday evening experiments' where they habitually play with new ideas. They ended up using another familiar material, ordinary sticky tape, to 'exfoliate' a graphite crystal and found that, after several rounds, they were able to peel off the elusive graphene monolayers. Virtually transparent and of atomic thickness, graphene can only be seen under very specific conditions, and coincidentally Geim and Novoselov chose exactly the right substrate to place their flakes on, allowing them to view them in an ordinary microscope. A new research field was born.

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[2]Chip off the old block — (букв.) «весь в отца». Имеется в виду игра слов: "chip" — сколотый кусочек, "the old block" — подразумевается графен как уже знакомый и изучавшийся учеными материал.

Graphene's remarkable strength and extreme conductivity, it is a hundred times stronger than steel and more conductive than copper, result from its hexagonal lattice of carbon atoms permeated by a sea of delocalized electrons. Aside from the insights into fundamental quantum physics they offer, graphene's properties have set the world's material scientists dreaming of, and exploring, a wealth of possible applications. Among the most realistic is its potential use in touch screens where the transparency, strength and conductivity it offers appear to provide a highly desirable combination. Perhaps most immediately enticing (заманчивый) is the vision of further miniaturizing computer chips by using graphene's atomic scale to overcome the size constraints now being encountered with silicon-based components.

Previous results of the Geim lab's playful approach to physics have included levitating live frogs, in a demonstration of the importance of diamagnetism, and the biomimetic nanomaterial known as gecko tape. As Geim himself says, "getting some play during working hours for which you are paid is the best job I can recommend for anyone around!"

(by Adam Smith, Editor-in-Chief, Nobelprize.org)

Unit 11

The Accelerating Expansion of the Universe

The Nobel Prize in Physics 2011 — Press Release

October 4, 2011

The Royal Swedish academy of Sciences decided to award the Nobel Prize in Physics for 2011 ***"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae".*** The prize is awarded with one half jointly to **Saul Perlmutter**, The Supernova Cosmology Project, Lawrence Berkeley National Laboratory and University of California, Berkeley, CA, USA, and the other half jointly to **Brian P. Schmidt**, the High-z Supernova Search Team, Australian National University, Weston Creek, Australia, and **Adam G. Riess**, the High-z Supernova Search Team, Johns Hopkins University and Space Telescope Science Institute, Baltimore, MD, USA.

Written in the stars

"Some say the world will end in fire, some say in ice..."

What will be the final destiny of the Universe? Probably it will end in ice, if we are to believe this year's Nobel Laureates in Physics. They have studied several dozen exploding stars, called supernovae, and discovered that the Universe is expanding at an ever-accelerating rate. The discovery came as a complete surprise even to the Laureates themselves.

In 1998, cosmology was shaken at its foundations as two research teams presented their findings. Headed by Saul Perlmutter, one of the teams had set to work in 1988. Brian Schmidt headed another team, launched at the end of 1994, where Adam Riess was to play a crucial role.

The research teams raced to map the Universe by locating the most distant supernovae. More sophisticated telescopes on the ground and in space, as well as more powerful computers and new digital imaging sensors (CCD, Nobel Prize in Physics in 2009), opened the possibility in the 1990s to add more pieces to the cosmological puzzle.

The teams used a particular kind of supernova, called type Ia supernova. It is an explosion of an old compact star that is as heavy as the Sun but as small as the Earth. A single such supernova can emit as much light as a whole galaxy. All in all, the two research teams found over 50 distant supernovae whose light was weaker than expected — this was a sign that the expansion of the Universe was accelerating. The potential pitfalls had been numerous, and the scientists found reassurance in the fact that both groups had reached the same astonishing conclusion.

For almost a century, the Universe has been known to be expanding as a consequence of the Big Bang about 14 billion years ago. However, the discovery that this expansion is accelerating is astounding. If the expansion will continue to speed up the Universe will end in ice.

The acceleration is thought to be driven by dark energy, but what that dark energy is remains an enigma — perhaps the greatest in physics today. What is known is that dark energy constitutes about three quarters of the Universe. Therefore the findings of the 2011 Nobel Laureates in Physics have helped to unveil a Universe that to a large extent is unknown to science. And everything is possible again.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2011/press.html)

Retell the text using the following word combinations.

to study several dozen exploding stars (supernovae), to expand at an ever-accelerating rate, to come as a complete surprise to smb, to be shaken at its foundations (cosmology), to present findings, to set to work, to play a crucial role, to locate the most distant supernovae, open the possibility, to add more pieces to the cosmological puzzle, to use a particular kind of supernova, to emit as much light as a whole galaxy, all in all, numerous potential pitfalls, to find reassurance in the fact that…, to reach the same astonishing conclusion, to remain an enigma, an astounding discovery, to unveil the Universe, unknown to a large extent to science

Popular Information

Read the information on dark energy and highlight the key points in writing.

So what is it that is speeding up the Universe? It is called *dark energy* and is a challenge for physics, a riddle that no one has managed to solve yet. Several ideas have been proposed. The simplest is to reintro-

duce Einstein's cosmological constant, which he once rejected. At that time, he inserted the cosmological constant as an anti-gravitational force to counter the gravitational force of matter and thus create a static Universe. Today, the cosmological constant instead appears to make the expansion of the Universe accelerate.

The cosmological constant is, of course, constant, and as such does not change over time. So dark energy becomes dominant when matter, and thus its gravity, gets diluted due to expansion of the Universe over billions of years. According to scientists, that would account for why the cosmological constant entered the scene so late in the history of the Universe, only five to six billion years ago. At about that time, the gravitational force of matter had weakened enough in relation to the cosmological constant. Until then, the expansion of the Universe had been decelerating.

The cosmological constant could have its source in the vacuum, empty space that, according to quantum physics, is never completely empty. Instead, the vacuum is a bubbling quantum soup where virtual particles of matter and antimatter pop in and out of existence and give rise to energy. However, the simplest estimation for the amount of dark energy does not correspond at all to the amount that has been measured in space, which is about 10^{120} times larger (1 followed by 120 zeros). This constitutes a gigantic and still unexplained gap between theory and observation — on all the beaches of the world there are no more than 10^{20} (1 followed by 20 zeros) grains of sand.

It may be that the dark energy is not constant after all. Perhaps it changes over time. Perhaps an unknown force field only occasionally generates dark energy. In physics there are many such force fields that collectively go by the name *quintessence*, after the Greek name for the fifth element. Quintessence could speed up the Universe, but only sometimes. That would make it impossible to foresee the fate of the Universe.

Whatever dark energy is, it seems to be here to stay. It fits very well in the cosmological puzzle that physicists and astronomers have been working on for a long time. According to current consensus, about three quarters of the Universe consist of dark energy. The rest is matter. But the regular matter, the stuff that galaxies, stars, humans and flowers are made of, is only five percent of the Universe. The remaining matter is called *dark matter* and is so far hidden from us.

The dark matter is yet another mystery in our largely unknown cosmos. Like dark energy, dark matter is invisible. So we know both only by their effects — one is pushing, the other one is pulling. They only have the adjective "dark" in common.

Therefore the findings of the 2011 Nobel Laureates in Physics have helped to unveil a Universe that is to 95% unknown to science.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2011/public.html)

Advanced Information

1) Translate the text at sight.

The discovery of the accelerating expansion of the Universe is a milestone for cosmology, as significant as the discovery of the minute temperature variations in the Cosmic Microwave Background (CMB) radiation with the COBE satellite (Nobel Prize in Physics 2006, John Mather and George Smoot). By studying the CMB, we may learn about the early history of the Universe and the origins of structure, whereas the expansion history of the Universe gives us insights into its evolution and possibly its ultimate fate.

The expansion of the Universe was discovered by Vesto Slipher, Carl Wirtz, Knut Lundmark, Georges Lemaître and Edwin Hubble in the 1920's. The expansion rate depends on the energy content — a Universe containing only matter should eventually slow down due to the attractive force of gravity. However, observations of type Ia supernovae (SNe) at distances of about 6 billion light years by two independent research groups, led by Saul Perlmutter and by Brian Schmidt and Adam Riess respectively, reveal that presently the expansion rate instead is accelerating.

Within the framework of the standard cosmological model, the acceleration is generally believed to be caused by the vacuum energy (sometimes called "dark energy") which — based on concordant data from the SNe, the observations of the anisotropies in the CMB and surveys of the clustering of galaxies — accounts for about 73% of the total energy density of the Universe. Of the remainder, about 23% is due to an unknown form of matter (called "dark matter"). Only about 4% of the energy density corresponds to ordinary matter like atoms.

In everyday life, the effects of the vacuum energy are tiny but measurable — observed for instance in the form of shifts of the energy levels of the hydrogen atom, the Lamb shift (Nobel Prize in Physics 1955).

The evolution of the Universe is described by Einstein's theory of general relativity. In relativistic field theories, the vacuum energy contribution is given by an expression mathematically similar to the famous

cosmological constant in Einstein's theory. The question of whether the vacuum energy term is truly time independent like the cosmological constant, or varies with time, is currently a very hot research topic.

(http://www.nobelprize.org/nobel_prizes/physics/laureates-/2011/advanced.html)

2) Read an excerpt from the Scientific Background on the Nobel Prize in Physics 2011 and answer the questions.

a) What does the Equivalence Principle state?

b) What was Einstein's attitude to the concept of an expanding Universe?

c) What did Vesto Slipher find working at the Lowell Observatory?

d) What does Hubble's law state?

e) What is the Cosmological Principle?

f) Who discovered the CMB radiation?

General Relativity and the Universe

The stars in the night sky must have always fascinated human beings. We can only guess what the people of ancient times speculated about when they saw the stars return every night to the same spots in the sky. We know of Greek philosophers who proposed a heliocentric astronomical model with the Sun in the middle and the planets circulating around it as early as the 3rd century B.C., but it was Nicolaus Copernicus, who in the 16th century developed the first modern version of a model. It took Galileo Galilei's genius in the beginning of the next century to really observe and understand the underlying facts, building one of the first telescopes for astronomy and hence laying the ground for modern astronomy. For the next three hundred years, astronomers collected evermore impressive tables of observations of the visible stars. In the Copernican system, the stars were assumed to be fixed to a distant sphere and nothing in the observations indicated anything to the contrary. In 1718, Edmund Halley discovered that stars actually could move in the sky, but it was believed that this happened in a static, fixed universe. Throughout the 18th and 19th century, the study of celestial bodies was placed on an ever-firmer footing with the famous laws of Kepler and Newton.

In November 1915, Albert Einstein (Nobel Prize in Physics 1921) presented his theory of gravity, which he nicknamed General Relativity (GR), an extension of his theory of special relativity. This was one of the greatest achievements in the history of science, a modern milestone. It was based on the Equivalence Principle, which states that the gravitational mass of a body is the same as its inertial mass. You cannot distinguish gravity from acceleration! Einstein had already checked that this could explain the precession of the perihelion of Mercury, a problem of Newtonian mechanics. The new insight was that gravity is really geometric in nature and that the curving of space and time, spacetime, makes bodies move as if they were affected by a force. The crucial physical parameters are the metric of spacetime, a matrix that allows us to compute infinitesimal distances (actually infinitesimal line elements - or proper times in the language of special relativity.) It became immediately clear that Einstein's theory could be applied to cosmological situations, and Karl Schwarzschild very soon found the general solution for the metric around a massive body such as the Sun or a star.

In 1917, Einstein applied the GR equations to the entire Universe, making the implicit assumption that the Universe is homogenous; if we consider cosmological scales large enough such that local clusters of matter are evened out. He argued that this assumption fit well with his theory and he was not bothered by the fact that the observations at the time did not really substantiate his conjecture. Remarkably, the solutions of the equations indicated that the Universe could not be stable. This was contrary to all the thinking of the time and bothered Einstein. He soon found a solution, however. His theory of 1915 was not the most general one consistent with the Equivalence Principle. He could also introduce a cosmological constant, a constant energy density component of the Universe. With this Einstein could balance the Universe to make it static.

In the beginning of the 1920s, the Russian mathematician and physicist Alexander Friedmann studied the problem of the dynamics of the Universe using essentially the same assumptions as Einstein, and found in 1922 that Einstein's steady state solution was really unstable. Any small perturbation would make the Universe non-static. At first Einstein did not believe Friedmann's results and submitted his criticism to *Zeitschrift für Physik*, where Friedmann's paper had been published. However, a year later Einstein found that he had made a mistake and

submitted a new letter to the journal acknowledging this fact. Even so, Einstein did not like the concept of an expanding Universe and is said to have found the idea "abominable". In 1924, Friedmann presented his full equations, but after he died in 1925 his work remained essentially neglected or unknown, even though it had been published in a prestigious journal. We have to remember that a true revolution was going on in physics during these years with the advent of the new quantum mechanics, and most physicists were busy with this process. In 1927, the Belgian priest and physicist Georges Lemaître working independently from Friedmann performed similar calculations based on GR and arrived at the same results. Unfortunately, Lemaître's paper was published in a local Belgian journal and again the results did not spread far, even though Einstein knew of them and discussed them with Lemaître.

In the beginning of the 20th century it was generally believed that the entire Universe only consisted of our galaxy, the Milky Way. The many nebulae which had been found in the sky were thought to be merely gas clouds in distant parts of the Milky Way. In 1912, Vesto Slipher, while working at the Lowell Observatory, pioneered measurements of the shifts towards red of the light from the brightest of these spiral nebulae. The redshift of an object depends on its velocity radially away from us, and Slipher found that the nebulae seemed to move faster than the Milky Way escape velocity.

In the following years, the nature of the spiral nebulae was intensely debated. Could there be more than one galaxy? This question was finally settled in the 1920s with Edwin Hubble as a key figure. Using the new 100-inch telescope at Mt Wilson, Hubble was able to resolve individual stars in the Andromeda nebula and some other spiral nebulae, discovering that some of these stars were Cepheids, dimming and brightening with a regular period.

The Cepheids are pulsating giants with a characteristic relation between luminosity and the time interval between peaks in brightness, discovered by the American astronomer Henrietta Leavitt in 1912. This luminosity-period relation, calibrated with nearby Cepheids whose distances are known from parallax measurements, allows the determination of a Cepheid's true luminosity from its time variation — and hence its distance (within ~10%) from the inverse square law.

Hubble used Leavitt's relation to estimate the distance to the spiral nebulae, concluding that they were much too distant to be part of the Milky Way and hence must be galaxies of their own. Combining his own measurements and those of other astronomers he was able to plot the distances to 46 galaxies and found a rough proportionality of an object's distance with its redshift. In 1929, he published what is today known as 'Hubble's law': a galaxy's distance is proportional to its radial recession velocity.

Even though Hubble's data were quite rough and not as precise as the modern ones, the law became generally accepted, and Einstein had to admit that the Universe is indeed expanding. It is said, that he called the introduction of the cosmological constant his "greatest mistake" . From this time on, the importance of the cosmological constant faded, although it reappeared from time to time.

It should be noted for the historic records that Lemaître in his 1927 paper correctly derived the equations for an expanding Universe obtaining a relation similar to Hubble's and found essentially the same proportionality constant (the "Hubble constant") as Hubble did two years later. After Hubble's result had spread, Arthur Eddington had Lemaître's paper translated into English in 1931, without the sections about Hubble's law. In a reply to Eddington, Lemaître also pointed out a logical consequence of an expanding Universe: The Universe must have existed for a finite time only, and must have emerged from an initial single quantum (in his words). In this sense, he paved the way for the concept of the Big Bang (a name coined much later by Fred Hoyle). It should also be noted that Carl Wirtz in 1924 and Knut Lundmark in 1925 had found that nebulae farther away recede faster than closer ones.

Hubble's and others' results from 1926 to 1934, even though not very precise, were encouraging indications of a homogeneous Universe and most scientists were quick to accept the notion. The concept of a homogeneous and isotropic Universe is called the Cosmological Principle. This goes back to Copernicus, who stated that the Earth is in no special, favoured place in the Universe. In modern language it is assumed that the Universe looks the same on cosmological scales to all observers, independent of their location and independent of in which direction they look in. The assumption of the Cosmological Principle was inherent in the work of Friedmann and Lemaître but virtually unknown in large parts of the scientific society. Thanks to the work of Howard Robertson in 1935-1936 and Arthur Walker in 1936 it became well known.

Robertson and Walker constructed the general metric of spacetime consistent with the Cosmological Principle and showed that it was not tied specifically to Einstein's equations, as had been assumed by Friedmann and Lemaître. Since the 1930s, the evidence for the validity of the

Cosmological Principle has grown stronger and stronger, and with the 1964 discovery of the CMB radiation by Arno Penzias and Robert Wilson (Nobel Prize in Physics 1978), the question was finally settled. The recent observations of the CMB show that the largest temperature anisotropies (on the order of 10^{-3}) arise due to the motion of the Milky Way through space. Subtracting this dipole component, the residual anisotropies are a hundred times smaller.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2011/advanced.html)

3) Translate the sentences into Russian.

a) The stars in the night sky must have always fascinated human beings.

b) We know of Greek philosophers who proposed a heliocentric astronomical model with the Sun in the middle and the planets circulating around it as early as the 3rd century B.C., but it was Nicolaus Copernicus, who in the 16th century developed the first modern version of a model.

c) In the Copernican system, the stars were assumed to be fixed to a distant sphere and nothing in the observations indicated anything to the contrary.

d) Einstein did not like the concept of an expanding Universe and is said to have found the idea "abominable".

e) The many nebulae which had been found in the sky were thought to be merely gas clouds in distant parts of the Milky Way.

f) The redshift of an object depends on its velocity radially away from us, and Slipher found that the nebulae seemed to move faster than the Milky Way escape velocity.

g) In a reply to Eddington, Lemaître also pointed out a logical consequence of an expanding Universe: The Universe must have existed for a finite time only, and must have emerged from an initial single quantum (in his words).

Unit 12

A New Era of Experimentation with Quantum Physics

The Nobel Prize in Physics 2012 — Popular Release
October 9, 2012

The Royal Swedish academy of Sciences decided to award the Nobel Prize in Physics for 2012 ***"for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems".*** The Nobel Prize is awarded to **Serge Haroche** Collège de France and Ecole Normale Supérieure, Paris, France, and **David J. Wineland**, National Institute of Standards and Technology (NIST) and University of Colorado Boulder, CO, USA.

Read the text and explain what Serge Haroche's and David J. Wineland's scientific and technological breakthrough consists in.

Particle control in a quantum world

Serge Haroche and David J. Wineland have independently invented and developed methods for measuring and manipulating individual particles while preserving their quantum-mechanical nature, in ways that were previously thought unattainable.

The Nobel Laureates have opened the door to a new era of experimentation with quantum physics by demonstrating the direct observation of individual quantum particles without destroying them. For single particles of light or matter the laws of classical physics cease to apply and quantum physics takes over. But single particles are not easily isolated from their surrounding environment and they lose their mysterious quantum properties as soon as they interact with the outside world. Thus many seemingly bizarre phenomena predicted by quantum physics could not be directly observed, and researchers could only carry out thought experiments that might in principle manifest these bizarre phenomena.

Through their ingenious laboratory methods Haroche and Wineland together with their research groups have managed to measure and control very fragile quantum states, which were previously thought inaccessible for direct observation. The new methods allow them to examine, control and count the particles.

Their methods have many things in common. David Wineland traps electrically charged atoms, or ions, controlling and measuring them with light, or photons.

Serge Haroche takes the opposite approach: he controls and measures trapped photons, or particles of light, by sending atoms through a trap.

Both Laureates work in the field of quantum optics studying the fundamental interaction between light and matter, a field which has seen considerable progress since the mid-1980s. Their ground-breaking methods have enabled this field of research to take the very first steps towards building a new type of superfast computer based on quantum physics. Perhaps the quantum computer will change our everyday lives in this century in the same radical way as the classical computer did in the last century. The research has also led to the construction of extremely precise clocks that could become the future basis for a new standard of time, with more than hundred-fold greater precision than present-day caesium clocks.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2012/press.html)

David Wineland — Interview

Read David Wineland's Nobel interview and answer the questions.

a) What is David Wineland's main interest?

b) What method does Wineland use to trap single atoms to observe the superposition of quantum states?

c) What chemical element are the clocks Wineland designs based on?

d) How close is modern physics to quantum computing?

"It's a long way before we have a useful quantum computer, but I think most of us ... feel that it will eventually happen"

[Adam Smith] – Oh hello, I'm sorry to call so very early, may I speak to Professor David Wineland please?
[David Wineland] – Yes, this is he.
[AS] – Oh good morning, my name is Adam Smith, from the Nobel Prize website in Stockholm. We have a tradition of recording extremely short interviews with new Laureates. Would you be able to speak for just a very few minutes?
[DW] [Laughs] – Sure. Okay.
[AS] – Thank you very much indeed. First of all, of course, our sincere congratulations on the award of the Nobel Prize.
[DW] – Oh, thank you.
[AS] – I know it's extremely early in the morning, in fact the middle of the night there. What were you doing when the call from Stockholm came?
[DW] – Well, I was sleeping, and my wife got the call and woke me up.
[AS] [Laughs] – Do you recall your initial reaction?
[DW] – Well, I mean a wonderful surprise, of course. Yes, just amazing, sure.
[AS] – I imagine it's thrown the house into some kind of disruption there.
[DW] – Well, we probably won't go back to sleep for a while [Laughs]. Yeah.
[AS] – I guess there's the normal business of life to run alongside handling the press that are about to descend on you.
[DW] – That's right, yeah.
[AS] – Your main interest, I gather, is developing far more accurate clocks and that's what you've been devoted to in your career.
[DW] – That's been the main theme. Yes, but there's been many spin-offs from that, including the work on single atoms.
[AS] – And the trapping of single atoms, this allows you to observe the superposition of quantum states?
[DW] – That's right.
[AS] – This is basically observing, if you like, the frontier between the classical world where the states don't superimpose and quantum states where you can have multiple states at the same time.
[DW] – Well, you might say that. That's right, yes.

[AS] – How do you trap the atoms?
[DW] – Well, in our case the atoms are ions, charged atoms. So we use electric fields to hold them in one place.
[AS] – And then you use laser beams to manipulate them, is that correct?
[DW] – That's right.
[AS] – Tell me more, please, about why need more accurate clocks.
[DW] – Well, I think historically it's always been true that when we've made better clocks there's always been an application. The main use throughout history for the last many centuries is that clocks are used in navigation and the better clocks we have the better navigation we can do. So that theme has carried through for many centuries. As we make better clocks that's still been the primary application. These days also the timing, the precise timing, you know, by good clocks is also used in communication. But historically the main use has been and continues to be in navigation.
[AS] – And how accurate are our most accurate clocks now? You have this mercury ion clock.
[DW] – Currently the most accurate one is also in our lab. It's based on aluminium. And accuracy meaning, you know, how well we can control the environmental effects and so on, is at about one part in 10 to the 17.
[AS] [Laughs] – And how long can you keep it running for? Is it indefinite?
[DW] – Well, so far these are laboratory devices. So they do not work continuously, but they can work many hours and days to produce these results.
[AS] – So the other application that is often talked about is quantum computing.
[DW] – Right.
[AS] – And does your work take us a step closer to quantum computing?
[DW] – Well, I think you might say that. But in the same breath, you have to say that it's a long way before we have a useful quantum computer. But I think most of us feel that even though that is a long, you know, long way off before we can realise such a computer, many of us feel it will eventually happen. It's primarily a matter of controlling these systems better and better. Both Serge Haroche and I work on atoms. There's many other platforms and condensed matter where this might happen. But wherever it happens I think we believe that in the long run we should be able to [inaudible] well enough to realise such a device.

[AS] – May I ask you, you work at the National Institute of Standards and Technology and it seems to be a hotbed for the production of new inventions and, indeed, Nobel Laureates. What is it that's so special about this place?
[DW] – I think that, one of the things, you know, certainly is the people, my management. People above me have been very supportive of these things. You know, it couldn't happen without that. I think supportive management, and it helps being around very good people. That's made the difference.
[AS] – Must be a very exciting place to be. And, indeed, it must be extraordinarily exciting looking at this new frontier, being the first to observe this new world of quantum states, which haven't been previously observable.
[DW] – Well, I wouldn't say ...I wouldn't put myself in the first, you know, maybe we're among the first. But there's many good people working on these things though. It's certainly a big enterprise by now and many people are working on this in this area.
[AS] – Sure, but there must be a constant thrill of excitement, of feeling you're on uncharted territory.
[DW] – Well, yeah, that's been really true in science, to be near the leading edge, I suppose. Yeah, it's always been great, really exciting to be in this field. [AS] – Thank you so much for talking to us. Again, apologies for calling in the very middle of the night ...[both laugh] ... when you come to Stockholm in December we have the chance to interview you at a greater length, which we very much look forward to. But for now, I wish you the very best of luck with what will surely be an exciting day.
[DW] – Well, thanks very much. All right, thank you.
[AS] – Thank you. Nice to speak to you. Bye bye.
[DW] – Bye bye.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2012/wineland-interview.html)

Translate the text into English in writing.

Важным практическим применением открытий Уайнленда стали квантовые часы, которые по точности превосходят широко используемые цезиевые стандарты времени. И механические, и цезиевые, и квантовые часы работают по одному принципу — качание маятника или балансира (в механических часах), колебания

сверхвысокой частоты (в цезиевых) или световые (в квантовых) служат единицей отсчёта времени. Основа квантовых часов Уайнленда –– ион ртути, запертый в «ловушке» и совершающий переходы с одного энергетического уровня на другой под действием лазерного излучения. Квантовые часы работают на гораздо более высокой частоте, чем цезиевые. Поэтому точность их такова, что если бы они начали отсчёт времени в момент возникновения Вселенной (почти 14 млрд лет назад), то сегодня они ошиблись бы лишь на несколько секунд.

Ещё более интересна и перспективна область, в которой нашли применение открытия лауреатов, — это квантовые компьютеры. Идея вычислительной системы, основанной на вероятностной логике и работающей с квантовыми битами — кубитами, которые могут находиться в трёх состояниях — двух фиксированных и в состоянии суперпозиции, — возникла в 90-х годах прошлого века. Квантовые компьютеры должны иметь крайне высокую вычислительную мощность, но ограничения квантовой механики не позволяли создать рабочие модели таких вычислителей.

Результаты исследований Ароша и Уайнленда позволили физикам преодолеть «запретный» квантовый барьер. Была разработана теория декогеренции, которая объясняет процесс нарушения состояния суперпозиции. Уайнленд создал из двух кубитов первый прототип квантового логического инвертора — элемент, осуществляющий операцию «контролируемое НЕ». Конечно, для создания полноценной вычислительной системы недостаточно лишь одного логического элемента, выполняющего отрицание, однако исследования нобелевских лауреатов открывают пути к дальнейшим открытиям и изобретениям в этой области.

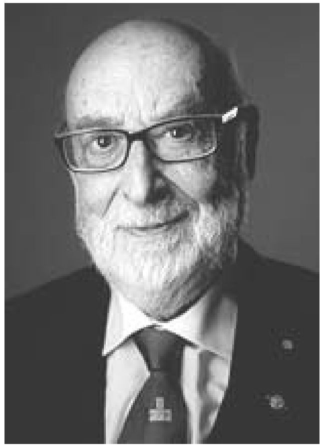
(*Наука и жизнь №11, 2012*)

Unit 13

The Origin of Mass of Subatomic Particles. The Higgs Boson

The Nobel Prize in Physics 2013 — Press Information

The Nobel Prize in Physics 2013 was awarded jointly to **François Englert** and **Peter W. Higgs** *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*.




François Englert and Peter W. Higgs

1) Read the text and answer the questions.

a) What kind of fields exist in quantum physics?

b) Why is the Higgs field so important for the Standard Model?

c) What is the difference between the Higgs field and other fields in physics?

d) How does the quantum mechanism discovered by F. Englert and P. Higgs provide a way for symmetry to both exist and be hidden from view at the same time?

e) How do the ATLAS and CMS detectors function?

f) Why is the Higgs particle not the final key to the Standard Model?

Here, at last!

The awarded mechanism is a central part of the Standard Model of particle physics that describes how the world is constructed. According to the Standard Model, everything, from flowers and people to stars and planets, consists of just a few building blocks: matter particles. These particles are governed by forces mediated by force particles that make sure everything works as it should.

The entire Standard Model also rests on the existence of a special kind of particle: the Higgs particle. It is connected to an invisible field that fills up all space. Even when our universe seems empty, this field is there. Had it not been there, electrons and quarks would be massless just like photons, the light particles. And like photons they would, just as Einstein's theory predicts, rush through space at the speed of light, without any possibility to get caught in atoms or molecules.

Nothing of what we know, not even we, would exist. Both François Englert and Peter Higgs were young scientists when they, in 1964, independently of each other put forward a theory that rescued the Standard Model from collapse. Almost half a century later, on Wednesday 4 July 2012, they were both in the audience at the European Laboratory for Particle Physics, CERN, outside Geneva, when the discovery of a Higgs particle that finally confirmed the theory was announced to the world.

The model that created order

The idea that the world can be explained in terms of just a few building blocks is old. Already in 400 BC, the philosopher Democritus postulated that everything consists of atoms — átomos is Greek for indivisible. Today we know that atoms are not indivisible. They consist of electrons that orbit an atomic nucleus made up of neutrons and protons. And neutrons and protons, in turn, consist of smaller particles called quarks. Actually, only electrons and quarks are indivisible according to the Standard Model.

The atomic nucleus consists of two kinds of quarks, up quarks and down quarks. So in fact, three elementary particles are needed for all matter to exist: electrons, up quarks and down quarks. But during the 1950s and 1960s, new particles were unexpectedly observed in both cosmic radiation and at newly constructed accelerators, so the Standard Model had to include these new siblings of electrons and quarks.

Besides matter particles, there are also force particles for each of nature's four forces — gravitation, electromagnetism, the weak force and the strong force. Gravitation and electromagnetism are the most well-known, they attract or repel, and we can see their effects with our own eyes. The strong force acts upon quarks and holds protons and neutrons together in the nucleus, whereas the weak force is responsible for radioactive decay, which is necessary, for instance, for nuclear processes inside the Sun.

The Standard Model of particle physics unites the fundamental building blocks of nature and three of the four forces known to us (the fourth, gravitation, remains outside the model). For long, it was an enigma how these forces actually work. For instance, how does the piece of metal that is attracted to the magnet know that the magnet is lying there, a bit further away? And how does the Moon feel the gravity of Earth?

Invisible fields fill space

The explanation offered by physics is that space is filled with many invisible fields. The gravitational field, the electromagnetic field, the quark field and all the other fields fill space, or rather, the four dimensional space-time, an abstract space where the theory plays out. The Standard Model is a quantum field theory in which fields and particles are the essential building blocks of the universe.

In quantum physics, everything is seen as a collection of vibrations in quantum fields. These vibrations are carried through the field in small packages, quanta, which appear to us as particles. Two kinds of fields exist: matter fields with matter particles, and force fields with force particles – the mediators of forces. The Higgs particle, too, is a vibration of its field – often referred to as the Higgs field.

Without this field the Standard Model would collapse like a house of cards, because quantum field theory brings infinities that have to be reined in and symmetries that cannot be seen. It was not until François Englert with Robert Brout, and Peter Higgs, and later on several others, showed that the Higgs field can break the symmetry of the Standard Model without destroying the theory that the model got accepted.

This is because the Standard Model would only work if particles did not have mass. As for the electromagnetic force, with its massless photons as mediators, there was no problem. The weak force, however, is mediated by three massive particles; two electrically charged W particles and one Z particle. They did not sit well with the light-footed photon. How could the electroweak force, which unifies electromagnetic and weak forces, come about? The Standard Model was threatened. This is where Englert, Brout and Higgs entered the stage with the ingenious mechanism for particles to acquire mass that managed to rescue the Standard Model.

The ghost-like Higgs field

The Higgs field is not like other fields in physics. All other fields vary in strength and become zero at their lowest energy level. Not the Higgs field. Even if space were to be emptied completely, it would still be filled by a ghost-like field that refuses to shut down: the Higgs field. We do not notice it; the Higgs field is like air to us, like water to fish. But without it we would not exist, because particles acquire mass only in contact with the Higgs field. Particles that do not pay attention to the Higgs field do not acquire mass, those that interact weakly become light, and those that interact intensely become heavy. For example, electrons, which acquire mass from the field, play a crucial role in the creation and holding together of atoms and molecules. If the Higgs field suddenly disappeared, all matter would collapse as the suddenly massless electrons dispersed at the speed of light.

So what makes the Higgs field so special? It breaks the intrinsic symmetry of the world. In nature, symmetry abounds; faces are regularly shaped, flowers and snowflakes exhibit various kinds of geometric symmetries. Physics unveils other kinds of symmetries that describe our world, albeit on a deeper level. One such, relatively simple, symmetry stipulates that it does not matter for the results if a laboratory experiment is carried out in Stockholm or in Paris. Neither does it matter at what time the experiment is carried out. Einstein's special theory of relativity deals with symmetries in space and time, and has become a model for many other theories, such as the Standard Model of particle physics. The equations of the Standard Model are symmetric; in the same way that a ball looks the same from whatever angle you look at it, the equations of the Standard Model remain unchanged even if the perspective that defines them is changed.

The principles of symmetry also yield other, somewhat unexpected, results. Already in 1918, the German mathematician Emmy Noether could show that the conservation laws of physics, such as the laws of conservation of energy and conservation of electrical charge, also originate in symmetry. Symmetry, however, dictates certain requirements to be fulfilled. A ball has to be perfectly round; the tiniest hump will break the symmetry. For equations other criteria apply. And one of the symmetries of the Standard Model prohibits particles from having mass. Now, this is apparently not the case in our world, so the particles must have acquired their mass from somewhere. This is where the now-awarded mechanism provided a way for symmetry to both exist and simultaneously be hidden from view.

The symmetry is hidden but is still there

Our universe was probably born symmetrical. At the time of the Big Bang, all particles were massless and all forces were united in a single primordial force. This original order does not exist anymore – its symmetry has been hidden from us. Something happened just 10-11 seconds after the Big Bang. The Higgs field lost its original equilibrium. How did that happen?

It all began symmetrically. This state can be described as the position of a ball in the middle of a round bowl, in its lowest energy state. With a push the ball starts rolling, but after a while it returns down to the lowest point.

However, if a hump arises at the centre of the bowl, which now looks more like a Mexican hat, the position at the middle will still be symmetrical but has also become unstable. The ball rolls downhill in any direction. The hat is still symmetrical, but once the ball has rolled down, its position away from the centre hides the symmetry. In a similar manner the Higgs field broke its symmetry and found a stable energy level in vacuum away from the symmetrical zero position.

This spontaneous symmetry breaking is also referred to as the Higgs field's phase transition; it is like when water freezes to ice. In order for the phase transition to occur, four particles were required but only one, the Higgs particle, survived. The other three were consumed by the weak force mediators, two electrically charged W particles and one Z particle, which thereby got their mass. In that way the symmetry of the electroweak force in the Standard Model was saved — the symmetry between the three heavy particles of the weak force and the massless photon of the electromagnetic force remains, only hidden from view.

Extreme machines for extreme physics

The Nobel Laureates probably did not imagine that they would get to see the theory confirmed in their lifetime. It took an enormous effort by physicists from all over the world. For a long time two laboratories, Fermilab outside Chicago, USA, and CERN on the Franco-Swiss border, competed in trying to discover the Higgs particle. But when Fermilab's Tevatron accelerator was closed down a couple of years ago, CERN became the only place in the world where the hunt for the Higgs particle would continue.

CERN was established in 1954, in an attempt to reconstruct European research, as well as relations between European countries, after the Second World War. Its membership currently comprises twenty states, and about a hundred nations from all over the world collaborate on the projects.

CERN's grandest achievement, the particle collider LHC (Large Hadron Collider) is probably the largest and the most complex machine ever constructed by humans. Two research groups of some 3,000 scientists chase particles with huge detectors — ATLAS and CMS. The detectors are located 100 metres below ground and can observe 40 million particle collisions per second. This is how often the particles can collide when injected in opposite directions into the circular LHC tunnel, 27 kilometres long.

Protons are injected into the LHC every ten hours, one ray in each direction. A hundred thousand billion protons are lumped together and compressed into an ultra-thin ray — not entirely an easy endeavour since protons with their positive electrical charge rather aim to repel one another. They move at 99.99999 per cent of the speed of light and collide with an energy of approximately 4 TeV each and 8 TeV combined (one teraelectronvolt = a thousand billion electronvolts). One TeV may not be that much energy, it more or less equals that of a flying mosquito, but when the energy is packed into a single proton, and you get 500 trillion such protons rushing around the accelerator, the energy of the ray equals that of a train at full speed. In 2015 the energy will be almost the double in the LHC.

A puzzle inside the puzzle

Particle experiments are sometimes compared to the act of smashing two Swiss watches together in order to examine how they are constructed. But it is actually much more difficult than so, because the particles scientists look for are entirely new — they are created from the energy released in the collision.

According to Einstein's well-known formula $E = mc^2$, mass is a kind of energy. And it is the magic of this equation that makes it possible, even for massless particles, to create something new when they collide; like when two photons collide and create an electron and its antiparticle, the positron, or when a Higgs particle is created in the collision of two gluons, if the energy is high enough.

The protons are like small bags filled with particles — quarks, antiquarks and gluons. The majority of them pass one another without much ado; on average, each time two particle swarms collide only twenty full frontal collisions occur. Less than one collision in a billion might be worth following through. This may not sound much, but each such collision results in a sparkling explosion of about a thousand particles. At 125 GeV, the Higgs particle turned out to be over a hundred times heavier than a proton and this is one of the reasons why it was so difficult to produce.

However, the experiment is far from finished. The scientists at CERN hope to bring further groundbreaking discoveries in the years to come. Even though it is a great achievement to have found the Higgs particle — the missing piece in the Standard Model puzzle — the Standard Model is not the final piece in the cosmic puzzle.

One of the reasons for this is that the Standard Model treats certain particles, neutrinos, as being virtually massless, whereas recent studies show that they actually do have mass. Another reason is that the model only describes visible matter, which only accounts for one fifth of all matter in the universe.

The rest is dark matter of an unknown kind. It is not immediately apparent to us, but can be observed by its gravitational pull that keeps galaxies together and prevents them from being torn apart. In all other respects, dark matter avoids getting involved with visible matter. Mind you, the Higgs particle is special; maybe it could manage to establish contact with the enigmatic darkness. Scientists hope to be able to catch, if only a glimpse, of dark matter, as they continue the chase of unknown particles in the LHC in the coming decades.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/public.html)

2) Translate the sentences into Russian.

a) Without this field the Standard Model would collapse like a house of cards, because quantum field theory brings infinities that have to be reined in and symmetries that cannot be seen.

b) Even if space were to be emptied completely, it would still be filled by a ghost-like field that refuses to shut down: the Higgs field.

c) If the Higgs field suddenly disappeared, all matter would collapse as the suddenly massless electrons dispersed at the speed of light.

d) This is apparently not the case in our world, so the particles must have acquired their mass from somewhere.

e) In order for the phase transition to occur, four particles were required but only one, the Higgs particle, survived.

f) One of the reasons for this is that the Standard Model treats certain particles, neutrinos, as being virtually massless, whereas recent studies show that they actually do have mass.

Banquet Speech

Read Peter Higgs's banquet speech and say why it has taken such a long time to detect the Higgs Boson.

Your Majesties, Your Royal Highnesses, Your Excellences, Ladies and Gentleman,

It is a great honour for François Englert and me to receive the Nobel Prize in Physics and we wish to express our sincere gratitude to the Royal Swedish Academy of Sciences and the Nobel Foundation.

It is a matter of great regret for both of us that Robert Brout did not live to share the Prize with us. The fact that it has been awarded just to the two of us implicitly recognizes his contribution, as is right. However, it should be remembered that the three of us were not the only theorists who contributed to the elucidation of what is called the BEH mechanism about fifty years ago.

The long time gap between the theoretical work and the award of the Prize is largely a consequence of the difficulty of performing experiments needed to detect the new particle that is an essential feature of our theory. More than thirty years of work on the development of accelerators, detectors and computer programmes have culminated in the claim made by CERN in July 2012. It was a great achievement by all the people involved, and we are grateful to them for enabling us to be here today.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2013/higgs-speech.html)

Unit 14

Blue Light-Emitting Diodes

The Nobel Prize in Physics 2014 — Press Release

October 7, 2014

The Nobel Prize in Physics 2014 was awarded jointly to **Isamu Akasaki**, **Hiroshi Amano** and **Shuji Nakamura** *"for the invention of efficient blue light-emitting diodes which has enabled bright and energy-saving white light sources"*.

New light to illuminate the world

This year's Nobel Laureates are rewarded for having invented a new energy-efficient and environment-friendly light source – the blue light-emitting diode (LED). In the spirit of Alfred Nobel the Prize rewards an invention of greatest benefit to mankind; using blue LEDs, white light can be created in a new way. With the advent of LED lamps we now have more long-lasting and more efficient alternatives to older light sources.

When **Isamu Akasaki**, **Hiroshi Amano** and **Shuji Nakamura** produced bright blue light beams from their semi-conductors in the early 1990s, they triggered a fundamental transformation of lighting technology. Red and green diodes had been around for a long time but without blue light, white lamps could not be created. Despite considerable efforts, both in the scientific community and in industry, the blue LED had remained a challenge for three decades.

They succeeded where everyone else had failed. Akasaki worked together with Amano at the University of Nagoya, while Nakamura was employed at *Nichia Chemicals*, a small company in Tokushima. Their inventions were revolutionary. Incandescent light bulbs lit the 20th century; the 21st century will be lit by LED lamps.

White LED lamps emit a bright white light, are long-lasting and energy-efficient. They are constantly improved, getting more efficient with higher luminous flux (measured in lumen) per unit electrical input power (measured in watt). The most recent record is just over 300 lm/W, which can be compared to 16 for regular light bulbs and close to 70 for fluorescent lamps. As about one fourth of world electricity consumption is used for lighting purposes, the LEDs contribute to saving the Earth's resources. Materials consumption is also diminished as LEDs last up to 100,000 hours, compared to 1,000 for incandescent bulbs and 10,000 hours for fluorescent lights.

The LED lamp holds great promise for increasing the quality of life for over 1.5 billion people around the world who lack access to electricity grids: due to low power requirements it can be powered by cheap local solar power.

The invention of the blue LED is just twenty years old, but it has already contributed to create white light in an entirely new manner to the benefit of us all.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/press.html)

Why is the invention awarded the 2014 Nobel Prize in physics said to correspond to the spirit of Alfred Nobel? To answer this question use the following word combinations and phrases from the text.

an energy-efficient and environment-friendly light source, an invention of greatest benefit to mankind, with the advent of LED lamps, to trigger a fundamental transformation of lighting technology, to contribute to saving the Earth's resources, to diminish material consumption, to hold great promise for increasing the quality of life, to be constantly improved

Advanced Information

Efficient blue light-emitting diodes leading to bright and energy-saving white light sources

Light-emitting diodes (LEDs) are narrow-band light sources based on semiconductor components, with wavelengths ranging from the infrared to the ultraviolet. The first LEDs were studied and constructed during the 1950s and 1960s in several laboratories. They emitted light at different wavelengths, from the infrared to the green. However, emitting

blue light proved to be a difficult task, which took three more decades to achieve. It required the development of techniques for the growth of high-quality crystals as well as the ability to control p-doping of semiconductors with high band gap, which was achieved with gallium-nitride (GaN) only at the end of the 1980s. The development of efficient blue LEDs also required the production of GaN-based alloys with different compositions and their integration into multilayer structures such as heterojunctions and quantum wells.

The invention of efficient blue LEDs has led to white light sources for illumination. When exciting a phosphor material with a blue LED, light is emitted in the green and red spectral ranges, which, combined with the blue light, appears as white. Alternatively, multiple LEDs of complementary colours (red, green and blue) can be used together. Both of these technologies are used in today's high-efficiency white electroluminescent light sources. These light sources, with very long lifetimes, have begun to replace incandescent and fluorescent lamps for general lighting purposes. Since lighting represents 20-30% of our electrical energy consumption, and since these new white light sources require ten times less energy than ordinary light bulbs, the use of efficient blue LEDs leads to significant energy savings, of great benefit to mankind.

This year's Nobel Prize in Physics honours the inventors of efficient blue LEDs: I. Akasaki, H. Amano and S. Nakamura.

Early history

The first report of electrically generated light by emission from a solid-state device came from H.J. Round working at Marconi Electronics in 1907. He applied voltage across two contacts on a carborundum (SiC) crystal. At low voltages yellow light was observed, but more colours were emitted at higher voltages. Electroluminescence was also studied by O. Losev (1903–1942), a device physicist in the Soviet Union, who in the 1920s and 1930s published several articles in international journals on electroluminescence from carborundum. These developments took place prior to the formulation of the modern theory of electronic structure of solid-state materials.

The understanding of the physics of semiconductors and p-n junctions progressed during the 1940s, leading to the invention of the transistor at Bell Telephone Laboratories in the USA in 1947 (Nobel Prize 1956 to Shockley, Bardeen and Brattain).It became clear that a p-n junction could be an interesting device for light emission. In 1951, K. Lehovec and co-workers of the Signal Corps Engineering Laboratory in the USA used these ideas to explain the electroluminescence in SiC as resulting from the injection of carriers across a junction followed by radiative recombination of electrons and holes. However, the observed photon energy was less than the energy gap of SiC, and they suggested that radiative recombination was likely to occur due to impurities or lattice defects.

In 1955, injection electroluminescence was shown in a number of III–V compounds. In 1955 and 1956, J.R. Haynes at Bell Telephone Laboratories demonstrated that electroluminescence observed in germanium and silicon was due to recombination of holes and electrons in a p-n junction.

Infrared LEDs

Techniques to make efficient p-n junctions with GaAs were rapidly developed during the following years. GaAs was attractive because of its direct band gap, enabling recombination of electrons and holes without involvement of phonons. The band gap is 1.4 eV corresponding to light in the infrared. In the summer of 1962, the observation of light emission from p-n-junctions was reported. A few months later, laser emission in GaAs at liquid nitrogen temperature (77 K), was demonstrated independently and almost simultaneously by three research groups at General Electric, IBM and the MIT.

For efficient diodes it is important that the semiconductors have direct band gaps. LEDs with indirect band gaps require phonon-assisted recombination, which limits the efficiency. The quantum efficiency of a LED is the ratio of the number of emitted photons to the number of electrons passing through the contact in a given time. It would be a few years, however, before laser diodes became widely used. Thanks to the development of heterostructures (Nobel Prize 2000 to Z.I. Alferov and H. Kroemer), and later quantum wells, allowing for a better confinement of the carriers while reducing the losses, laser diodes could operate continuously at room temperature, with applications in a large variety of areas.

Visible LEDs

Following early experiments at the end of the 1950s, progress in making efficient LEDs using GaP (indirect band gap equal to 2.2 eV) was made in parallel by three research groups from Philips Central Laboratory in Germany (H.G. Grimmeiss), the Services Electronics Laboratories (SERL) in the UK (J.W. Allen) and Bell telephone laboratories in the USA (M. Gershenzon). They had different objectives, ranging from com-

munication, lighting and television to indicator lamps for electronics and telephones. Using different dopants (e.g. Zn–O or N) at various concentrations, different wavelengths were generated ranging from red to green. By the late 1960s a number of manufacturers in different countries were making red and green LEDs based on GaP.

Mixed crystals including Ga, As, and P (GaPxAs1-x) are interesting since the emission wavelength can be shorter than for GaAs, reaching the visible range while the band gap is direct for x below 0.45. N. Holonyak Jr. and co-workers at the General Electric laboratory in the USA, began to work with GaPxAs1-x in the late 1950s, and succeeded in making p-n junctions and observing LED emission. Laser diode emission at 710 nm (red) was reported in 1962.

Early work on blue LEDs

The step to the emission of blue light proved to be considerably more difficult. Early attempts with ZnSe and SiC, with high indirect band gaps, did not lead to efficient light emission. The material that enabled the development of blue LEDs was GaN (Gallium Nitride).

Gallium Nitride

GaN is a semiconductor of the III-V class, with Wurtzite crystal structure. It can be grown on a substrate of sapphire (Al_2O_3) or SiC, despite the difference in lattice constants. GaN can be doped, e.g. with silicon to n-type and with magnesium to p-type. Unfortunately, doping interferes with the growth process so that the GaN becomes fragile. In general, defects in GaN crystals lead to good electron conductivity, i.e. the material is naturally of n-type. GaN has a direct band gap of 3.4 eV, corresponding to a wavelength in the ultraviolet.

Already at the end of the 1950s, the possibility of a new lighting technology using GaN, the band gap of which had just been measured, was seriously considered at Philips Research Laboratories. H.G. Grimmeiss and H. Koelmans obtained efficient photoluminescence from GaN over a wide spectral range using different activators and a patent was filed. However, at that time it was very difficult to grow GaN crystals.

Only small crystals, forming a powder, could be produced, in which p-n junctions could not be created. The researchers at Philips decided to concentrate on GaP instead. GaN crystals were more efficiently produced at the end of the 1960s by growing GaN on a substrate using the HVPE technique (Hydride Vapour Phase Epitaxy). A number of laboratories in the United States, in Japan and in Europe studied the growth techniques and doping of GaN with the goal of developing blue LEDs, but material problems still seemed insurmountable. The surface roughness was not controlled, the HVPE-grown material was contaminated with transition metal impurities and p-doping was passivated due to the presence of hydrogen, forming complexes with acceptor dopants. The role of hydrogen was not understood at that time.

New growth techniques

In the 1970s, new crystal growth techniques, MBE (Molecular Beam Epitaxy) and MOVPE (Metalorganic Vapour Phase Epitaxy) were developed. Efforts were made to adapt these techniques for growing GaN. Isamu Akasaki began studying GaN as early as 1974, at the time working at the Matsushita Research Institute in Tokyo. In 1981, he took up a professorship at Nagoya University and continued his research on GaN, together with Hiroshi Amano and other co-workers. It would take until 1986 before GaN with high crystal quality and good optical properties could be produced with the MOVPE technique. The breakthrough was the result of a long series of experiments and observations. A thin layer (30 nm) of polycrystalline AlN was first nucleated on a substrate of sapphire at low temperature (500 °C) and then heated up to the growth temperature of GaN (1000 °C). During the heating process, the layer develops a texture of small crystallites with a preferred orientation on which GaN can be grown. A high quality surface could be obtained, which was very important to grow thin multilayer structures in the following steps of the LED development. In this way, high quality device-grade GaN was obtained for the first time. GaN could also be produced with significantly lower background n-doping. Shuji Nakamura at Nichia Chemical Corporation, a small chemical company in Japan, later developed a similar method where AlN was replaced with a thin layer of GaN grown at low temperature.

Doping of GaN

A major problem for manufacturing p-n junctions was the difficulty to p-dope GaN in a controlled manner. At the end of the 1980s, Amano, Akasaki and co-workers made an important observation they noted that when Zn-doped GaN was studied with a scanning electron microscope, it emitted more light, thus indicating better p-doping. In a similar way, when Mg-doped GaN was irradiated with low energy electrons, it resulted in better p-doping properties. This was an important breakthrough and opened the way to p-n junctions in GaN.

The effect of electron irradiation was explained a few years later, in an article by Nakamura and co-workers. Acceptors such as Mg or Zn form complexes with hydrogen and thus become passive. Electron beams dissociate these complexes and activate the acceptors. Nakamura showed that even a simple thermal treatment (annealing) leads to efficient activation of Mg acceptors. The effect of hydrogen on the neutralization of dopants was known from previous work using other materials by Pankove, G.F. Neumark Rothschild, and others.

A crucial step in developing efficient blue LEDs was the growth and p-doping of alloys (AlGaN, InGaN), which are necessary in order to produce heterojunctions. Such heterojunctions were realized in the early 90s in both Akasaki's and Nakamura's research groups.

Double heterostructures and quantum wells

The development of infrared LEDs and laser diodes had shown that heterojunctions and quantum wells were essential to achieve high efficiency. In such structures holes and electrons are injected in a small volume where recombination occurs more efficiently and with minimal losses. Akasaki and co-workers developed structures based on AlGaN/GaN while Nakamura with great success exploited the combinations InGaN/GaN and InGaN/AlGaN for producing heterojunctions, quantum wells and multiple quantum wells. In 1994, Nakamura and co-workers achieved a quantum efficiency of 2.7% using a double heterojunction InGaN/AlGaN. With these important first steps, the path was cleared towards the development of efficient blue LEDs and their application was open. Both teams have continued to develop blue LEDs, aiming towards higher efficiency, versatility and applications. Blue laser emission based on GaN was observed in 1995–1996 by both groups.

Today's efficient GaN-based LEDs result from a long series of breakthroughs in basic materials physics and crystal growth, in device physics with advanced heterostructure design, and in optical physics for the optimization of the light out-coupling.

Applications

Illumination technology is presently going through a revolution, namely the transition from light bulbs and fluorescent tubes to LEDs. The light bulb, invented by Thomas Edison in 1879, has a low efficiency ≈16 lm/W representing approximately 4% energy efficiency from electricity into light. A lumen is a unit used to characterize the light flux, which takes into account the eye's spectral response. The fluorescent tube, containing mercury and invented by P. Cooper Hewitt in 1900, reaches an efficiency of 70 lm/W. White LEDs currently reach more than 300 lm/W, representing more than 50% wallplug efficiency.

White LEDs used for lighting are often based on efficient blue LEDs that excite a phosphor so that the blue light is converted to white light. These high-quality LEDs with their very long lifetime (100 000 hours) are getting cheaper, and the market is currently exploding. A little further on in the future, three-colour LEDs may replace the combination of blue LED and phosphor for efficient lighting. This technology will allow for dynamic control of colour composition.

Replacing light bulbs and fluorescent tubes with LEDs will lead to a drastic reduction of electricity requirements for lighting. Since 20-30% of the electricity consumed in industrial economies is used for lighting, considerable efforts are presently being devoted to replacing old lighting technologies with LEDs.

Today, GaN-based LEDs provide the dominant technology for back-illuminated liquid crystal displays in many mobile phones, tablets, laptops, computer monitors, TV screens, etc. Blue and UV-emitting GaN diode lasers are also used in high-density DVDs, which has advanced the technology for storing music, pictures and movies. Future application may include the use of UV-emitting AlGaN/GaN LEDs for water purification, as UV light destroys the DNA of bacteria, viruses and microorganisms. In countries with insufficient or non-existent electricity grids, the electricity from solar panels stored in batteries during daylight, powers white LEDs at night. There, we witness a direct transition from kerosene lamps to white LEDs.

(http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/advanced.html)

EXERCISES

1) Translate the terms into Russian.

narrow-band light source, semiconductor component, wavelength, light-emitting diode, p-doping of semiconductors, dopant, background n-doping, band gap, gallium nitride, heterojunction, quantum well, carborundum crystal, solid-state device, light flux, the eye's spectral re-

sponse, p-n junction, radiative recombination, quantum efficiency, heterostructure, confinement of carriers, efficient photoluminescence, Hydride Vapour Phase Epitaxy (HVPE), electron irradiation, acceptor, scanning electron microscope

2) Answer the questions.

a) What did the development of efficient blue LEDs require?

b) What technologies are used in today's high-efficiency white electroluminescent light sources?

c) Why does the use of efficient blue LEDs lead to significant energy savings?

d) Whose theoretical developments took place prior to the formulation of the modern theory of electronic structure of solid-state materials?

e) Who realized that a p-n junction could be an interesting device for light emission?

f) Why was GaAs attractive in developing techniques to make efficient p-n junctions?

g) Why is it important that the semi-conductors have direct band gaps?

h) What is the quantum efficiency of an LED?

i) Which research groups made progress in making efficient LEDs using GaP at the end of the 1950s and what experiments did they conduct?

j) What are the basic properties of gallium nitride?

k) What research did Philips Research Laboratories carry out using gallium nitride?

l) What new crystal growth technique did Shuji Nakamura develop?

m) What important observation did Amano, Akasaki and their colleagues make in connection with the doping of GaN?

n) Which alloys are necessary in order to produce heterojunctions?

o) What combinations did Nakamura exploit for producing heterojunctions and quantum wells?

p) What are the basic applications of LEDs?

3) Translate the sentences into Russian.

a) Light-emitting diodes (LEDs) are narrow-band light sources based on semiconductor components, with wavelengths ranging from the infrared to the ultraviolet.

b) However, emitting blue light proved to be a difficult task, which took three more decades to achieve.

c) The observed photon energy was less than the energy gap of SiC, and they suggested that radiative recombination was likely to occur due to impurities or lattice defects.

d) For efficient diodes it is important that the semiconductors have direct band gaps.

e) Thanks to the development of heterostructures, and later quantum wells, allowing for a better confinement of the carriers while reducing the losses, laser diodes could operate continuously at room temperature, with applications in a large variety of areas.

f) The step to the emission of blue light proved to be considerably more difficult.

g) Replacing light bulbs and fluorescent tubes with LEDs will lead to a drastic reduction of electricity requirements for lighting.

4) Write a summary of the the text in 15–18 sentences.

Texts for rendering

Text 1

Церемония вручения Нобелевских премий, учрежденных Альфредом Нобелем, и Нобелевской премии мира проходит каждый год в день смерти А. Нобеля, в Стокгольме (Швеция) и Осло (Норвегия). 10 декабря 1901 года состоялась первая церемония вручения Нобелевских премий. Сам же Нобелевский комитет, выплачивающий премии, был создан в 1900 году. Альфред Нобель, шведский изобретатель и фабрикант, первоначально в своем завещании, составленном 14 марта 1893 года, выразил желание направить средства от своих патентов на строительство крематориев в крупных городах, чем, по его мнению, должен был заниматься стокгольмский Каролинский институт. Однако еще в 1886 году папа римский признал кремацию неподобающей формой погребения.

В 1895 году Нобель составил другое завещание, где приказал создать фонд, проценты с которого будут выдаваться в виде премии тем, кто в течение предшествующего года принес наибольшую пользу человечеству. Указанные проценты, в соответствии с завещанием, делились на пять равных частей, которые предназначаются для поощрения открытий в области физики, химии, физиологии или медицины, литературы и особые достижения перед человечеством в деле мира (Нобелевская премия мира).

За время существования премии было введено лишь одно новшество: в 1968 году Шведский банк по случаю своего 300-летия предложил выделить деньги на премию по экономике, и Нобелевский комитет принял на себя обязательство по их распределению.

Официально именуемая как премия по экономике памяти Альфреда Нобеля впервые была присвоена в 1969 году. По традиции премии по физике, химии, медицине, литературе и экономике вручает в Стокгольме в концертном зале король Швеции.

Каждый лауреат получает из рук монарха золотую медаль с изображением учредителя премий Альфреда Нобеля и диплом. Денежная часть премии переводится лауреатам согласно их пожеланиям.

В тот же день вечером в стокгольмской ратуше проходит нобелевский банкет с участием короля и королевы Швеции, членов монаршей семьи, нобелевских лауреатов, главы правительства Швеции, председателя риксдага, видных ученых, общественных деятелей. В этом празднестве участвуют более тысячи гостей. Нобелевскую премию мира в Осло в присутствии короля Норвегии и членов королевской семьи вручает председатель норвежского Нобелевского комитета. Премия мира включает диплом лауреата, медаль и денежный чек.

Сумма премии непостоянна, она изменяется в зависимости от доходов Нобелевского фонда.

Принятие решения о присуждении премии мира доверено Норвежскому Нобелевскому комитету, члены которого выбираются стортингом (парламентом Норвегии) из числа норвежских общественно-политических деятелей, но они полностью независимы от стортинга в принятии решения о лауреате. Правом предлагать кандидатуры обладают нынешние и бывшие члены норвежского Нобелевского комитета и консультанты норвежского Нобелевского института, национальные парламенты и правительства, члены Межпарламентского союза, Международного суда в Гааге и Международного арбитража, Международного бюро мира, Института международного права, профессора университетов, читающие курсы правоведения, государственного права, истории или философии, лауреаты Нобелевской премии мира.

Премия мира может присуждаться как отдельным лицам, так и официальным и общественным организациям.

Text 2

ВСЕЛЕННАЯ В РЕНТГЕНОВСКИХ ЛУЧАХ И ПОТОКАХ НЕЙТРИНО

Нобелевскую премию по физике 2002 года, присужденную "за основополагающий вклад в астрофизику", получили трое исследователей: американец Раймонд Девис-младший вместе с японцем Масатоши Кошиба за регистрацию космических нейтрино и Риккардо Джаккони, американский астроном, за обнаружение космических источников рентгеновского излучения.

Нейтрино, эта самая таинственная из элементарных частиц, была буквально "придумана" в 1931 году немецким физиком Вольфгангом Паули, чтобы объяснить парадоксы, обнаруженные при экспериментальном исследовании бета-распада (в этой реакции протон p превращается в нейтрон n с испусканием электронов e^- — бета-лучей). Часть энергии при распаде исчезала бесследно, и вдобавок наблюдалось несохранение спина частиц. В. Паули предположил, что недостающую энергию уносит некая частица, не имеющая массы, которую невозможно обнаружить в принципе(впоследствии ее назвали электронным нейтрино).

Однако уже через несколько лет отечественные физики (А. Лейпунский, А. Алиханов, А. Алиханян) получили косвенное экспериментальное подтверждение, что нейтрино действительно появляется в ходе определенных реакций. Принципиально новый подход к задаче регистрации нейтрино осуществил Раймонд Девис в начале 1960-х годов. Детектором нейтрино стал бак, заполненный 615 тоннами тетрахлорэтилена. Детектор был установлен на дне заброшенной шахты, чтобы толща земли задерживала все прилетающие частицы, кроме нейтрино, имеющих огромную проникающую способность. Атомы хлора, реагируя с нейтрино, превращались в атомы аргона. Эксперимент продолжался тридцать лет, и к 1994 году среди $2x10^{30}$ атомов хлора было обнаружено порядка 2000 атомов аргона. Так Р. Девис впервые доказал, что "придуманная" частица действительно существует в природе.

Эксперименты по исследованию нейтрино продолжались, и вскоре стало ясно, что кроме электронного нейтрино n_e существуют мюонное и тау-нейтрино — n_m и n_t. Все они появляются только в ходе специфических реакций. Так, электронные нейтрино, приходящие от Солнца, возникают при термоядерных реакциях в его недрах. Эти реакции хорошо описывает так называемая Стандартная солнечная модель. Однако по мере роста точности эксперимента начало выясняться, что поток солнечных нейтрино в несколько раз слабее, чем следует из теории. Следовательно, либо Стандартная солнечная модель неверна и нуждается в пересмотре, либо электронные нейтрино по пути от Солнца меняют "сорт", превращаясь в мюонные. Такой процесс называется осцилляцией, он хорошо изучен на других частицах — мезонах — и возможен, если только нейтрино имеют массу. А это противоречило устоявшимся представлениям, что у нейтрино массы нет.

Выяснить истину смог Масатоши Кошиба. Он сконструировал нейтринный детектор в виде огромной емкости, заполненной сверхчистой водой и оснащенной несколькими тысячами фотоприемников. Они регистрируют световые вспышки (излучение Вавилова — Черенкова), которые вызывают в воде приходящие нейтрино. На первой модели детектора ("Камиоканде") в 1987 году М. Кошиба наблюдал нейтринную вспышку, пришедшую из Большого Магелланова облака — туманности, расположенной в 170 тысячах световых лет от Земли. Спустя девять лет он построил еще более крупный детектор — "Суперкамиоканде", на котором надежно установил: нейтрино испытывают осцилляции и, следовательно, имеют массу. Спустя несколько лет открытие подтвердили другие исследователи на своих установках. Эти работы были признаны революционными не только в области астрофизики, но и в физике элементарных частиц. Они заставили пересмотреть некоторые положения Стандартной модели элементарных частиц, которая рассматривала нейтрино как безмассовую частицу.

Еще один метод исследования Вселенной — рентгеновскую астрономию — создал Риккардо Джаккони. Он сконструировал рентгеновский телескоп с зеркалами, которые полностью отражают и фокусируют высокочастотное излучение, формируя изображение хорошего качества. На созданной аппаратуре он открыл несколько источников космического излучения в рентгеновском диапазоне. Большинство из них — двойные звезды: одна, обычная, вращается вблизи компактной и массивной нейтронной звезды или, возможно, черной дыры. Мощное поле тяготения центрального компонента вытягивает вещество звезды, которое движется с ускорением по спирали к центру, уплотняется и образует так называемый аккреционный диск. В нем атомы сталкиваются, тормозятся и начинают испускать рентгеновское излучение в плоскости диска.

В 1999 году Р. Джаккони построил рентгеновскую обсерваторию, названную "Чандра" в честь известного американского теоретика и астрофизика, нобелевского лауреата С. Чандрасекара. Ее аппаратура позволила обнаружить сверхмассивные черные дыры в ядрах галактик и рентгеновские пульсары, получить уникальные снимки звезд, туманностей и других небесных объектов в рентгеновских лучах. А еще Р. Джаккони руководил исправлением космического телескопа "Хаббл", зеркало которого было изготовлено с грубой ошибкой.

Новые области науки, созданные трудами исследователей-лауреатов, — нейтринная и рентгеновская астрономия – открывают огромные возможности в исследовании Вселенной, результаты которых сегодня трудно предугадать.

(*Наука и жизнь № 12, 2002 г.*)

Text 3

АСИМПТОТИЧЕСКАЯ СВОБОДА И КОНФАЙНМЕНТ

Нобелевская премия по физике 2004 года присуждена американским исследователям Дэвиду Гроссу, Дэвиду Политцеру и Фрэнку Вильчеку за "открытие явления асимптотической свободы в теории сильных взаимодействий".

Частицы, участвующие в сильном взаимодействии, — адроны, к которым, в частности, относятся протоны и нейтроны, состоят из кварков. Имеется шесть "сортов" (физики называют их "ароматами") кварков, и у каждого есть свой антикварк. Кварковая модель предполагает, что один тип адронов (барионы) состоит из трех кварков, другой (мезоны) — из кварка и антикварка. Но здесь возникает сложность: из законов квантовой механики следует, что стабильной частица будет, только обладая наименьшей энергией, когда все кварки находятся в одном и том же состоянии. Это, однако, запрещено так называемым принципом Паули: кварки имеют полуцелый спин (1/2) и относятся к классу фермионов.

Выход предложили российские физики Н.Н. Боголюбов, Б.В. Струминский, А.Н. Тахвелидзе и японец Й. Намбу. Они ввели еще одно квантовое число — "цвет", который способен принимать три разных значения: красный, синий и зеленый (в отечественной литературе по предложению академика Л.Б. Окуня принят желто-сине-красный набор). Антикварки обладают дополнительными цветами (фиолетовым, оранжевым и зеленым).

Кварки могут быть любого цвета, но в частице сочетаются в таких цветовых состояниях, что в сумме дают "белый цвет", поэтому адроны "бесцветны". Цветовые заряды взаимодействуют аналогично зарядам электрическим: одинаковые отталкиваются, противоположные притягиваются, обмениваясь квантами цветового поля — глюонами. Характер их взаимодействий, весьма сложный, определяется законами квантовой хромодинамики. Наиболее важный вывод из них состоит в том, что и сами глюоны, переносчики сильного взаимодействия между кварками, в отличие от фотонов, квантов электромагнитного взаимодействия, электрических зарядов не имеющих, тоже обладают цветовым зарядом (академик Л.Б. Окунь образно назвал их "светящимся светом"). Это приводит к так называемому явлению антиэкранировки заряда: эффективные заряды кварков и глюонов велики на большом расстоянии, а при его уменьшении становятся малыми. Расчеты, проделанные на основе теории, показывают, что константа кваркового взаимодействия прямо пропорциональна расстоянию между кварками. Иными словами: чем ближе кварки друг к другу, тем взаимодействие между ними становится слабее, асимптотически уменьшаясь до нуля. В масштабах адрона кварки ведут себя как свободные частицы, а при попытке разорвать адрон сила их взаимного притяжения резко возрастает. И все попытки получить кварк-глюонную плазму, "разбив" протоны в ускорителе на встречных пучках, наталкиваются на большие технические трудности. Этот парадоксальный закон квантовой хромодинамики и получил название асимптотической свободы, а удержание цветных кварков внутри "бесцветных" адронов именуется конфайнментом (от англ. confinement — ограничение).

Теория асимптотической свободы была создана в 1973 году; она внесла крупный вклад в Стандартную модель, описывающую фундаментальные взаимодействия – электромагнитное, сильное и слабое — между элементарными частицами. Благодаря созданию этой теории надежно установлены и проработаны все качественные параметры сильного взаимодействия на малых расстояниях (порядка размера адрона) и сделан важный шаг в познании глубинных свойств материи.

(*Наука и жизнь № 12, 2004 г.*)

Text 4

ГИГАНТСКОЕ МАГНЕТОСОПРОТИВЛЕНИЕ — ТРИУМФ ФУНДАМЕНТАЛЬНОЙ НАУКИ

Нобелевскую премию 2007 года по физике получили физики из Европы Альбер Фер (Albert Fert) и Петер Грюнберг (Peter Grunberg), независимо друг от друга открывшие эффект гигантского магнетосопротивления (GMR — Giant Magnetoresistance). Это не первая награда ученых: за последние двадцать лет их заслуги отметили Физические общества Америки и Европы, Международный союз по физике и прикладной физике, наградили премией Японский фонд науки и

технологии и израильский Фонд Вольфа. Открытие стало важным шагом в развитии технологии хранения информации. За необычайно короткий срок удалось перейти от лабораторных образцов к промышленному использованию эффекта GMR в считывающих головках жестких дисков и сверхчувствительных магнитных сенсорах. Однако, как бы ни было велико практическое значение открытия, нельзя не отметить, что Нобелевская премия по физике 2007 года — это, прежде всего, — триумф фундаментальной науки.

Мы с вами — свидетели удивительных достижений последних лет в области компактного хранения информации: размеры жестких дисков уменьшаются, а емкость увеличивается и измеряется уже терабайтами (тысячами миллиардов байт). Однако этот технологический прогресс вряд ли был бы возможен без продолжительных фундаментальных исследований магнитных и квантово-механических свойств материалов.

Еще 150 лет назад британский физик Уильям Томпсон (лорд Кельвин) начал изучать влияние магнитного поля на электрическое сопротивление материалов. В 1857 году он опубликовал статью, в которой описал, как изменяется сопротивление железа в зависимости от направления магнитного поля. Оказалось, что, если пропускать электрический ток вдоль магнитного поля, сопротивление возрастает, а если поперек — уменьшается. Это явление получило название анизотропного магнетосопротивления. На его основе созданы широко используемые на практике магниторезистивные материалы, в частности пермаллой — сплав железа и никеля.

Следующий шаг сделал английский физик Невилл Мотт, получивший в 1977 году Нобелевскую премию по физике “за фундаментальные теоретические исследования электронной структуры магнитных и неупорядоченных систем”. В середине тридцатых годов XX века он обратил внимание коллег на некоторые аномалии переноса электричества в ферромагнетиках, возникающие из-за того, что у электрона, помимо заряда, есть спин.

Понятие “спин” вошло в физику более восьмидесяти лет назад. Спин — это собственный момент вращения электрона (хотя, строго говоря, никакого вращения у электрона нет), его важное квантовое свойство. Со спином связан и магнитный момент электрона, поэтому его поведение в магнитном материале зависит от направления спина. Большинство электронов выстраиваются так, что их спин направлен вдоль магнитного поля, но некоторая часть электронов имеет противоположно направленный спин. Различия в направлении спинов можно использовать для получения разнообразных магнитоэлектрических эффектов. Однако до последнего времени электроника, используемая в компьютерной и бытовой технике, “эксплуатировала” только заряд электрона. Более того, по словам ирландского физика Майкла Коуи, традиционная электроника игнорировала спин. Это известное высказывание получило название “леммы Коуи”.

Эра спиновой электроники началась в 1988 году, когда было открыто гигантское магнетосопротивление (GMR) в многослойных материалах с чередующимися тонкими слоями ферромагнитных и немагнитных металлов. Толщина отдельного слоя составляет всего несколько атомов. Сопротивление таких образцов велико, если магнитные поля в ферромагнетиках направлены в противоположные стороны, и минимально, когда магнитные поля параллельны.

В чем причина этого эффекта? Электрическое сопротивление проводника тем выше, чем чаще электроны, влекомые электрическим полем, сталкиваются с препятствиями (неоднородностями кристаллической решетки, примесями) и отклоняются от прямого пути. При этом электроны с разнонаправленными спинами при встрече с препятствиями ведут себя немного по-разному. Одни из них, например, те, спины которых совпадают с направлением магнитного поля, тормозятся в меньшей степени, а противоположно направленные — в большей. Какие электроны будут иметь преимущество, зависит от типа магнитного материала, в который специально вводят примеси других веществ. Например, если добавить в никель небольшое количество железа или кобальта, электроны со спином, направленным вниз, будут рассеиваться в 20 раз сильнее, чем электроны, спин которых направлен вверх.

Явление гигантского магнетосопротивления удается наблюдать только в очень тонких пленках. При движении в толстых проводниках электрон успевает сменить направление спина под влиянием разных причин. Предпосылкой к открытию эффекта GMR стали технологии для изготовления тончайших (нанометровых) слоев металла, появившиеся в семидесятые годы XX века. Так что GMR-технологию можно рассматривать как одно из первых применений популярных сегодня нанотехнологий.

Новое научно-технологическое направление, использующее спиновые эффекты, получило название “спинтроника”. Были разработаны спиновые клапаны и магнитные туннельные переходы, которые позволили на порядки увеличить плотность записи информации.

(*Наука и жизнь № 11, 2007 г.*)

Text 5

НОБЕЛЕВСКАЯ ПРЕМИЯ ПО ФИЗИКЕ 2010 ГОДА. НОВОЕ ЛИЦО УГЛЕРОДА

Нобелевскую премию по физике 2010 года присудили за исследования графена — двумерного материала, проявляющего необычные и одновременно весьма полезные свойства. Его открытие сулит не только новые технологии, но и развитие фундаментальной физики, результатом чего могут стать новые знания о строении материи. Лауреатами Нобелевской премии по физике нынешнего года стали Андре Гейм и Константин Новосёлов — профессора Манчестерского университета (Великобритания), выпускники Московского физико-технического института.

Графен, материал толщиной всего в один атом, построен из «сетки» атомов углерода, уложенных, подобно пчелиным сотам, в ячейки гексагональной (шестиугольной) формы. Это ещё одна аллотропная форма углерода наряду с графитом, алмазом, нанотрубками и фуллереном. Материал обладает отличной электропроводностью, хорошей теплопроводностью, высокой прочностью и практически полностью прозрачен.

Идея получения графена «лежала» в кристаллической решётке графита, которая представляет собой слоистую структуру, образованную слабо связанными слоями атомов углерода. То есть графит, по сути, можно представить как совокупность слоёв графена (двумерных кристаллов), соединённых между собой.

Графит — материал слоистый. Именно это свойство нобелевские лауреаты и использовали для получения графена, несмотря на то что теория предсказывала (и предыдущие эксперименты подтверждали), что двумерный углеродный материал при комнатной температуре существовать не может — он будет переходить в другие аллотропные формы углерода, например, сворачиваться в нанотрубки или в сферические фуллерены.

Международная команда учёных под руководством Андре Гейма, в которую входили исследователи из Манчестерского университета (Великобритания) и Института проблем технологии микроэлектроники и особо чистых материалов (Россия, г. Черноголовка), получила графен простым отшелушиванием слоёв графита. Для этого на кристалл графита наклеивали обычный скотч, а потом снимали: на ленте оставались тончайшие плёнки, среди которых были и однослойные. (Как тут не вспомнить: «Всё гениальное — просто»!) Позже с помощью этой техники были получены и другие двумерные материалы, в том числе высокотемпературный сверхпроводник BiSrCaCuO.

Сейчас такой способ называется «микромеханическим расслоением», он позволяет получать наиболее качественные образцы графена размером до 100 микрон.

Другой замечательной идеей будущих нобелевских лауреатов было нанесение графена на подложку из окиси кремния (SiO_2). Благодаря этой процедуре графен стало возможным наблюдать под микроскопом (от оптического до атомно-силового) и исследовать.

Первые же эксперименты с новым материалом показали, что в руках учёных не просто ещё одна форма углерода, а новый класс материалов со свойствами, которые не всегда можно описать с позиций классической теории физики твёрдого тела.

Полученный двумерный материал, будучи полупроводником, обладает проводимостью, как у одного из лучших металлических проводников — меди. Его электроны имеют весьма высокую подвижность, что связано с особенностями его кристаллического строения. Очевидно, что это качество графена вкупе с его нанометровой толщиной делает его кандидатом на материал, который мог бы заменить в электронике, в том числе в будущих быстродействующих компьютерах, не удовлетворяющий нынешним запросам кремний. Исследователи полагают, что новый класс графеновой наноэлектроники с базовой толщиной транзисторов не более 10 нм (на графене уже получен полевой транзистор) не за горами.

Сейчас физики работают над дальнейшим увеличением подвижности электронов в графене. Расчёты показывают, что ограничение подвижности носителей заряда в нём (а значит, проводимости) связано с наличием в SiO_2-подложке заряженных примесей. Если научиться получать «свободновисящие» плёнки графена, то подвижность электронов можно увеличить на два порядка — до 2×10^6 см^2/Вс. Такие эксперименты уже ведутся, и довольно успешно. Правда, идеальная двумерная плёнка в свободном состоянии нестабильна, но если она будет деформирована в пространстве (то есть

будет не идеально плоской, а, например, волнистой), то стабильность ей обеспечена. Из такой плёнки можно сделать, к примеру, наноэлектромеханическую систему — высокочувствительный газовый сенсор, способный реагировать даже на одну-единственную молекулу, оказавшуюся на его поверхности.

Другие возможные приложения графена: в электродах суперконденсаторов, в солнечных батареях, для создания различных композиционных материалов, в том числе сверхлёгких и высокопрочных (для авиации, космических аппаратов и т.д.), с заданной проводимостью. Последние могут чрезвычайно сильно различаться. Например, синтезирован материал графан, который в отличие от графена — изолятор. Получили его, присоединив к каждому атому углерода исходного материала по атому водорода. Важно, что все свойства исходного материала — графена — можно восстановить простым нагревом (отжигом) графана. В то же время графен, добавленный в пластик (изолятор), превращает его в проводник.

Почти полная прозрачность графена предполагает использование его в сенсорных экранах, а если вспомнить о его «сверхтонкости», то понятны перспективы его применения для будущих гибких компьютеров (которые можно свернуть в трубочку подобно газете), часов-браслетов, мягких световых панелей.

Но любые приложения материала требуют его промышленного производства, для которого метод микромеханического расслоения, используемый в лабораторных исследованиях, не годится. Поэтому сейчас в мире разрабатывается огромное число других способов его получения. Уже предложены химические методы получения графена из микрокристаллов графита. Один из них, к примеру, даёт на выходе графен, встроенный в полимерную матрицу. Описаны также осаждение из газовой фазы, выращивание при высоком давлении и температуре, на подложках карбида кремния. В последнем случае, который наиболее приспособлен к промышленному производству, плёнка со свойствами графена формируется при термическом разложении поверхностного слоя подложки.

Фантастически велика ценность нового материала для развития физических исследований. Многие явления, для изучения которых требовалось строительство огромных ускорителей элементарных частиц, теперь можно исследовать, вооружившись гораздо более простым инструментом — тончайшим в мире материалом.

(*Наука и жизнь № 11, 2010 г.*)

Text 6

РАЗОГНАВШИЕ ГРАНИЦЫ ВСЕЛЕННОЙ

Астрофизики Сол Перлмуттер, Брайан Шмидт и Адам Рис удостоены Нобелевской премии по физике 2011 года за открытие, кардинально изменившее наши представления о Вселенной.

Представления о том, как развивается Вселенная и какой она станет в будущем, менялись по мере совершенствования и методов наблюдения, и космологических теорий. Долгое время считалось, что Вселенная «необъятна, бесконечна и существует вечно». Об этом рассказывали в советских школах ещё лет 60 назад, хотя в 1916 году Альберт Эйнштейн создал свою теорию гравитации, общую теорию относительности. В 1922 году советский математик А.А. Фридман показал, что уравнения Эйнштейна описывают не стационарную, а эволюционирующую Вселенную. Она должна либо расширяться, либо сжиматься. Но ещё в 1914 году американский астроном Весто М. Слайфер обнаружил, что галактики не просто «висят» в космическом пространстве, а разлетаются с большой скоростью. Туманность Андромеды, например, несётся к нашей Солнечной системе, обнаруживая в своём спектре, в силу эффекта Доплера, синее смещение. Но подавляющее число далёких галактик убегают от нас, демонстрируя красное смещение спектра. Спустя несколько лет, астроном Эдвин П. Хаббл вывел зависимость величины красного смещения галактики от расстояния до неё — постоянную Хаббла. Наблюдения, подтверждённые расчётами, свидетельствовали, что Вселенная действительно расширяется. Тут же возникли вопросы: что вызвало это расширение и будет ли оно продолжаться бесконечно или же силы тяготения звёзд затормозят разлёт и стянут Вселенную в точку? Выбор одного из этих двух сценариев зависел от величины тяготения, то есть от массы Вселенной. Подсчитать её можно было, только замерив светимости звёзд, ибо зависимость «масса/светимость» хорошо известна. Такой метод оказался слишком груб, с большими ошибками в оценках величины массы, и дальнейшая судьба Вселенной по-прежнему оставалась загадкой.

Но в 1937 году Фриц Цвикки, исследуя движения звёзд в скоплении Волосы Вероники, рассчитал массу скопления. Она оказалась в 500 раз больше той, которую давала светимость. Так была обнаружена тёмная материя, или скрытая масса. Природа её до сих пор непонятна, она не видна и проявляет себя только через тяготение. Но теперь уже стало ясно, что бесконечного расширения не будет.

Ответ на первый вопрос: что заставило Вселенную расширяться? — дал в 1948 году Г.А. Гамов. Он разработал теорию «горячей Вселенной», родившейся примерно 14 миллиардов лет назад из невообразимо малого объёма, сингулярности, в результате Большого взрыва и раздувания (инфляции) с огромной скоростью. И по всему выходило, что Вселенная развивается циклично. Разбегание галактик сменится их сближением, возникнет сингулярность, взрыв, и всё начнётся сначала.

Но прошло ещё 50 лет, и астрофизики преподнесли мировому сообществу очередной сюрприз. Трое исследователей из разных стран — Сол Перлмуттер, Брайан Шмидт и Адам Рис, проводя наблюдения за сверхновыми звёздами, обнаружили, что Вселенная не просто расширяется (об этом стало известно почти 60 лет назад), а расширяется с ускорением. Эта сенсационная весть была опубликована осенью 1998 года в авторитетном астрономическом журнале, вызвав огромный интерес и некоторый скепсис даже у самих авторов (они пытались обнаружить ошибку в расчётах, но её не было).

Сверхновые, которыми занимались Нобелевские лауреаты, — это старые звёзды, которые заканчивают своё существование мощнейшим взрывом. На некоторое время сверхновая становится ярче целой галактики с её миллионами звёзд, а затем рассеивается в пространстве, образуя туманность. Яркость сверхновых настолько велика, что их можно наблюдать вплоть до самых границ видимой Вселенной. А зная светимость сверхновой, несложно найти расстояние до неё. И вот тут-то и оказалось, что часть этих объектов находится значительно дальше, чем следовало из современной космологической модели. А это значит, что Вселенная всегда расширялась с ускорением. И «распирает» её некая «тёмная энергия», более мощная, чем энергия гравитации. И Вселенную, похоже, ждёт конец не в пламени очередного Большого взрыва, а в непроглядной тьме и космическом холоде.

О природе самóй «тёмной энергии» пока приходится только гадать. Ею может быть некое поле, энергия физического вакуума (который не просто пустота, а сложная квантовая система). Именно это поле 14 миллиардов лет назад вызвало инфляцию новорождённой Вселенной, но и теперь, понизив свою напряжённость в огромном объёме современной Метагалактики, продолжает разгонять её границы.

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Text 7

ОТКРЫТИЯ, ИЗМЕНИВШИЕ КВАНТОВУЮ МЕХАНИКУ

Нобелевская премия по физике 2012 года присуждена двум исследователям — французу Сержу Арошу и американцу Дэвиду Уайнленду, которые, независимо один от другого, разработали методы управления отдельными квантовыми частицами и наблюдения за ними. Исследовать их очень сложно: свою квантовую природу при взаимодействии с окружением они теряют. Из-за этого до недавних пор физикам приходилось ограничиваться лишь мысленными экспериментами и теоретическими расчётами.

Теория

Можно сказать, что первый парадокс квантовой механики состоит в том, что на сегодня этот раздел физики одновременно и самый точный, и самый противоречивый. До сих пор все теоретические расчёты в данной области были абсолютно верны, однако смысл формул квантовой механики весьма трудно, а порой и невозможно объяснить с позиций здравого смысла и на обыденном языке. Дело в том, что в привычном нам мире мы имеем дело только с большими объектами, с размерами на много порядков больше размеров атомов и элементарных частиц. В мире же квантовой механики действуют совсем иные, противоречащие законам классической механики правила. Так называемый принцип неопределённости Гейзенберга (открытый им в 20-х годах XX века) гласит, что невозможно измерить координаты частицы, не вызвав непредсказуемого изменения её скорости, и наоборот.

Поясним смысл этого принципа. Чтобы визуально определить, например, положение обычного (неквантового) объекта в пространстве, достаточно осветить его (или использовать какое-то другое излучение) и зафиксировать зрением либо чувствительным элементом отражённое от предмета излучение. Из опыта мы знаем: сколько ни свети на предмет — с места он не сдвинется, следовательно, наши измерения никак не влияют на объект. Но в квантовом мире ситуация иная. Ведь для того, чтобы определить положение или скорость квантовой частицы, нет иных способов, кроме как либо использовать другую частицу или излучение (которые, несомненно, станут взаимодействовать с исходной, изменяя её координаты и/или скорость), либо уничтожить её, «поймав» детектором. Таким образом, любое измерение воздействует на квантовую систему, изменяя её состояние. Если удастся точно зафиксировать положение частицы, то погрешность определения её скорости будет бесконечна, и наоборот.

Из-за принципа неопределённости объекты квантового мира описывают специальными волновыми функциями, которые определяют вероятности нахождения объекта в определённой точке пространства. Распространение этих волн подчиняется уравнениям Шрёдингера — одним из главных уравнений квантовой механики. Наблюдение же за квантовой системой разрушает её, превращая волну в обычную частицу. Этот процесс называется редукцией фон Неймана или коллапсом волновой функции.

Всё, о чём рассказано выше, относится к копенгагенской интерпретации квантовой механики — одному из вариантов объяснения физики событий, происходящих в квантовом мире. Её концепцию создали Нильс Бор и Вернер Гейзенберг в 1927 году, и она долгое время считалась наиболее достоверной. На сегодняшний день её постепенно начинает вытеснять многомировая интерпретация, основы которой заложил американский теоретик Хью Эверетт ещё в 1957 году. Эта теория подразумевает, что есть множество «параллельных» вселенных, в которых имеются одни и те же фундаментальные константы и действуют одинаковые законы физики, но вселенные эти находятся в разных состояниях. Такое представление позволило обойтись без теории коллапса функций, заменив её обратимостью эволюции состояний системы и квантовой сцепленностью, при которой квантовые состояния объектов остаются взаимосвязанными вне зависимости от расстояния между объектами.

Серж Арош и его фотоны

И Арош и Уайнленд изучали взаимодействие фотонов с атомами, но их подходы были различны: Арош использовал атомы для определения наличия фотонов внутри резонатора, а Уайнленд воздействовал на атомы лазерным излучением.

В парижской лаборатории Ароша фотоны запускались в резонатор — камеру диаметром около трёх сантиметров, состоящую из двух вогнутых зеркал. Зеркала из сверхпроводящего материала были охлаждены практически до абсолютного нуля, что сделало их самыми «блестящими» в мире: единственный фотон мог существовать в камере, отражаясь от зеркал, 130 миллисекунд. До момента поглощения фотон пробегал 40 000 километров — практически «кругосветное» расстояние. Обеспечив долгую жизнь «подопытному» фотону, Арош для его обнаружения решил использовать так называемые ридберговские атомы, высоковозбуждённый внешний электрон в которых находится на очень высоком энергетическом уровне. В экспериментах Ароша его высота была порядка 125 нанометров, приблизительно в тысячу раз больше, чем у атомов с электроном в основном (невозбуждённом) состоянии.

Гигантские атомы по одному, со скоростью, подобранной так, чтобы они не успевали поглотить фотон, пропускались через резонатор. Взаимодействие с фотоном изменяло фазу волновой функции атома, то есть смещало её «гребни» и «провалы». Это фазовое смещение можно измерить. Его наличие означает, что фотон есть, а отсутствие — что фотона нет. Совершенствуя методы исследований, Арошу с коллегами удалось не только определить наличие фотонов внутри резонатора, но и подсчитать их число.

Дэвид Уайнленд ловит ионы

Как уже говорилось, Дэвид Уайнленд в своих исследованиях использовал иной подход. В его лаборатории проводились эксперименты по захвату ионов в сильно охлаждённую «ловушку» из электрических полей (за изобретение этой «ловушки», вакуумной камеры, в которой присутствуют постоянное и высокочастотное электрические поля, Вольфганг Пауль и Ханс Демельт получили в 1989 году Нобелевскую премию). Пойманный таким образом ион, находящийся при этом в вакууме при экстремально низкой температуре, полностью изолирован от внешних воздействий.

В нормальных условиях ион может находиться на одном из энергетических уровней. Подбирая частоту излучения и длительность импульсов, Уайнленду удалось сначала «опустить» ион на самый низкий (основной) уровень, а затем придать ему такое количество энергии, чтобы он оказался между основным и первым возбуждённым уровнями, причём так, что вероятность нахождения иона в обоих состояниях одинакова. Имея в своём распоряжении частицу в настоящем квантовом состоянии, удаётся наблюдать и исследовать суперпозицию состояний, в которой квантовая функция может схлопываться к конечному числу состояний, в данном случае к двум.

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Text 8

ПОСЛЕДНИЙ КАМЕНЬ В ОСНОВАНИИ СТАНДАРТНОЙ МОДЕЛИ

Захватывающая эпопея с поиском и открытием бозона Хиггса завершилась логичным финалом. Нобелевская премия по физике

2013 года присуждена бельгийцу Франсуа Энглеру и англичанину Питеру Хиггсу «за теоретическое открытие механизма, который способствует нашему пониманию происхождения массы субатомных частиц и который недавно был подтверждён открытием предсказанной фундаментальной частицы, экспериментами ATLAS и CMS на Большом адронном коллайдере в ЦЕРНе».

В последние десятилетия бозон Хиггса, гипотеза о существовании которого была выдвинута в 1964 году, стал «культовой» элементарной частицей, предметом широкого обсуждения не только в профессиональной среде, но и среди людей, далёких от физики. В немалой степени всеобщему интересу способствовал запуск Большого адронного коллайдера, одной из главных задач которого и был поиск неуловимой частицы.

Бозон Хиггса крайне необходим современной физике. Это не просто ещё одна элементарная частица: её обнаружение позволило закрыть последнюю дыру в экспериментальном обосновании электрослабой теории (Нобелевская премия 1979 года), являющейся частью Стандартной модели — теории устройства нашего мира на микроуровне. Все остальные её положения уже прошли экспериментальную проверку. В частности, предсказанные в 1967 году переносчики слабого взаимодействия W- и Z-бозоны обнаружены ещё в 1983 году (Нобелевская премия 1984 года). Если было бы доказано, что бозон Хиггса не существует, то потребовался бы пересмотр Стандартной модели.

Открытие бозона Хиггса в 2012 году подтвердило не только важный сам по себе механизм формирования массы частиц, но и принципиальную обоснованность наших представлений о природе. Именно это и оценено Нобелевской премией.

Основополагающую роль в Стандартной модели играет понятие симметрии, означающее, что при определённом преобразовании параметров системы не происходит изменения её законов. Например, одинаковость законов физики в разные моменты времени — это временнáя симметрия, а в разных точках пространства — пространственная симметрия, или симметрия относительно преобразований координат. Математически это проявляется в том, что описывающие частицы уравнения не меняют свой вид (инвариантны) при преобразованиях. Помимо наглядной пространственно-временнóй симметрии были обнаружены и более сложные неочевидные симметрии для «цветовых», фазовых и других преобразований. В этом случае говорят о преобразованиях во внутреннем пространстве.

Очень важный момент — соответствие каждому виду симметрии своего закона сохранения. Так, временнóй симметрии соответствует закон сохранения энергии, а внутренняя симметрия электродинамики приводит к закону сохранения заряда. И наоборот, наличие закона сохранения означает наличие соответствующей симметрии. Наличие симметрий уравнений для частиц не только приводит к различным законам сохранения, но и определяет свойства взаимодействий, разрешённые моды распада частиц, времена их жизни и так далее. Именно это позволяет строго обосновать симметрии экспериментально.

С другой стороны, наличие симметрий служит запретом на свойства частиц, которые нарушают симметрию. Вот здесь и возникает одна из принципиальных проблем Стандартной модели: её экспериментально обоснованные симметрии запрещают существование масс у кварков, лептонов и частиц — переносчиков взаимодействий. Однако эксперимент однозначно показывает наличие масс у этих частиц, за исключением фотона и глюона.

Для решения проблем, связанных с симметриями, Ёитиро Намбу в 1960 году предложил так называемый механизм спонтанного нарушения симметрии (Нобелевская премия 2008 года), известный до этого в статистической физике, например, в теориях сверхтекучести и сверхпроводимости. Суть его в том, что взаимодействия, определяющие динамику физической системы (описывающие её дифференциальные уравнения), обладают одной, ненарушенной, симметрией, а основное состояние системы — иной симметрией. Другими словами, нарушение касается только начальных условий. Классический пример спонтанного нарушения симметрии — магнит, имеющий выделенное направление магнитного поля, в то время как уравнения Максвелла, описывающие электромагнитное поле, изотропны.

Термин «спонтанное», то есть самопроизвольное, здесь означает, что система сама выбирает несимметричное состояние в силу его энергетической выгодности.

В 1964 году Франсуа Энглер (совместно с умершим в 2011 году Робертом Браутом) и независимо от них Питер Хиггс предложили механизм приобретения массы бозонами в результате спонтанного нарушения симметрии. О нём также говорят как о нарушении электрослабой симметрии.

Суть механизма в том, что всё пространство однородно заполнено особым полем, минимальная средняя энергия (конденсат) которого отлична от нуля и постоянна во времени и пространстве. В это поле, словно в вязкую среду, погружены все остальные частицы Стандартной модели. Но главным является особенность взаимодействия поля с движущейся частицей — оно не влияет на равномерное

движение, но мешает ускорению тем больше, чем сильнее взаимодействие. Это означает, что частицы, взаимодействующие с полем (кварки, лептоны, W- и Z-бозоны), приобретают массу, пропорциональную силе взаимодействия с ним. Не взаимодействующие с этим полем фотон и глюон остаются безмассовыми.

Спонтанное нарушение симметрии заключается в том, что уравнения движения частиц симметричны, а начальное значение — ненулевая средняя величина поля — нарушает симметрию. В квантовой теории каждому полю соответствуют квантовые флуктуации, проявляющие себя как частицы. Частица данного поля и получила название «бозон Хиггса». Она тоже обладает массой, поскольку взаимодействует с собственным полем. Новое поле не должно выделять никакого направления в пространстве. Поля с таким свойством называют скалярными, и им соответствуют частицы с нулевым спином.

Несмотря на то что первая опубликованная работа принадлежит Р. Брауту и Ф. Энглеру, механизм и бозон часто связывают с именем только П. Хиггса, который первым увидел, что теория предсказывает существование новой частицы с нулевым спином.

(*Наука и жизнь № 11, 2013 г.*)

Text 9

НОБЕЛЕВСКАЯ ПРЕМИЯ ПО ФИЗИКЕ 2014 ГОДА. ОНИ ОСВЕТИЛИ МИР ПО-НОВОМУ

Нобелевская премия по физике 2014 года присуждена за изобретение синего светодиода. Это произвело технологическую революцию, позволив создать яркие, долговечные, энергосберегающие и экологически чистые источники белого света.

Нобелевская премия по физике 2014 года будет вручена Исаму Акасаки (Isamu Akasaki), Хироси Амано (Hiroshi Amano) и Сюдзи Накамура (Shuji Nakamura), которые в начале 1990-х годов разработали светодиод, излучающий синий свет, и тем самым произвели революцию в создании источников света.

К тому времени уже существовали светодиоды, излучающие красный и зеленый свет, однако без синих светодиодов было невозможно создать источники белого света. Но создание синих светодиодов оказалось сложной проблемой, которую, несмотря на значительные усилия, не могли решить в течение 30 лет. Нобелевские лауреаты 2014 года добились успеха там, где потерпели неудачу все остальные.

Создание синего светодиода позволило разработать принципиально новые светодиодные источники яркого белого света, потребляющие значительно меньше электроэнергии и более долговечные по сравнению с источниками света другой физической природы.

Они непрерывно совершенствуются и становятся все ярче. Эффективность источников света характеризуют световым потоком (измеряется в люменах, лм), приходящимся на единицу мощности, затрачиваемой электроэнергии (измеряется в Ваттах, Вт). Самый последний рекорд составляет чуть более 300 лм/Вт. То есть при одинаковом потреблении электроэнергии светодиодный излучатель светит как 16 обычных ламп накаливания или почти 5 флуоресцентных ламп. Поскольку около четверти мирового потребления электроэнергии используется именно для освещения, то легко представить огромную ценность светодиодных источников света для экономии ресурсов Земли.

А ведь у новых источников света есть и другие достоинства. Они гораздо долговечнее других, что повышает их экономичность и экологичность: светодиоды работают до 100 000 часов, в то время как люминесцентные лампы в среднем до 10 000 часов, а лампы накаливания всего 1 000 часов.

Светодиодные источники света могут существенно повысить качество жизни более 1,5 млрд человек, не имеющих доступа к электрической сети. Их малое энергопотребление позволяет получить достаточно света при использовании дешевой местной солнечной энергии.

Но светодиоды используются не только для освещения. Снабжена светодиодами бытовая техника, они светят на LCD-экранах телевизоров, компьютеров и мобильных телефонов, и даже во вспышках фотокамер. На светодиодах работают различные информационные панели и световые указатели. Наследником синего светодиода стал ультрафиолетовый светодиод, с помощью которого можно, например, стерилизовать воду.

(*Наука и жизнь № 11, 2014 г.*)

Использованная литература и интернет-ресурсы

1. Материалы официального сайта Нобелевского комитета (http://www.nobelprize.org)
2. Материалы журнала “Наука и жизнь” (2000–2014)

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