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Методические указания

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BLUE-LASER CD TECHNOLOGY

1. Be sure you know the meanings of the highlighted words.
2. Read the text.

I. Coaxing semiconductor crystals into **lasing** blue light is no easy task, but the rewards among them, greater storage space on optical disks, are **well worth**. The key device inside a compact-disc or CD-ROM player is a tiny but potent laser, which serves as an **exceptionally sharp** optical **stylus**. It enables the player to read information stored on the CD's surface in the form of **tiny pits.** (In the next generation of optical-disk players, the laser also writes information onto the disk by making reversible changes in the material.) The wavelength of the laser's light limits the number of pits and so the amount of data-that can be stored on the disc: the shorter the wavelength, the smaller the pits it can read.

II. **Currently** the lasers inside CD players are made from gallium arsenide (GaAs) and related semiconductors-compounds that, once energized, **emit** light having a wavelength of approximately 820 nanometers (billionths of a meter). This infrared light can read pits no smaller than about a micron in size, which is **roughly** one fiftieth the diameter of a human hair. As described in the preceding article by Alan E.Bell, new optical-disk formats are being developed that take advantage of **breakthroughs** in red semiconductor lasers to increase this information density. But blue diode lasers-emitting light at a wavelength of 460 nanometers-could do even better, because they could read far smaller pits. **Marked with** these smaller pits, an audio CD could store, say, all nine of Beethoven's symphonies, instead of just one. Multimedia applications would also **stand** to benefit **enormously**. Despite their potential, it has been difficult to create blue lasers for CD players. To see why, we must consider how these semiconductor devices work. The lasers inside CD players or CD-ROM readers are tiny **specks** of highly perfect, **atomically engineered crystals**, divided into two main regions. Each side of this diode has a distinct electrical character. On the so-called n-type side, an excess of electrons carry electric current. On the p-type side, **abundant** holes-positively charged particles marking the absence of electrons play the equivalent role. When a positive voltage is applied to the p-side and a negative voltage is applied to the n-side, the electrons and holes rush toward one another.

III. The particles meet in an **ultrathin trench**, a **no-man's-land termed** the quantum cell. There they recombine, **annihilating** one another and, under favorable conditions, emitting photons, the smallest units of light. When the emission **coupled** with a feedback mechanism namely, a highly reflective pair of mirrors **embedded** in the device that "recycle" the photons-lasing results: all the photons are coherent and endow the emerging pencil-sharp beam with its exceptional qualities.

IV. The energy of the photons, equivalent to the wavelength of the emitted light, is determined by a fundamental electronic **yardstick**: the band-gap energy, or roughly, the "electronic elasticity", of the semiconductor material in which the recombination event **occurs**. For diode lasers made from GaAs, the band-gap energy is about 1.45 electron volts. To produce blue wavelength light, the band-gap energy needs to be nearly doubled. Thus, researchers must turn to another class of semiconductors, called the side band-gap materials, examples of which include zinc selenide (ZnSe), a II-VI compound, so named for its placement on the periodic chart, and a III-V compound, gallium nitride (GaN). These materials might be better described as semi-insulators, a name that **highlights** just one basic problem in using them in electrical devices.

V. In the early 1980s **a handful of scientists** began trying to form II-VI semiconductor crystals using a technique called molecular beam **epitaxy**. In this method atomic **"showerheads"** in an ultrahigh-vacuum chamber **gently** rain constituent elements on a substrate, creating an atomic "skyscraper". (The process **resembles** erecting a building brick by brick, in this case with atomic precision.) Using this approach, scientists quickly devised "designer materials" of high crystal-line quality. From this work came a better understanding of how quantum-well layers worked and how researchers could coax blue and green photons from sophisticated man-made materials. (The wavelength of green light is only slightly longer than that of blue light.) But the quest for useful blue and green diode lasers was not ended. These early devices emitted light only when they were energized by another, **desktop-size excitation laser**.

VI. For nearly a decade, investigators could find no say to energize blue and green lasers electrically. Although they could easily **dope** ZnSe crystals with an excess of electrons, they could not similarly provide them with an **overabundance of holes**. Thus, they could not fabricate a **pn-junction**. Then, in 1990, researchers perfected leans to incorporate nitrogen atoms into the process and finally succeeded in doping ZnSe with extra holes. The next summer 3M laboratories and, independently, our joint team at Brown and Purdue universities described the first blue and green diode lasers. These lasers could not be operated **continuously** and had to be cooled to the temperature of liquid nitrogen (77 kelvins).

Shortly thereafter, though, the 3M and the Brown-Purdue groups had improved their designs, achieving both continuous operation at 77 kelvins and pulsed operation at room temperature.

VII. In the fall of 1993 researchers from both Sony laboratories and the Brown-Purdue group attained the continuous operation of a diode laser-energized with only five volts-for up to tens of seconds at room temperature. The very first blue and green laser devices needed as such as 30 volts. The dramatic improvement resulted from some further crafty atomic engineering of the materials. Most recently, Sony has created a green diode laser that emits light at a wavelength of 520 nanometers and operates continuously for about 100 hours at room temperature. The Brown-Purdue team has demonstrated a blue laser at 460 nanometers. Of course, 100 hours is still insufficient for practical applications. But knowing that the now **ubiquitous** GaAs-based infrared diode lasers suffered from essentially the same problems at their infancy, we are optimistic. Very recently, Nichia Chemical Industries in Japan has made progress working with gallium nitride materials. Researchers there have produced beautiful blue light-emitting diodes and lade preliminary demonstrations of a blue laser, though under pulsed, highvoltage conditions.

The Bright, Blue Future

VIII. Despite their limitations, blue and green diode lasers can be improved in a number of ways. By paying detailed attention to the atomic arrangements in the crystal, engineers can make crystals that can better **withstand** the very high current densities required to energize a laser. The illustration below shows a schematic of a laser device constructed from a combination of II-VI semiconductors, mostly derived from ZnSe. The specific sequence of precision-engineered layers optimizes the delivery of the input electrical energy into the ultrathin zinc cadmium selenide (ZnCdSe) quantum well, the electronic and optical heart of the laser. The arrangement also provides the proper optical housing for guiding the emitted photons and generating the feedback mechanism. **The quantum well**, which is about one one-hundredth of a micron in thickness, is formed by confining electrons and holes between the two zinc sulfur selenide (ZnSSe) layers, which have a wider band-gap energy.

IX. Although the recombination of one electron and one hole in a semiconductor may seem fairly intuitive, quantum mechanics **strips** these particles **of** their individuality. In fact, the electrons and holes pair off by electrostatic (coulombic) attraction and form pairs called excitons. Typically, at room temperature, vibrations in the **crystal lattice** break these **entities** apart. So, too, if many particles are packed into a small area, the scattering between them breaks excitons. But in a thin layer of **a wide band-gap** semiconductor, such as ZnCdSe, the excitonic pairs are **squeezed so** much that they stay correlated even at room temperature or in an overcrowded laser device. These longer-lived pairs are actually more likely to emit photons, and so the device requires less current to **sustain** lasing.

X. Another design feature corrects a problem that arises because the wavelength for blue and green emissions exceeds the thickness of the quantum well by nearly two orders of magnitude. Yet another material, zinc magnesium sulfur selenide (ZnHgSSe), is used to define an optical **waveguide**, which is used **to trap** the light in the vertical direction. In 1993 researchers at Philips Laboratories showed how this light guiding improved the laser's operation. Lithography and other similar processing techniques physically remove material in the lateral direction, creating an optical waveguide with a **"mesa"** effect. As a result, the entire structure channels blue and green light in predominantly one (axial) direction; the radiation bounces between the crystallographically **cleaved** end **facets** that form nearly perfect mirrors, then exits through one of them as well.

3. In what paragraphs (I-X) can you find answers to the following questions:

1. Can you explain what it means: "The shorter the wavelength, the smaller the pits it can read"?
2. Under what conditions do blue and green diode lasers require less current to sustain lasing?
3. What technique helps us to solve the problems of exceeding the thickness of the quantum well?
4. What is "molecular beam epitaxy"?
5. What problem had to be solved to create the first blue and green diode lasers? Where were they created?
6. How can we design a highly reflective pain of mirrors?
7. What type of diode laser-emitting light can do better – blue or infra-red?
8. What is the difference between Brown-Purdue blue laser and Sony green laser?
9. What energy do we need to produce blue wavelength light?
10. How can we improve blue and green diode lasers performance?
11. Why has it been difficult to create blue lasers for CD players?

ELECTRIC FIELD

1. Be sure you know the meanings of the highlighted words.
2. Read the text.

I. In physics, **the space** surrounding an electric charge has a property called an electric field. This electric field **exerts** a force **on** other charged objects. The concept of electric field was introduced by Michael Faraday.

II. The electric field is a vector with SI units of newtons per coulomb ($N*C^{-1}$) or, equivalently, volts per meter ($V*m^{-1}$). The direction of the field at a point is defined by the direction of the electric force exerted on a positive test charge placed at that point. The strength of the field is defined by **the ratio** of the electric force on a charge at a point to the **magnitude** of the charge placed at that point. Electric fields contain electrical energy with energy density proportional to the square of the field intensity.

III. A moving charge **creates** not just an electric field but also a magnetic field, and in general the electric and magnetic fields are not completely separate phenomena; what one observer **perceives as** an electric field, another observer in a different **frame of reference** perceives as a mixture of electric and magnetic fields. For this reason, one speaks of "electromagnetism" or "electromagnetic fields". In quantum mechanics, **disturbances** in the electromagnetic fields are called photons, and the energy of photons is **quantized.**

Definition (for electrostatics)

IV. Electric field is defined as the electric force per unit charge. The direction of the field **is taken to** be the direction of the force it would exert on a positive test charge. The electric field is radially **outward** from a positive charge and radially in toward a negative point charge.

The electric field is defined as the proportionality constant between charge and force (in other words, the force per unit of test charge):

$$E = \frac{F}{q},$$

where F is the electric force given by Coulomb’s law,

q is the charge of a “test charge”.

However, note that this equation is only true in the case of electrostatics, that is to say, when there is nothing moving. The more general case of moving charges causes this equation to become the Lorentz force equation.

Coulomb’[s law

V. The field surrounding a point charge is given by Coulomb’s law:

$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q}{r^2} \cdot \hat{r},$$

where Q is the charge of the particle creating the electric field,

r is the distance from the particle with charge Q to the E-field evaluation point,

$\hat{r}$ is the Unit vector pointing from the particle with charge Q to the E-field evaluation point, and

ε_0 is the Permittivity of free space.

Coulomb’s law is actually a special case of Gauss’s Law, a more fundamental description of the relationship between the distribution of electric charge in space and the resulting electric field. Gauss’s law is one of Maxwell's equations, a set of four laws governing electromagnetics.

Properties (in electrostatics)

VI. According to Equation (1) above, electric field is dependent on position. The electric field **due to** any single charge **falls off as** the square of the distance from that charge.

Electric fields follow the superposition principle. If more than one charge is present, the total electric field at any point is equal to the vector sum of the respective electric fields that each object would create in the absence of the others.

$$E_{total} = \sum_i E_i = E_1 + E_2 + E_3 \ldots \ .$$

If this principle is extended to an infinite number of infinitesimally small elements of charge, the following formula results:

$$E = \frac{1}{4\pi\varepsilon_0} \int \frac{\rho}{r^2} \hat{r} d^3 r \ ,$$

where ρ is the charge density, or the amount of charge per unit volume.

The electric field at a point is equal to the negative gradient of the electric potential there. In symbols,

$$E = -\nabla \varphi \, .$$

Where $\varphi(x, y, z)$ is the scalar field representing the electric potential at a given point. If several spatially distributed charges generate such an electric potential, e.g. in a solid, an electric field gradient may also be defined.

Considering the permittivity ε of a material, which may differ from the permittivity of free space ε_0, the electric displacement field is:

$$D = \varepsilon E \, .$$

Parallels between electrostatics and gravity

Coulomb’s law, which describes the interaction of electric charges:

$$F = \frac{1}{4\pi\varepsilon_0} \frac{Qq}{r^2} \hat{r} = qE \ ,$$

is similar to the Newtonian gravitation law: $F = G\frac{Mm}{r^2}\hat{r} = mg$.

This suggests **similarities** between the electric field E and the gravitational field g, so sometimes mass is called “gravitational charge”.

Similarities between electrostatic and gravitational forces:

1. Both act in a vacuum.
2. Both are central and conservative.

3. Both obey an inverse-square law (both are inversely proprotional to square of r).

4. Both **propagate** with finite speed c

Differences between electrostatic and gravitational forces:

1. Electrostatic forces are much greater than gravitational forces (by about 10^{36} times).

2. Gravitational forces are always attractive in nature, whereas electrostatic forces may be either attractive or **repulsive**.

3. Gravitational forces are independent of the medium whereas electrostatic forces depend on the medium. This is due to the fact that a medium contains charges; the fast motion of these charges, in response to an external electromagnetic field, produces a large secondary electromagnetic field which should be **accounted for**. While slow motion of ordinary masses in response to changing gravitational field produces extremely weak secondary “gravimagnetic field” which may be neglected in most cases (except, of course, when mass moves with relativistic speeds).

Time-varying fields

VII. Charges do not only produce electric fields. As they move, they generate magnetic fields, and if the magnetic field changes, it generates electric fields. This "secondary" electric field can be computed using Faraday's law of induction,

$$\nabla \times E = -\frac{\partial B}{\partial t},$$

where $\nabla \times E$ indicates **the curl** of the electric field, and $-\frac{\partial B}{\partial t}$ represents the vector rate of decrease of magnetic flux density with time. This means that a magnetic field changing in time produces a curled electric field, possibly also changing in time.

The situation in which electric or magnetic fields change in time is no longer electrostatics, but rather electrodynamics or electromagnetics.

3. In what paragraphs (I-VIII) can you find answers to the following questions:
    1. Are there more differences or similarities between electrostatic and gravitational forces?
    2. How can we define “secondary” electric field?
    3. What is the definition of electric field for electrostatic?
    4. What is electric field in physics?
    5. Why do we speak of “electromagnetism”?
    6. Is Coulomb’s law quite independent?
    7. Why is mass in Coulomb’s law sometimes called “gravitational charge”?
    8. How can we define the strength of electric field?
    9. What principle do electric fields follow?

LESSONS FOR NANOTECHNOLOGY IN COMPUTER DESIGN

1. Be sure you know the meanings of the highlighted words.
2. Read the text.

I. The ability of Teramac mainframe to operate reliably in the presence of large numbers of defects shows that a CCC architecture is applicable to, and may be essential for, computational nanotechnology. As perfect devices become more expensive **to fabricate**, **defect tolerance** becomes a more valuable method **to deal with** the imperfections. Any computer with nanoscale components will contain a significant number of defects, as well as massive numbers of wires and switches for communication purposes. It therefore makes sense to consider architectural issues and defect tolerance early in the development of a new paradigm. The Teramac design and assembly philosophy **differs** significantly **from** the usual ideas of building complex computer systems, and thus there are several important lessons for nanotechnology.

II. The first lesson is that it is possible to build a very powerful computer that contains defective components and wiring, **as long as** there is sufficient communication **bandwidth** in the system to find and use the healthy resources. The machine is built cheaply but imperfectly, a map of the defective resources is prepared, and then the computer is **configured with** only the healthy resources. At present, such an approach is not economically **competitive** with CMOS technology, which requires perfection in all the components of a computer, because so many of the resources in a CCC are not used (for example, most of the LUTs in Teramac). However, the cost of the fabrication plants for integrated circuits (Fabs) is escalating exponentially with time as chips continue **to shrink** in size, an observation that is sometimes called Moore's f second law (2). By the year 2012, a single Fab could cost $30 billion (1) or more, which may simply be too expensive and risky to build. At the same time, the **sophistication of** inexpensive chemically synthesized components is increasing dramatically. There may eventually be **a crossover** from y one manufacturing paradigm to another, and the defect tolerance possibilities raised by Teramac could be the key enabling economic issue that **ushers** in the era of chemically assembled electronic computers.

III. A second and related lesson from Teramac is that the resources in a computer do not have to be regular, but rather they must have a sufficiently **high degree of connectivity**. The wiring mistakes in the MCMs introduced a significant element of **randomness to** the connectivity of the system, such that it was not possible to know what resources were connected together without performing a test. Thus, it is not essential to place a component at a specific position as long as the components can be located logically. **A crude analogy** here is the comparison between the American and the Japanese post offices. If residences are laid out in a Cartesian coordinate system, then it does not **take** much **complexity in** the mail-delivery system to find an address. In Japan, however, there are no regular street addresses. Nevertheless, the knowledge of many local postmen is sufficient to deliver a letter. A system at the nanoscale that has some random character can still be functional if there is enough local intelligence to locate resources, either through the laws of physics or through the ability to reach down through random but **fixed** local connections.

IV. The third lesson addresses the issue of what are the most essential components for an electronic nanotechnology. In Teramac, wires are by far die most **plentiful resource**, and the most important are the address lines that control the **settings** of the configuration switches and the data lines that link the LUTs to perform the calculations. In a nanotechnology paradigm, these wires may be physical or logical, but they will be essential for the enormous amount of communication bandwidth that will be required. Next, in terms of the number of elements, are the **crossbar switches** and the configuration bits that control them. This may well be the most important active device that will be needed for computational nanotechnology. One possible physical implementation of a crossbar switch is illustrated in Fig. 4, although this example should not be viewed as **restrictive**. The replacement of the six transistors required by an FPGA for a single configurable bit by one quantum dot that may require only a single electron to change its state would represent an enormous energy saving for a bit operation. This would represent **a tremendous advance** toward the thermodynamic limit for a **nonreversible** machine. The LUTs make up less than 3% of the fat-free utilizable resources of Teramac.

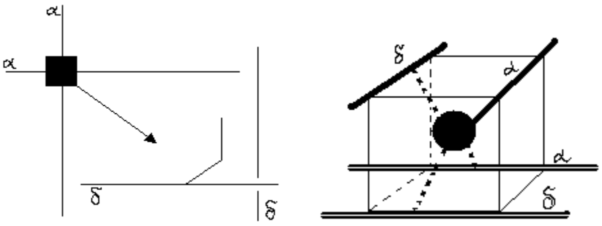

Fig. 4. An idealized version of the chemically fabricated configurable bit (right), compared with the logical description of a configurable bit redrawn from Fig. 1. The components labeled α and δ are the address lines and data lines, respectively. The orange component (δ) is the switch. The address lines are used to locate and "set" the bit. Once the bit is set, the connection between the two data lines is shorted, and thus the status of the bit may be read. A chemically fabricated switch could consist of a single semiconductor quantum dot in capacitive contact with the two address wires. The dot is also in tunnelling or ohmic contact with two data-wires. Ligands that connect the dot to the four wires are varied to control the nature of the contact. Operationally, this switch is a dual-gated single-electron transistor (5). When the two address lines are biased "on," the quantum dot is shifted out of the Coulomb blockade voltage region, and the data lines are effectively shorted.

3. In what paragraphs (I-X) can you find answers to the following questions:
    1. What is an analogy between post delivery in America and Japan and the random character of nanoscale?
    2. Want makes a very powerful computer with defective components be quite workable?
    3. What is Moore’s second law?
    4. What is the most important active device that will be needed for computational nanotechnology?
    5. What makes mainframe Termac quite applicable for nanotechnology design?

6. What does it mean: a crossover form one manufacturing paradigm to another?
7. What technology is more competitive nowdays: CMOS or CCC?
8. What is the second lesson related from Termac?
9. What design helps us to save enormous energy for a bit operation?
10. On what reason can we formulate several important lessons for nanotechnology?

ELECTRON

1. Be sure you know the meanings of the highlighted words.
2. Read the text.

I. The Electron is a fundamental **subatomic particle** that **carries an** electric charge. It is **a spin** -½ **lepton** that participates in electromagnetic interactions, and its mass is less than one thousandth of that of the smallest atom. Its electric charge is defined **by convention** to be negative, with a value of -1 in atomic units. Together with atomic nuclei, electrons make up atoms; their **interaction with** adjacent nuclei is the main cause of chemical bonding.

Overview

II. The word *electron* **was coined** in 1891 by George Johnstone Stoney and is **derived from** the term *electric force* introduced by William Gilbert. Its origin is in Greek: ήλεκτρον (elektron), meaning *amber.* J.J. Thomson **is credited** with having first measured the charge/mass ratio and is considered to be the discoverer of the electron. Within an atom, electrons surround a nucleus composed of protons and neutrons in an electron **configuration**. The variations in electric field generated by differing numbers of electrons and their configurations in atoms determine the chemical properties of the elements. These fields play a fundamental role in chemical bonds and chemistry. Electrons in motion produce an electric current and a magnetic field. Some types of electric currents are termed electricity. Our understanding of how electrons behave has been significantly modified during the past century, the greatest advances being the development of quantum mechanics in the 20th century. This brought the idea of **wave-particle duality**, that is, that electrons **show** both wave-like and particle-like **properties**, to varying degrees. Equally important, particle physics has **furthered** our understanding of how the electron interacts with other particles.

Classification

III. The electron is one of a class of subatomic particles called **leptons**, which are believed to be fundamental particles (that is, they cannot be broken down into smaller constituent parts). As with all particles, electrons can also act as waves. This is called the wave-particle duality, also known by the term **complementarity** coined by Niels Bohr and can be demonstrated using the **double-slit** experiment.

The antiparticle of an electron is the positron, which has the same mass but positive **rather than** negative charge. The discoverer of the positron, Carl P. Anderson, proposed calling standard electrons negatrons, and using *electron* as a **generic** term to describe both the positively and negatively charged variants. This usage never **caught on** and is rarely if ever encountered today.

Properties and behavior

IV. Electrons have a negative electric charge of-1.6022 x 10^{49} **coulomb**, a mass of 9.11 x 10^{-31} kg based on charge/mass measurements and a relativistic **rest mass** of about 0.511 MeV/c^2 . The mass of the electron is approximately $^1/_{1836}$ of the mass of the proton. The common electron symbol is $\mathbf{e}^{-}$. According to quantum mechanics, electrons can be represented by wavefunctions, from which a calculated **probabilistic** electron density can be determined. The **orbital** of each electron in an atom can be described by a wavefunction. Based on the Heisenberg **uncertainty principle**, the exact **momentum** and position of the actual electron cannot be simultaneously determined. This is a limitation which, in this instance, simply states that the more **accurately** we know a particle's position, the less accurately we can know its momentum, and **vice versa**. The electron has spin ½ and is a fermion (it follows Fermi-Dirac statistics). In addition to its **intrinsic** angular momentum, an electron has an intrinsic magnetic moment: along its spin axis.

V. Electrons in an atom are **bound to** that atom; electrons moving freely in vacuum, space or certain media are free electrons that can be **focused into** an electron beam. When free electrons move, there is a net flow of charge, this flow is called an electric current. The **drift velocity** of electrons in metal wires is on the order of mm/hour. However, the speed at which a current at one point in a wire **causes** a current in other parts of the wire is typically 75% of light speed. In some superconductors, pairs of electrons move as Cooper pairs in which their motion is **coupled to** nearby matter via lattice vibrations called phonons. The distance of separation between Cooper pairs is **roughly** 100 nm. (Rohlf, J.W.) A body has an electric charge when that body has more or fewer electrons than are required to balance the positive charge of the nuclei. When there is an excess of electrons, the object is said to be negatively charged. When there are fewer electrons than protons, the object is said to be positively charged. When the number of electrons and the number of protons are equal, their charges **cancel** each other and the object is said to be electrically neutral. A macroscopic body can develop an electric charge through **rubbing**, by the phenomenon of **triboelectricity**. When electrons and positrons **collide**, they **annihilate** each other and produce pairs of high energy photons or other particles. On the other hand, high-energy photons may transform into an electron and a positron by a process called pair production, but only in the presence of a nearby charged particle, such as a nucleus.

VI. The electron is currently described as a fundamental particle or an elementary particle. It has no substructure (although British physicist Humphrey Maris claims to have found a way to split the electron into "electrinos" using an electron **bubble).** Hence, **for convenience**, it is usually defined or assumed to be a point-like mathematical point charge, with no **spatial** extension. However, when a test particle is forced to approach an electron, we measure changes in its properties (charge and mass). This effect is common to all elementary particles: Current theory suggests that this effect is due to the influence of vacuum fluctuations in its local space, so that the properties measured from a significant distance are considered to be the sum of **the bare** properties and the vacuum effects (see renormalization). The classical electron radius is 2.8179 x 10^{-15} m. This is the radius that is **inferred** from the electron's electric charge, by using the classical theory of electrodynamics alone, ignoring quantum mechanics. Classical electrodynamics (Maxwell's electrodynamics) is the older concept that is widely used for practical applications of electricity, electrical engineering, semiconductor physics, and electromagnetics; quantum electrodynamics, on the other hand, is useful for applications involving modern particle physics and some aspects of optical, laser and quantum physics.

VII. Based on current theory, the speed of an electron can approach, but never reach, *c* (the speed of light in a vacuum). This limitation is attributed to Einstein's theory of special relativity which defines the speed of light as a constant within all inertial frames. However, when relativistic electrons are injected into a dielectric medium, such as water, where the local speed of light is significantly less than *c,* the electrons will (temporarily) be traveling faster than light in the medium. As they interact with the medium, they generate **a faint** bluish light, called Cherenkov radiation. The effects of special relativity are based on a quantity known as y or the Lorentz factor, y is a function of v, the velocity of the particle, and *c* It is defined as:

$$\gamma = 1/\sqrt{1-(\upsilon^2 - c^2)}\,.$$

The energy necessary to accelerate a particle is y minus one times the rest mass. For example, the linear accelerator at Stanford can accelerate an electron to **roughly** 51 GeV. This gives a gamma of 100,000, since the rest mass of an electron is 0.51 MeV/c^2 (the relativistic mass of this electron is 100,000 times its rest mass). Solving the equation above for the speed of the electron (and using an approximation for large γ) gives:

$$\upsilon = \left(1 - \frac{1}{2}\gamma^{-2}\right)c = 0.99999999995c\,.$$

In practice

In the universe

VIII. Scientists believe that the number of electrons existing in the known universe is at least 10^{79}. This number **amounts to** an average density of about one electron per cubic metre of space. Astronomers have determined that 90% of all of the detectable mass in the universe is hydrogen, which is made of one electron and one proton. Based on the classical electron radius and assuming a dense sphere packing, it can be calculated that the number of electrons that would fit in the observable universe is on the order of 10^{130}.

In industry

Electron beams are used in **welding**, lithography, scanning electron microscopes and transmission electron microscopes. LEED and RHEED are also important tools where electrons are used. They are also at the heart of **cathode ray tubes**, which are used **extensively** as display devices in laboratory instruments, computer monitors and television sets. In photomultiplier tubes, one photon **strikes** the photocathode, initiating **an avalanche** of electrons that produces a detectable current.

In the laboratory

Electron microscopes are used **to magnify** details up to 500,000 times. Quantum effects of electrons are used in Scanning tunneling microscope to study features at the atomic scale.

In theory

IX. In relativistic **quantum mechanics**, the electron can be described by the Dirac Equation which defines the electron as a (mathematical) point. In quantum field theory, the behavior of the electron can be described by quantum electrodynamics (QED), a U(l) **gauge theory**. In Dirac's model, an electron is defined to be a mathematical point, a point-like, **charged "bare" particle** surrounded by a sea of interacting pairs of virtual particles and antiparticles. These provide a correction of just over 0.1% to the predicted value of the electron's gyromagnetic ratio from exactly 2 (as predicted by Dirac's single-particle model). The **extraordinarily precise** agreement of this prediction with the experimentally determined value is viewed as one of the great achievements of modern physics. In the Standard Model of particle physics, the electron is the first-generation charged **lepton**. It forms a **weak**

isospin doublet with the electron neutrino; these two particles interact with each other through the both the charged and neutral current weak interaction. The electron is very similar to the two more massive particles of higher generations, the muon and the tau lepton, which are identical in charge, spin, interaction but differ in mass. The antimatter **counterpart of** the electron is the positron. The positron has the same amount of electrical charge as the electron, except that the charge is positive. It has the same mass and spin as the electron. When an electron and a positron meet, they may annihilate each other, giving rise to two gamma-rav photons. If the electron and positron had negligible momentum, each gamma ray will have an energy of 0.511 MeV. See also Electron-positron annihilation. Electrons are a key element in electromagnetism, a theory that is accurate for macroscopic systems, and for classical modelling of microscopic systems.

3. In what paragraphs (I-VIII) can you find answers to the following questions:

1. What is electric current?
2. What determines chemical bonds in a body?
3. How can you in general define of what electron is?
4. What kind of limitation is used in quantum mechanics?
5. What can be rarely encountered today?
6. What is triboelectricity?
7. What is “Cherenkov radiation”?
8. What is pair production?
9. What are vacuum fluctuations?
10. What science applies the notion of wave-particle duality to electron?
11. What is electron in standard Model of particle physics?
12. What is the number of electrons existing in the Universe?
13. How does quantum mechanics define electron?
14. What is considered to be the counterpart of the electron?

HOW DO MIRRORS REFLECT PHOTONS?

1. Be sure you know the meanings of the highlighted words.
2. Read the text.

I. There are many types of mirrors, and each behaves somewhat differently. The most common type is a silver mirror, consisting of a thin layer of silver on the bottom side of a glass side. Additional layers of copper or other materials may **be deposited on** the back side of the silver layer, but these are not **relevant for** the optical properties.

II. To understand how such mirrors work, let us first describe the **interaction** of light with some media **in the semiclassical view**. Light consists of electromagnetic waves, which induce some oscillation of electrons in any substance **hit** by the light. In an insulator such as glass, the electrons are **firmly** bound and can only oscillate around their normal position. This movement influences **the propagation** of light so that its wave velocity is reduced, while there is only a small loss of energy. This is different in a metal, where some of the electrons are free **to move over** large distances, but their motion is **damped** so that energy is **dissipated**. The wave amplitude **decays** very quickly in the metal – usually within a small fraction of the wavelength. Associated with that decay is a loss of energy in the wave and some heating of the metal. Most of the incident optical power, however, is reflected at the air/metal interface. In other words, the power is transferred to another wave with a different propagation direction (opposite to the original direction for normal **incidence** on the surface).

III. In the case of a silver mirror, this reflection occurs at the interface of glass to silver, essentially because the optical **properties of** the metal are very different from those of glass. (As a general rule, waves experience significant reflection at interfaces between media with **substantially** different propagation properties.) In the case of this silver mirror, there is also another, weaker reception at the air/glass interface. In the end we obtain a reflected wave with essentially the same properties as the incident wave **apart from** some loss of power, which typically **amounts to** a few percent for silver mirrors. This reflection loss does not matter for a mirror used in the bathroom, but such metallic mirrors are usually not suitable for use in lasers. The loss of light pelf is often **unacceptable**, and the associated heating of the mirror can **cause** difficulties, in particular **via** thermally induced deformations. These affect the **spatial** properties of the reflected light. For example, **bulging** of the mirror surface can defocus a laser beam.

IV. Other types of mirrors, so-called dielectric mirrors, are superior for use in lasers. They consist only of nonconductive materials (insulators), typically with an alternating **sequence** of thin layers. For example, a sequence of 15 pairs of **silica** (SiO_2) and **titanium dioxide** (TiO_2) layers-each having a thickness of a few hundred nanometers-deposited on some glass substrate can serve as a highly reflecting mirror for laser applications. Here, the reflection at each single interface of two layers is rather weak, but dozens of such reflections are **superimposed** to obtain a high overall reflectivity. Such mirrors can easily reflect more than 99.9 percent - in extreme cases even more than 99.9999 percent - of the optical power.

V. A **noteworthy** feature of dielectric mirrors is that they are highly reflecting only for light in a very limited range of wavelengths. If this wavelength range is located the **infrared** region of the optical spectrum, such mirrors may not even look like mirrors, since they allow most of the incident visible light to pass through. Dielectric mirrors may also be designed for special purposes-for example, to reflect 80 percent of green light while transmitting nearly 20 percent and **simultaneously** to transmit red light nearly completely. Certain mirror designs even allow **temporal** compression of **ultrashort** pulses of light to even smaller **durations**, such as a few femtoseconds (one billionth of one millionth of a second). This effect is related to tiny wavelength-dependent time delays that light experiences in the mirror structure.

In a quantum-mechanical picture, light consists of photons, or **packages** of optical energy. The photons of the light reflected from a metal (or a dielectric mirror) are identical to the incidents, apart from the changed propagation direction. The loss of light in the metal means that some fraction of the photons are lost, while the energy consent of each reflected photon is fully **preserved**. Which of the photons are lost is a **matter of chance**; there is a certain probability for each photon to be absorbed. So if one illuminates a metal with a source of single photons, there will be complete reflection (and no heating of the metal) in most cases, and complete absorption with associated heating (creation of so-called phonons in the metal) in some cases.

3. In what paragraphs (I-X) can you find answers to the following questions:
   1. What happens if we locate dielectric mirror in the infrared region of the optical spectrum?
   2. Why are common metallic mirrors not suitable for use in lasers?
   3. What is the most essential for the optical properties of mirrors?
   4. In what substances is energy dissipated?
   5. What is the design of dielectric mirrors?
   6. What are dielectric mirrors applications?
   7. Why can dielectric mirrors reflect more than 99,9% of the optical power?
   8. How do electrons move in glass?
   9. How is power transferred to another wave?

MAGNETISM

1. Be sure you know the meanings of the highlighted words.
2. Read the text.

In physics, magnetism is one of the phenomena by which materials exert an attractive or repulsive force on other materials. Some well known materials that exhibit easily detectable magnetic properties are iron, some steels, and the mineral lodestone; however, all materials are influenced to greater or lesser degree by the presence of a magnetic field.

Physics of magnetism

Magnetic forces are fundamental forces that arise from the movement of electrical charge. Maxwell's equations and the Biot-Savart law describe the origin and behavior of the fields that govern these forces. Thus, magnetism is seen whenever electrically charged particles are in motion. This can arise either from movement of electrons in an electric current, resulting in "electromagnetism", or from the quantum-mechanical spin and orbital motion of electrons, resulting in what are known as "permanent magnets". Electron spin is the dominant effect within atoms. The so-called 'orbital motion' of electrons around the nucleus is a secondary effect that slightly modifies the magnetic field created by spin.

Charged particle in a magnetic field

When a charged particle moves through a magnetic field B, it feels a force F given by the cross product:

$$F = qv \times B,$$

where q is the electric charge of the particle, v is the velocity vector of the particle, B is the magnetic field.

Because this is a cross product, the force is perpendicular to both the motion of the particle and the magnetic field. It follows that the magnetic force does no work on the particle; it may change the direction of the particle's movement, but it cannot cause it to speed up or slow down.

This might give you pause: Simple bar magnets seem to be entirely able to pick up small metal objects, which certainly seems to require that they do work on those objects. As David J. Griffiths points out in his textbook Introduction to Electrodynamics, this law is absolute - the magnetic field doesn't do any work. However, quite like the normal force of an inclined plane, which also can't do work, the magnetic field can redirect the efforts of existing forces, and then those forces can indeed do work in the relevant direction.

One tool (often introduced in physics courses) for determining the direction of the velocity vector of a moving charge, the magnetic field, and the force exerted is labeling the index finger “V”, the middle finger “B”, and the thumb “F”. When making a gun-like configuration (with the middle finger crossing under the index finger), the fingers represent the velocity vector, magnetic field vector, and force vector, respectively.

Magnetic dipoles

Normally, magnetic fields are seen as dipoles, having a “South pole” and a “North pole”. A magnetic field contains energy, and physical systems stabilize into the configuration with the lowest energy. Therefore, when placed in a magnetic field, a magnetic dipole tends to align itself in opposed polarity to that field, thereby canceling the field strength as much as possible and lowering the energy stored in that field to a minimum. For instance, two identical bar magnets normally line up North to South resulting in no magnetic field, and resist any attempts to reorient them to point in the same direction. The energy required to reorient them in that configuration is then stored in the resulting magnetic field, which is double the strength of the field of each individual magnet. (This is, of course, why a magnet used as a compass interacts with the Earth's magnetic field to indicate North and South).

Magnetic monopoles

Contrary to normal experience, some theoretical physics models predict the existence of magnetic monopoles. Paul Dirac observed in 1931 that, because electricity and magnetism show a certain symmetry, just as quantum theory predicts that individual positive or negative electric charges can be observed without the opposing charge, isolated South or North magnetic poles should be observable. In practice, however, although charged particles like protons and electrons can be easily isolated as individual electrical charges, magnetic south and north poles have not been found in isolation. Using quantum theory Dirac showed that if magnetic monopoles exist, then one could explain why the observed elementary particles carry charges that are multiples of the charge of the electron.

Atomic magnetic dipoles

The physical cause of the magnetism of objects, as distinct from electrical currents, is the atomic magnetic dipole. Magnetic dipoles, or magnetic moments, result on the atomic scale from the two kinds of movement of electrons. The first is the orbital motion of the electron around the nucleus; this motion can be considered as a current loop, resulting in an orbital dipole magnetic moment along the axis of the nucleus. The second, much stronger, source of electronic magnetic moment is due to a quantum mechanical property called the spin dipole magnetic moment (although current quantum mechanical theory states that electrons neither physically spin, nor orbit the nucleus).

The overall magnetic moment of the atom is the net sum of all of the magnetic moments of the individual electrons. Because of the tendency of magnetic dipoles to oppose each other to reduce the net energy, in an atom the opposing magnetic moments of some pairs of electrons cancel each other, both in orbital motion and in spin magnetic moments. Thus, in the case of an atom with a completely filled electron shell or subshell, the magnetic moments normally completely cancel each other out and only atoms with partially-filled electron shells have a magnetic moment, whose strength depends on the number of unpaired electrons.

The differences in configuration of the electrons in various elements thus determine the nature and magnitude of the atomic magnetic moments, which in turn determine the differing magnetic properties of various materials.

Types of magnets

Electromagnets

Electromagnets are useful in cases where a magnet must be switched on or off; for instance, large cranes to lift junked automobiles.

For the case of electric current moving through a wire, the resulting field is directed according to the "right hand rule." If the right hand is used as a model, and the thumb of the right hand points along the wire from positive towards the negative side ("conventional current", the reverse of the direction of actual movement of electrons), then the magnetic field will wrap around the wire in the direction indicated by the fingers of the right hand. As can be seen geometrically, if a loop or helix of wire is formed such that the current is traveling in a circle, then all of the field lines in the center of the loop are directed in the same direction, resulting in a magnetic dipole whose strength depends on the current around the loop, or the current in the helix multiplied by the number of turns of wire. In the case of such a loop, if the fingers of the right hand are directed in the direction of conventional current flow (i.e. positive to negative, the opposite direction to the actual flow of electrons), the thumb will point in the direction corresponding to the North pole of the dipole.

Permanent magnets

Magnetic metallic elements

Many materials have unpaired electron spins, but the majority of these materials are paramagnetic. When the spins interact with each other in such a way that the spins align spontaneously, the materials are called ferromagnetic (what is often loosely termed as "magnetic"). Due to the way their regular crystalline atomic structure causes their spins to interact, some metals are (ferro) magnetic when found in their natural states, as ores. These include iron ore (magnetite or lodestone), cobalt, and nickel, as well the rare earth metals gadolinium and dysprosium (when at a very low temperature). Such naturally occurring (ferro) magnets were used in the first experiments with magnetism. Technology has expanded the availability of magnetic materials to include various manmade products, all based, however, on naturally magnetic elements.

Composites

Ceramic or ferrite

Ceramic, or ferrite, magnets are made of a sintered composite of powdered iron oxide and barium/strontium carbonate ceramic. Due to the low cost of the materials and manufacturing methods, inexpensive magnets (or nonmagnetized ferromagnetic cores, for use in electronic component such as radio antennas, for example) of various shapes can be easily mass produced. The resulting magnets are noncorroding, but brittle and must be treated like other ceramics.

Alnico magnets are made by casting or sintering a combination of aluminium, nickel and cobalt with iron and small amounts of other elements added to enhance the properties of the magnet. Sintering offers superior mechanical characteristics, whereas casting delivers higher magnetic fields and allows for the design of intricate shapes. Alnico magnets resist corrosion and have physical properties more forgiving than ferrite, but not quite as desirable as a metal.

Injection molded

Injection molded magnets are a composite of various types of resin and magnetic powders, allowing parts of complex shapes to be manufactured by injection molding. The physical and magnetic properties of the product depend on the raw materials, but are generally lower in magnetic strength and resemble plastics in their physical properties.

Flexible

Flexible magnets are similar to injection molded magnets, using a flexible resin or binder such as vinyl, and produced in flat strips or sheets. These magnets are lower in magnetic strength but can be very flexible, depending on the binder used.

Rare earth magnets

'Rare earth' (lanthanoid) elements have a partially occupied/electron shell (which can accommodate up to 14 electrons.) The spin of these electrons can be aligned, resulting in very strong magnetic fields, and therefore these elements are used in compact high-strength magnets where their higher price is not a factor.

Samarium cobalt

Samarium cobalt magnets are highly resistant to oxidation, with higher magnetic strength and temperature resistance than alnico or ceramic materials. Sintered samarium cobalt magnets are brittle and prone to chipping and cracking and may fracture when subjected to thermal shock.

3. In what paragraphs () can you find answers to the following questions:
   1. What are very high-strength magnets?
   2. What are iron ore, cobalt, nickel and some rare earth metals distinguished for?

3. What phenomenon explains the fact that a compass indicates North and South?
4. How can fingers represent the velocity vector?
5. What magnets are noncorroding but brittle?
6. Can we name injection molded materials magnets?
7. What is magnetic dipole?
8. How is magnetism determined in physics?
9. How can we determine the differing magnetic properties of various materials?
10. What is the dominant effect within atoms?
11. What are magnetic monopoles?