# Applied science

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# Applied science

**Applied science** is the application of scientific knowledge transferred into a physical environment. Examples include testing a theoretical model through the use of formal science or solving a practical problem through the use of natural science.

Fields of engineering are closely related to applied sciences. Applied science is important for technology development. Its use in industrial settings is usually referred to as research and development (R&D).

Applied science differs from fundamental science, which seeks to describe the most basic objects and forces, having less emphasis on practical applications. Applied science can be like biological science and physical science.

## In education

In the United Kingdom's educational system, Applied Science refers to a suite of "vocational" science qualifications that run alongside "traditional" GCSE or A Level Sciences .[1] Level 2 Courses (GCSE Equivalent): BTEC Applied Science, OCR Nationals, GCSE Applied Science, GCSE Additional Applied Science. Level 3 Courses (A Level Equivalent): GCE Applied Science, BTEC Applied Science, OCR Nationals. Applied Science courses generally contain more coursework (also known as portfolio or internally assessed work) compared to their traditional counterparts. These are an evolution of the GNVQ qualifications that were offered up to 2005 These courses regularly come under scrutiny and are due for review following the Wolf Report 2011 [2] however their merits are argued elsewhere [3]

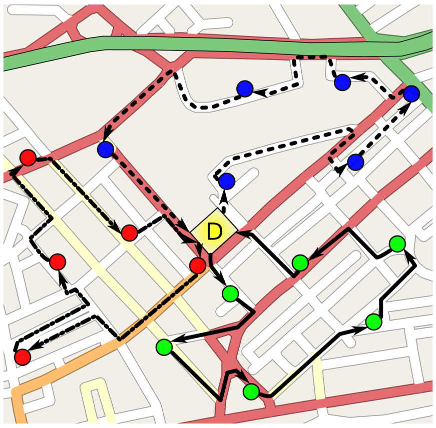
In the United States, The College of William & Mary offers an undergraduate minor as well as Master of Science and Doctor of Philosophy degrees in "applied science." Courses and research cover varied fields including neuroscience, optics, materials science and engineering, nondestructive testing, and nuclear magnetic resonance.[4]

## References

[1] http://www.nuffieldfoundation.org/applied-science-invisible-revolution
[2] https://www.education.gov.uk/publications/standard/publicationDetail/Page1/DFE-00031-2011
[3] http://www.education.leeds.ac.uk/research/files/78.pdf
[4] http://www.wm.edu/as/appliedscience/

# Disciplines

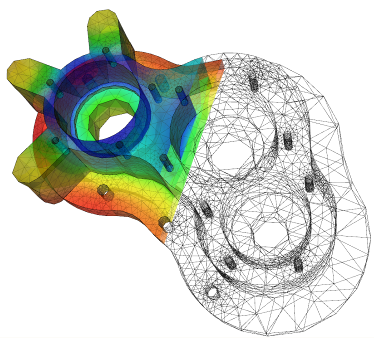
# Applied mathematics




Efficient solutions to the vehicle routing problem require tools from combinatorial optimization and integer programming.

**Applied mathematics** is a branch of mathematics that concerns itself with mathematical methods that are typically used in science, engineering, business, and industry. Thus, "applied mathematics" is a mathematical science with specialized knowledge. The term "applied mathematics" also describes the professional specialty in which mathematicians work on practical problems; as a profession focused on practical problems, *applied mathematics* focuses on the formulation and study of mathematical models. In the past, practical applications have motivated the development of mathematical theories, which then became the subject of study in pure mathematics, where mathematics is developed primarily for its own sake. Thus, the activity of applied mathematics is vitally connected with research in pure mathematics.

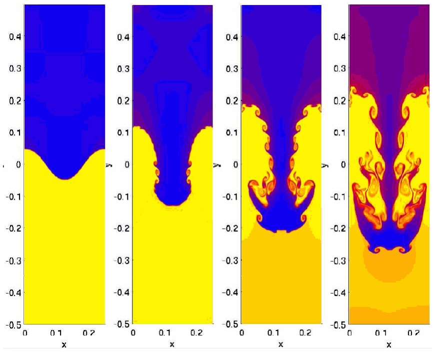
## Divisions



A numerical solution to the heat equation on a pump casing model using the finite element method.

There is no consensus as to what the various branches of applied mathematics are. Such categorizations are made difficult by the way mathematics and science change over time, and also by the way universities organize departments, courses, and degrees.

Historically, applied mathematics consisted principally of applied analysis, most notably differential equations; approximation theory (broadly construed, to include representations, asymptotic methods, variational methods, and numerical analysis); and applied probability. These areas of mathematics were intimately tied to the development of Newtonian physics, and in fact the distinction between mathematicians and physicists was not sharply drawn before the mid-19th century. This history left a legacy as well: until the early 20th century subjects such as classical mechanics were often taught in applied mathematics departments at American universities rather than in physics departments, and fluid mechanics may still be taught in applied mathematics departments.[1] As well as physics, engineering and computer science have traditionally made use of applied mathematics.



Fluid mechanics is often considered a branch of applied mathematics.

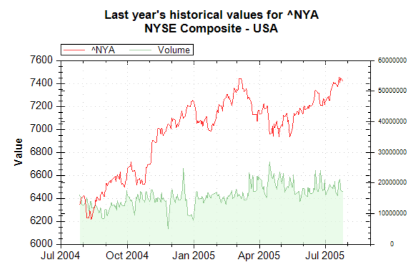
Today, the term *applied mathematics* is used in a broader sense. It includes the classical areas above, as well as other areas that have become increasingly important in applications. Even fields such as number theory that are part of pure mathematics are now important in applications (such as cryptography), though they are not generally considered to be part of the field of applied mathematics *per se*. Sometimes the term *applicable mathematics* is used to distinguish between the traditional applied mathematics that developed alongside physics and the many areas of mathematics that are applicable to real-world problems today.

Many mathematicians distinguish between *applied mathematics*, which is concerned with mathematical methods, and the *applications of mathematics* within science and engineering. A biologist using a population model and applying known mathematics would not be *doing* applied mathematics, but rather *using* it; however mathematical biologists have posed problems that have stimulated the growth of pure mathematics. However, mathematicians like Poincaré and Arnold deny the existence of "applied mathematics" and claim that there are only "applications of mathematics"; similarly, nonmathematicians blend applied mathematics and applications of mathematics. The use and development of mathematics to solve industrial problems is also called *industrial mathematics*.[2]

The success of modern numerical mathematical methods and software has led to the emergence of computational mathematics, computational science, and computational engineering, which use high performance computing for the simulation of phenomena and the solution of problems in the sciences and engineering. These are often considered interdisciplinary disciplines.

## Utility

Historically, mathematics was most important in the natural sciences and engineering. However, since World War II, fields outside of the physical sciences have spawned the creation of new areas of mathematics, such as game theory and social choice theory, which grew out of economic considerations, or neural networks, which arose out of the study of the brain in neuroscience.




Mathematical finance is concerned with the modelling of financial markets.

The advent of the computer has created new applications: studying and using the new computer technology itself (computer science), using computers to study problems arising in other areas of science (computational science), and studying the mathematics of computation (for example, theoretical computer science, computer algebra, numerical analysis). Statistics is probably the most widespread mathematical science used in the social sciences, but other areas of mathematics are proving increasingly useful in these disciplines, most notably in economics.

## Status in academic departments

Academic institutions are not consistent in the way they group and label courses, programs, and degrees in applied mathematics. At some schools, there is a single mathematics department, whereas others have separate departments for Applied Mathematics and (Pure) Mathematics. It is very common for Statistics departments to be separate at schools with graduate programs, but many undergraduate-only institutions include statistics under the mathematics department.

Many applied mathematics programs (as opposed to departments) consist of primarily cross-listed courses and jointly-appointed faculty in departments representing applications. Some Ph.D. programs in applied mathematics require little or no coursework outside of mathematics, while others require substantial coursework in a specific area of application. In some respects this difference reflects the distinction between "application of mathematics" and "applied mathematics".

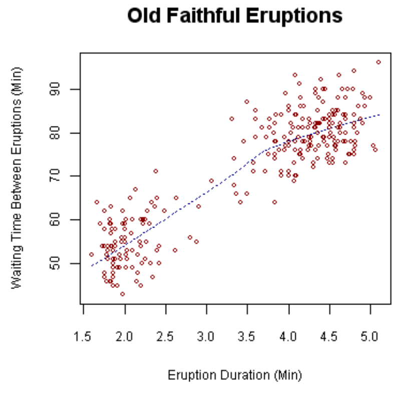
Some universities in the UK host departments of *Applied Mathematics and Theoretical Physics*, but it is now much less common to have separate departments of pure and applied mathematics. A notable exception to this is the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge, housing the Lucasian Professor of Mathematics whose past holders include Isaac Newton, Charles Babbage, James Lighthill, Paul Dirac and Stephen Hawking.

Schools with separate applied mathematics departments range from Brown University, which has a well-known and large Division of Applied Mathematics that offers degrees through the doctorate, to Santa Clara University, which offers only the M.S. in applied mathematics [3] . Research universities dividing their mathematics department into pure and applied sections include Harvard and MIT.

In Canada the only school with an Applied Mathematics program colloquially known as "Apple Math" is Queen's University in the Faculty of Engineering & Applied Science.

## Other associated mathematical sciences

Applied mathematics is closely related to other mathematical sciences.




Applied mathematics has substantial overlap with statistics.

### Scientific computing

Scientific computing includes applied mathematics (especially numerical analysis), computing science (especially high-performance computing), and mathematical modelling in a scientific discipline.

### Computer Science

Computer science relies on logic, algebra, and combinatorics.

### Operations research and management science

Operations research and management science are often taught in faculties of engineering, business, public policy.

### Statistics

Applied mathematics has substantial overlap with the discipline of statistics. Statistical theorists study and improve statistical procedures with mathematics, and statistical research often raises mathematical questions. Statistical theory relies on probability and decision theory, and makes extensive use of scientific computing, analysis, and optimization; for the design of experiments, statisticians use algebra and combinatorial design. Applied mathematicians and statisticians often work in a department of mathematical sciences (particularly at colleges and small universities).

### Actuarial science

Actuarial science uses probability, statistics, and economic theory.

### Economics

A standard classification system in mathematics is the Mathematics Subject Classification (MSC). It is used by many mathematics journals to allow authors to classify their articles. In the MSC Applied mathematics/other classification there is category 91:

> Game theory, economics, social and behavioral sciences.

MSC2010 [4] classifications for 'Game theory' are at 91A here [5]. Classifications for 'Mathematical economics' are at 91B here [6]. In the latter, subjects in economics are listed, as possibly distinguished from mathematical methods that are used to develop them. For example 'Social choice' (91B14) is a subject in economics, but it is developed using methods of mathematical logic.

The *Handbook of Mathematical Economics* series (Elsevier), currently 4 volumes, distinguishes between mathematical methods in economics per 1st-page chapter links in the accompanying footnote[7] and mathematical approaches to different subjects in in economic theory.[8]

Another source with a similar distinction is *The New Palgrave: A Dictionary of Economics* (1987, 4 vols., 1,300 subject entries). In it, a "Subject Index" includes mathematical entries under 2 headings (vol. IV, pp. 982-3):

> Mathematical Economics (24 listed, such as "acyclicity", "aggregation problem", "comparative statics", "lexicographic orderings", "linear models", "orderings", and "qualitative economics")
>
> Mathematical Methods (42 listed, such as "calculus of variations", "catastrophe theory", "combinatorics," "computation of general equilibrium", "convexity", "convex programming", and "stochastic optimal control").

A widely-used classification system in economics that includes mathematical methods on the subject is the JEL classification codes. Articles in journals are usually classified according to the system. It was originated by the *Journal of Economic Literature* for classifying new books and articles. The relevant categories are listed below with the same Wikipedia links at JEL classification codes#Mathematical and quantitative methods JEL: C Subcategories. *The New Palgrave Dictionary of Economics* (2008, 2nd ed.) also uses the JEL codes to classify its entries. The corresponding footnotes below have links to abstracts of *The New Palgrave Online* [9] for each JEL category (10 or fewer per page, similar to Google searches).

- JEL: C02 - Mathematical Methods (following JEL: C00 - General and JEL: C01 - Econometrics)
- JEL: C6 - Mathematical Methods and Programming
  - JEL: C60 - General[10]
  - JEL: C61 - Optimization techniques; Programming models; Dynamic analysis [11]
  - JEL: C62 - Existence and stability conditions of equilibrium[12]
  - JEL: C63 - Computational techniques[13]
  - JEL: C67 - Input–output models

JEL: C68 - Computable General Equilibrium models[14]

JEL: C7 - Game theory and Bargaining theory[15]

JEL: C70 - General[16]

JEL: C71 - Cooperative games[17]

JEL: C72 - Noncooperative games[18]

JEL: C73 - Stochastic and Dynamic games; Evolutionary games; Repeated Games[19]

JEL: C78 - Bargaining theory; Matching theory[20]

Mathematical methods listed in economics texts include those of:

- Alpha C. Chiang and Kevin Wainwright, 2005. *Fundamental Methods of Mathematical Economics*, McGraw-Hill Irwin.. Contents. [21]
- Akira Takayama, 1985. *Mathematical Economics*, 2nd ed. Cambridge. Contents [22].
- Stephen Glaister, 1984. *Mathematical Methods for Economists*, 3rd ed., Blackwell. Contents. [23]
- Michael Carter, 2001. *Foundations of Mathematical Economics*, MIT Press. Contents [24].
- D. Wade Hands, 2004. *Introductory Mathematical Economics*, 2nd ed. Oxford. Contents [25].

### Other disciplines

The line between applied mathematics and specific areas of application is often blurred. Many universities teach mathematical and statistical courses outside of the respective departments, in departments and areas including business, engineering, physics, chemistry, psychology, biology, computer science, and mathematical physics.

## References

[1] Stolz, M. (2002), "The History Of Applied Mathematics And The History Of Society" (http://www.springerlink.com/index/T152575218M865W4.pdf), *Synthese* **133** (1): 43–57, doi:10.1023/A:1020823608217, , retrieved 2009-07-07

[2] University of Strathclyde (17 January 2008), *Industrial Mathematics* (http://www.maths.strath.ac.uk/applying/postgraduate/research_topics/industrial_mathematics), , retrieved 8 January 2009

[3] *Santa Clara University Dept of Applied Mathematics* (http://www.scu.edu/academics/bulletins/undergraduate/Department-of-Applied-Mathematics.cfm), , retrieved 2011-03-05

[4] http://msc2010.org/mscwiki/index.php?title=MSC2010

[5] http://msc2010.org/mscwiki/index.php?title=91Axx

[6] http://msc2010.org/mscwiki/index.php?title=91Bxx

[7] Kenneth J. Arrow and Michael D. Intriligator, ed. (1981), *Handbook of Mathematical Economics*, v. 1 (http://www.sciencedirect.com/science/handbooks/15734382/1).

[8] • Kenneth J. Arrow and Michael D. Intriligator, ed. (1982). *Handbook of Mathematical Economics*, v. 2 (http://www.sciencedirect.com/science/handbooks/15734382/2).

• _____ (1986). *Handbook of Mathematical Economics*, v. 3 (http://www.sciencedirect.com/science/handbooks/15734382/3).

• Hildenbrand, Werner, and Hugo Sonnenschein, ed. (1991). *Handbook of Mathematical Economics*, v. 4 (http://www.sciencedirect.com/science/handbooks/15734382).

[9] http://www.dictionaryofeconomics.com/dictionary

[10] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C6

[11] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C61

[12] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C62

[13] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C63

[14] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C68

[15] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C7

[16] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C70

[17] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C71

[18] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C72

[19] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C73

[20] http://www.dictionaryofeconomics.com/search_results?q=&field=content&edition=all&topicid=C78

[21] http://www.mhprofessional.com/product.php?isbn=0070109109

[22] http://books.google.com/books?id=685iPEaLAEcC&printsec=find&pg=PR9=onepage&q&f=false#v=onepage&q&f=false

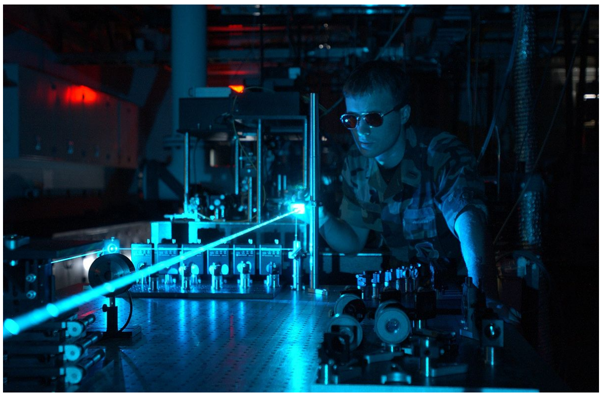
[23] http://books.google.com/books?id=Ct2nrJSHxsQC&printsec=find&pg=PR5=onepage&q&f=false#v=onepage&q&f=false
[24] http://books.google.sh/books?id=KysvrGGfzq0C&printsec=find&pg=PR7=onepage&q&f=false
[25] http://www.oup.com/us/catalog/he/subject/Economics/OtherCourses/MathematicalEconomics/?view=usa&sf=toc&ci=9780195133783

## External links

- The Society for Industrial and Applied Mathematics (http://www.siam.org/) (SIAM) is a professional society dedicated to promoting the interaction between mathematics and other scientific and technical communities. Aside from organizing and sponsoring numerous conferences, SIAM is a major publisher of research journals and books in applied mathematics.

# Applied physics

**Applied physics** is a general term for physics which is intended for a particular technological or practical use.[1] It is usually considered as a bridge or a connection between "pure" physics and engineering.[2]

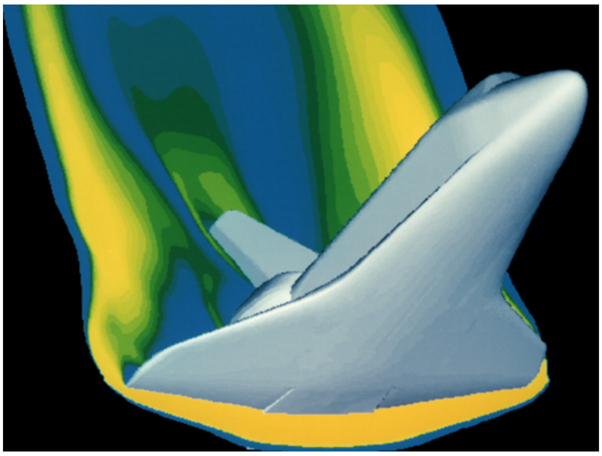


Experiment using a laser

"Applied" is distinguished from "pure" by a subtle combination of factors such as the motivation and attitude of researchers and the nature of the relationship to the technology or science that may be affected by the work.[3] It usually differs from engineering in that an applied physicist may not be designing something in particular, but rather is using physics or conducting physics research with the aim of developing new technologies or solving an engineering problem. This approach is similar to that of applied mathematics. In other words, applied physics is rooted in the fundamental truths and basic concepts of the physical sciences but is concerned with the utilization of these scientific principles in practical devices and systems.[4]

A magnetic resonance image

Applied physicists can also be interested in the use of physics for scientific research. For instance, people working on accelerator physics seek to build better accelerators for research in theoretical physics.



Computer modeling of the space shuttle during re-entry

## Fields and areas of research

- Accelerator physics
- Acoustics
- Agrophysics
- Analog Electronics
- Force microscopy and imaging
- Ballistics
- Biophysics
- Communication Physics
- Computational physics
- Control Theory
- Digital Electronics
- Econophysics
- Engineering physics
- Fiber Optics
- Fluid dynamics
- Geophysics
- Laser physics
- Medical physics
- Metrological Physics
- Microfluidics
- Nanotechnology
- Nondestructive testing
- Nuclear engineering
- Nuclear technology
- Optics
- Optoelectronics
- Photovoltaics
- Plasma physics
- Quantum electronics
- Semiconductor physics and devices
- Soil Physics
- Solid state physics
- Space physics
- Spintronics
- Superconductors
- Vehicle dynamics

## Journals by publisher

- American Institute of Physics
  - Journal of Applied Physics
  - Applied Physics Letters
- Japan Society of Applied Physics
  - Japanese Journal of Applied Physics
  - Applied Physics Express
- IOP Publishing
  - Journal of Physics D: Applied Physics
- Springer

- Applied Physics (journal)
- Applied Physics A
- Applied Physics B

## Institutions/organizations

- International Union of Pure and Applied Physics
- Harvard School of Engineering and Applied Sciences
- Applied Physics Laboratory, John Hopkins University
- School of Pure and Applied Physics, Mahatma Gandhi University
- Institute of Applied Physics and Computational Mathematics, Beijing, China
- Institute of Applied Physics, National Academy of Sciences of Ukraine

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[1] "Applied Physics" (http://www.articleworld.org/index.php/Applied_physics). *ArticleWorld*. . Retrieved 10 September 2011.
[2] "Applied Physics at Caltech - Overview" (http://www.aph.caltech.edu/overview.html). Caltech. . Retrieved 10 September 2011.
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# Archaeology

**Archaeology**, or **archeology**[1] (from Greek ἀρχαιολογία, *archaiologia* – ἀρχαῖος, *arkhaios*, "ancient"; and -λογία, *-logia*, "-logy[2] "), is the study of human society, primarily through the recovery and analysis of the material culture and environmental data that they have left behind, which includes artifacts, architecture, biofacts and cultural landscapes (the archaeological record). Because archaeology employs a wide range of different procedures, it can be considered to be both a science and a humanity,[3] and in the United States it is thought of as a branch of anthropology,[4] although in Europe it is viewed as a separate discipline.


Excavations at the site of Gran Dolina, in the Atapuerca Mountains, Spain, 2008

Archaeology studies human history from the development of the first stone tools in eastern Africa 3.4 million years ago up until recent decades.[5] (Archaeology does not include the discipline of paleontology.) It is of most importance for learning about prehistoric societies, when there are no written records for historians to study, making up over 99% of total human history, from the Palaeolithic until the advent of literacy in any given society.[3] Archaeology has various goals, which range from studying human evolution to cultural evolution and understanding culture history.[6]

The discipline involves surveyance, excavation and eventually analysis of data collected to learn more about the past. In broad scope, archaeology relies on cross-disciplinary research. It draws upon anthropology, history, art history, classics, ethnology, geography,[7] geology,[8] [9] [10] linguistics, physics, information sciences, chemistry, statistics, paleoecology, paleontology, paleozoology, paleoethnobotany, and paleobotany.

Archaeology developed out of antiquarianism in Europe during the 19th century, and has since become a discipline practiced across the world. Since its early development, various specific sub-disciplines of archaeology have developed, including maritime archaeology, feminist archaeology and archaeoastronomy, and numerous different scientific techniques have been developed to aid archaeological investigation. Nonetheless, today, archaeologists face many problems, ranging from dealing with pseudoarchaeology to the looting of artifacts and opposition to the excavation of human remains.

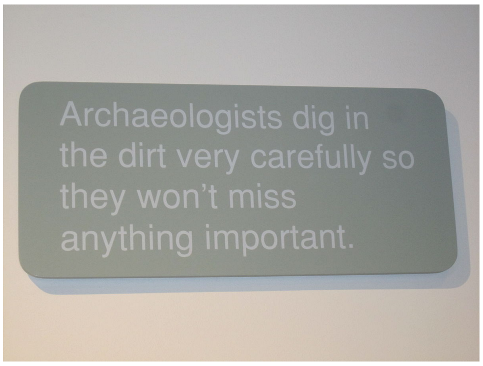
## Purpose

The skull of the Taung child, uncovered in South Africa. The Child was an infant of the *Australopithecus africanus* species, an early form of hominin

The purpose of archaeology is to learn more about past societies and the development of the human race. Over 99% of the history of humanity has occurred within prehistoric cultures, who did not make use of writing, thereby not leaving written records about themselves that we can study today. Without such written sources, the only way to learn about prehistoric societies is to use archaeology. Many important developments in human history occurred during prehistory, including the evolution of humanity during the Palaeolithic period, when the hominins developed from the australopithecines through to the early homos in Africa and finally into modern *Homo sapiens*. Archaeology also sheds light on many of humanity's technological advances, for instance the ability to use fire, the development of stone tools, the discovery of metallurgy, the beginnings of religion and the creation of agriculture. Without archaeology, we would know nothing of these evolutionary and technological changes in humanity that pre-date writing.[11]

However, it is not only prehistoric, pre-literate cultures that can be studied using archaeology but historic, literate cultures as well, through the sub-discipline of historical archaeology. For many literate cultures, such as Ancient Greece and Mesopotamia, their surviving records are often incomplete and biased to some extent. In many societies, literacy was restricted to the elite classes, such as the clergy or the bureaucracy of court or temple. The literacy even of aristocrats has sometimes been restricted to deeds and contracts. The interests and world-view of elites are often quite different from the lives and interests of the populace. Writings that were produced by people more representative of the general population were unlikely to find their way into libraries and be preserved there for posterity. Thus, written records tend to reflect the biases, assumptions, cultural values and possibly deceptions of a limited range of individuals, usually a small fraction of the larger population. Hence, written records cannot be trusted as a sole source. The material record may be closer to a fair representation of society, though it is subject to its own biases, such as sampling bias and differential preservation.[12]

### Theory




Sign at Lubbock Lake Landmark in Lubbock, Texas

There is no one singular approach to archaeological theory that has been adhered to by all archaeologists. When archaeology developed in the late 19th century, the first approach to archaeological theory to be practiced was that of cultural-history archaeology, which held the goal of explaining why cultures changed and adapted rather than just highlighting the fact that they did, therefore emphasizing historical particularism.[13] In the early 20th century, many archaeologists who studied past societies with direct continuing links to existing ones (such as those of Native Americans, Siberians, Mesoamericans etc.) followed the direct historical approach, compared the continuity between the past and contemporary ethnic and cultural groups.[13] In the 1960s, an archaeological movement largely led by American archaeologists like Lewis Binford and Kent Flannery arose that rebelled against the established cultural-history archaeology.[14] [15] They proposed a "New Archaeology", which would be more "scientific" and "anthropological", with hypothesis testing and the scientific method very important parts of what became known as processual archaeology.[13]

In the 1980s, a new postmodern movement arose led by the British archaeologists Michael Shanks,[16] [17] [18] [19] Christopher Tilley,[20] Daniel Miller,[21] [22] and Ian Hodder,[23] [24] [25] [26] [27] [28] which has become known as post-processual archaeology. It questioned processualism's appeals to scientific positivism and impartiality, and emphasised the importance of a more self-critical theoretical reflexivity. However, this approach has been criticized by processualists as lacking scientific rigor, and the validity of both processualism and post-processualism is still under debate. Meanwhile, another theory, known as historical processualism has emerged seeking to incorporate a focus on process and post-processual archaeology's emphasis of reflexivity and history.[29]

Archaeological theory now borrows from a wide range of influences, including neo-Darwinian evolutionary thought, phenomenology, postmodernism, agency theory, cognitive science, Functionalism, gender-based and Feminist archaeology, and Systems theory.

## Methods

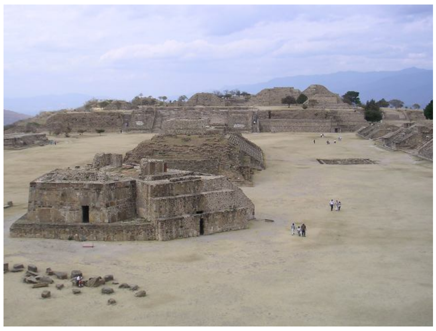
An archaeological investigation usually involves several distinct phases, each of which employs its own variety of methods. Before any practical work can begin however, a clear objective as to what the archaeologists are looking to achieve must be agreed upon. This done, a site is surveyed to find out as much as possible about it and the surrounding area. Second, an excavation may take place to uncover any archaeological features buried under the ground. And, third, the data collected from the excavation is studied and evaluated in an attempt to achieve the original research objectives of the archaeologists. It is then considered good practice for the information to be published so that it is available to other archaeologists and historians, although this is sometimes neglected.[30]

## Remote sensing

Before actually starting to dig in a location, satellite imagery can be used to look where sites are located within a large area.[31]

## Field survey

The archaeological project then continues (or alternatively, starts with) with a field survey. Regional survey is the attempt to systematically locate previously unknown sites in a region. Site survey is the attempt to systematically locate features of interest, such as houses and middens, within a site. Each of these two goals may be accomplished with largely the same methods.



Monte Alban archaeological site

Survey was not widely practiced in the early days of archaeology. Cultural historians and prior researchers were usually content with discovering the locations of monumental sites from the local populace, and excavating only the plainly visible features there. Gordon Willey pioneered the technique of regional settlement pattern survey in 1949 in the Viru Valley of coastal Peru,[32] [33] and survey of all levels became prominent with the rise of processual archaeology some years later.[34]

Survey work has many benefits if performed as a preliminary exercise to, or even in place of, excavation. It requires relatively little time and expense, because it does not require processing large volumes of soil to search out artifacts. (Nevertheless, surveying a large region or site can be expensive, so archaeologists often employ sampling methods.)[35] As with other forms of non-destructive archaeology, survey avoids ethical issues (of particular concern to descendant peoples) associated with destroying a site through excavation. It is the only way to gather some forms of information, such as settlement patterns and settlement structure. Survey data are commonly assembled into maps, which may show surface features and/or artifact distribution.

The simplest survey technique is surface survey. It involves combing an area, usually on foot but sometimes with the use of mechanized transport, to search for features or artifacts visible on the surface. Surface survey cannot detect sites or features that are completely buried under earth, or overgrown with vegetation. Surface survey may also include mini-excavation techniques such as augers, corers, and shovel test pits. If no materials are found, the area surveyed is deemed sterile.

Aerial survey is conducted using cameras attached to airplanes, balloons, or even Kites. A bird's-eye view is useful for quick mapping of large or complex sites. Aerial photographs are used to document the status of the archaeological dig. Aerial imaging can also detect many things not visible from the surface. Plants growing above a buried man made structure, such as a stone wall, will develop more slowly, while those above other types of features (such as middens) may develop more rapidly. Photographs of ripening grain, which changes colour rapidly at maturation, have revealed buried structures with great precision. Aerial photographs taken at different times of day will help show the outlines of structures by changes in shadows. Aerial survey also employs infrared, ground-penetrating radar wavelengths, LiDAR and thermography.

Geophysical survey can be the most effective way to see beneath the ground. Magnetometers detect minute deviations in the Earth's magnetic field caused by iron artifacts, kilns, some types of stone structures, and even ditches and middens. Devices that measure the electrical resistivity of the soil are also widely used. Archaeological features whose electrical resistivity contrasts with that of surrounding soils can be detected and mapped. Some archaeological features (such as those composed of stone or brick) have higher resistivity than typical soils, while others (such as organic deposits or unfired clay) tend to have lower resistivity.

Although some archaeologists consider the use of metal detectors to be tantamount to treasure hunting, others deem them an effective tool in archaeological surveying. Examples of formal archaeological use of metal detectors include musketball distribution analysis on English Civil War battlefields, metal distribution analysis prior to excavation of a 19th century ship wreck, and service cable location during evaluation. Metal detectorists have also contributed to archaeology where they have made detailed records of their results and refrained from raising artifacts from their archaeological context. In the UK, metal detectorists have been solicited for involvement in the Portable Antiquities Scheme.

Regional survey in underwater archaeology uses geophysical or remote sensing devices such as marine magnetometer, side-scan sonar, or sub-bottom sonar.

## Excavation


Excavations at the 3800-year-old Edgewater Park Site, Iowa

Archaeological excavation existed even when the field was still the domain of amateurs, and it remains the source of the majority of data recovered in most field projects. It can reveal several types of information usually not accessible to survey, such as stratigraphy, three-dimensional structure, and verifiably primary context.

Modern excavation techniques require that the precise locations of objects and features, known as their provenance or provenience, be recorded. This always involves determining their horizontal locations, and sometimes vertical position as well (also see Primary Laws of Archaeology). Likewise, their association, or relationship with nearby objects and features, needs to be recorded for later analysis. This allows the archaeologist to deduce which artifacts and features were likely used together and which may be from different phases of activity. For example, excavation of a site reveals its stratigraphy; if a site was occupied by a succession of distinct cultures, artifacts from more recent cultures will lie above those from more ancient cultures.


Archaeological excavation that discovered prehistoric caves in Vill (Innsbruck), Austria

Excavation is the most expensive phase of archaeological research, in relative terms. Also, as a destructive process, it carries ethical concerns. As a result, very few sites are excavated in their entirety. Again the percentage of a site excavated depends greatly on the country and "method statement" issued. In places 90% excavation is common. Sampling is even more important in excavation than in survey. It is common for large mechanical equipment, such as backhoes (JCBs), to be used in excavation, especially to remove the topsoil (overburden), though this method is increasingly used with great caution. Following this rather dramatic step, the exposed area is usually hand-cleaned with trowels or hoes to ensure that all features are apparent.

The next task is to form a site plan and then use it to help decide the method of excavation. Features dug into the natural subsoil are normally excavated in portions to produce a visible archaeological section for recording. A feature, for example a pit or a ditch, consists of two parts: the cut and the fill. The cut describes the edge of the feature, where the feature meets the natural soil. It is the feature's boundary. The fill is what the feature is filled with, and will often appear quite distinct from the natural soil. The cut and fill are given consecutive numbers for recording purposes. Scaled plans and sections of individual features are all drawn on site, black and white and colour photographs of them are taken, and recording sheets are filled in describing the context of each. All this information serves as a permanent record of the now-destroyed archaeology and is used in describing and interpreting the site.


An archaeologist sifting for POW remains on Wake Island.

### Analysis

Once artifacts and structures have been excavated, or collected from surface surveys, it is necessary to properly study them, to gain as much data as possible. This process is known as post-excavation analysis, and is usually the most time-consuming part of the archaeological investigation. It is not uncommon for the final excavation reports on major sites to take years to be published.

At its most basic, the artifacts found are cleaned, cataloged and compared to published collections, to classify them typologically and to identify other sites with similar artifact assemblages. However, a much more comprehensive range of analytical techniques are available through archaeological science, meaning that artifacts can be dated and their compositions examined. The bones, plants and pollen collected from a site can all be analyzed (using the techniques of zooarchaeology, paleoethnobotany, and palynology), while any texts can usually be deciphered.

These techniques frequently provide information that would not otherwise be known and therefore contribute greatly to the understanding of a site.

### Virtual archaeology

Some time around 1995 archaeologists started using computer graphics to build virtual 3D models of sites such as the throne room of an ancient Assyrian palace or ancient Rome.[36] This is done by collecting normal photographs and using computer graphics to build the virtual 3D model.[36] In more general terms, computers can be used to recreate the environment and conditions of the past, such as objects, buildings, landscapes and even ancient battles.[36] Computer simulation can be used to simulate the living conditions of an ancient community and to see how it would have reacted to various scenarios (such as how much food to grow, how many animals to slaughter, etc.)[36] Computer-built topographical models have been combined with astronomical calculations to verify whether or not certain structures (such as pillars) were aligned with astronomical events such as the sun's position at a solstice.[36]

## Academic sub-disciplines

As with most academic disciplines, there are a very large number of archaeological sub-disciplines characterised by a specific method or type of material (e.g., lithic analysis, music, archaeobotany), geographical or chronological focus (e.g. Near Eastern archaeology, Islamic archaeology, Medieval archaeology), other thematic concern (e.g. maritime archaeology, landscape archaeology, battlefield archaeology), or a specific archaeological culture or civilisation (e.g. Egyptology, Indology, Sinology).

### Historical archaeology

Historical archaeology is the study of cultures with some form of writing.

In England, archaeologists have uncovered the long-lost layouts of medieval villages abandoned after the crises of the 14th century and the equally lost layouts of 17th century parterre gardens swept away by a change in fashion. In downtown New York City archaeologists have exhumed the 18th century remains of the African burial ground.

### Ethnoarchaeology

Ethnoarchaeology is the archaeological study of living people.[37] [38] [39] [40] [41] [42] The approach gained notoriety during the emphasis on middle range theory that was a feature of the processual movement of the 1960s. Early ethnoarchaeological research focused on hunting and gathering or foraging societies. Ethnoarchaeology continues to be a vibrant component of post-processual and other current archaeological approaches.[43] [44] [45] [46] Ethnoarchaeology is the use of ethnography to increase and improve analogs, which are then used as analogies to interpret the archaeological record. In short, ethnoarchaeology is the application of ethnography to archaeology.[47]

### Experimental archaeology

Experimental archaeology represents the application of the experimental method to develop more highly controlled observations of processes that create and impact the archaeological record.[48] [49] [50] [51] [52] In the context of the logical positivism of processualism with its goals of improving the scientific rigor of archaeological epistemologies the experimental method gained importance. Experimental techniques remain a crucial component to improving the inferential frameworks for interpreting the archaeological record.

### Archaeometry

Archaeometry is a field of study that aims to systematize archaeological measurement. It emphasizes the application of analytical techniques from physics, chemistry, and engineering. It is a lively field of research that frequently focuses on the definition of the chemical composition of archaeological remains for source analysis.[53] Archaeometry also investigates different spatial characteristics of features, employing such methods as space syntax and geodesy, which can be analyzed using computer-based geographic information system technologies. A relatively nascent subfield is that of archaeological materials, designed to enhance understanding of prehistoric and non-industrial culture through scientific analysis of the structure and properties of materials associated with human activity.[54]

### Cultural resources management

While archaeology can be done as a pure science, it can also be an applied science, namely the study of archaeological sites that are threatened by development. In such cases, archaeology is a subsidiary activity within Cultural resources management (CRM), also called heritage management in the United Kingdom.[55] Today, CRM accounts for most of the archaeological research done in the United States and much of that in western Europe as well. In the US, CRM archaeology has been a growing concern since the passage of the National Historic Preservation Act (NHPA) of 1966, and most taxpayers, scholars, and politicians believe that CRM has helped preserve much of that nation's history and prehistory that would have otherwise been lost in the expansion of cities, dams, and highways. Along with other statutes, the NHPA mandates that projects on federal land or involving federal funds or permits consider the effects of the project on each archaeological site.

The application of CRM in the United Kingdom is not limited to government-funded projects. Since 1990 PPG 16[56] has required planners to consider archaeology as a material consideration in determining applications for new development. As a result, numerous archaeological organisations undertake mitigation work in advance of (or during) construction work in archaeologically sensitive areas, at the developer's expense.

In England, ultimate responsibility of care for the historic environment rests with the Department for Culture, Media and Sport[57] in association with English Heritage.[58] In Scotland, Wales and Northern Ireland, the same responsibilities lie with Historic Scotland,[59] Cadw[60] and the Northern Ireland Environment Agency[61] respectively.

Among the goals of CRM are the identification, preservation, and maintenance of cultural sites on public and private lands, and the removal of culturally valuable materials from areas where they would otherwise be destroyed by human activity, such as proposed construction. This study involves at least a cursory examination to determine whether or not any significant archaeological sites are present in the area affected by the proposed construction. If these do exist, time and money must be allotted for their excavation. If initial survey and/or test excavation indicates the presence of an extraordinarily valuable site, the construction may be prohibited entirely. CRM is a thriving entity, especially in the United States and Europe where archaeologists from private companies and all levels of government engage in the practice of their discipline.

Cultural resources management has, however, been criticized. CRM is conducted by private companies that bid for projects by submitting proposals outlining the work to be done and an expected budget. It is not unheard-of for the agency responsible for the construction to simply choose the proposal that asks for the least funding. CRM archaeologists face considerable time pressure, often being forced to complete their work in a fraction of the time that might be allotted for a purely scholarly endeavor. Compounding the time pressure is the vetting process of site reports that are required (in the US) to be submitted by CRM firms to the appropriate State Historic Preservation Office (SHPO). From the SHPO's perspective there is to be no difference between a report submitted by a CRM firm operating under a deadline, and a multi-year academic project. The end result is that for a Cultural Resource Management archaeologist to be successful, they must be able to produce academic quality documents at a corporate world pace.

The annual ratio of open academic archaeology positions (inclusive of Post-Doc, temporary, and non tenure track appointments) to the annual number of archaeology MA/MSc and PhD students is grossly disproportionate. This dearth of academic positions causes a predictable excess of well educated individuals who join the ranks of the following year's crop of non-academically employed archaeologists. Cultural Resource Management, once considered an intellectual backwater for individuals with "strong backs and weak minds"[62] has reaped the benefit of this massive pool of well educated professionals. This results in CRM offices increasingly staffed by advance degreed individuals with a track record of producing scholarly articles but who have the notches on their trowels to show they have been in the trenches as a shovelbum.

## History of archaeology

Flavio Biondo, an Italian Renaissance humanist historian, created a systematic and documented guide to the ruins and topography of ancient Rome in the early 15th century for which he has been called an early founder of archaeology. Ciriaco de' Pizzicolli or Cyriacus of Ancona (31 July 1391 — 1453/55) was a restlessly itinerant Italian humanist who came from a prominent family of merchants in Ancona. Ciriaco traveled all around the Eastern Mediterranean, noting down his archaeological discoveries in his day-book, *Commentaria,* that eventually filled six volumes. He has been called *father of archaeology*.

After that, modern archaeology has its origins in the antiquarianism of Europe in the mid-19th century, where it developed soon after the scientific advancement of geology, which had shown that the Earth was billions rather than thousands of years old, as was then commonly believed. Soon after this, in 1859, Charles Darwin's *On the Origin of Species* was published, outlining his theory of evolution, eventually leading scientists to believe that humanity was in fact millions of years old, thereby providing a time limit within which the burgeoning archaeological movement could study. Meanwhile, in 1836 the Danish historian Christian Jürgensen Thomsen published *A Ledetraad til Nordisk Oldkyndighed* (*Guideline to Scandinavian Antiquity*) translated into English in 1848, in which he proposed the idea that collections of European artifacts from prehistory could be divided up into a three age system: the Stone

Age, Bronze Age and Iron Age.Thomsen was not the first scholar to propose the three age system (that idea dated back to Greek and Roman thinkers), but he was the first to apply these categories to material culture, and with that innovation came significant advances in the concept of seriation, or stylistic changes through time.[63]

It was these three concepts of human antiquity, evolution and the Three-Age system that are often thought of as the building blocks for modern archaeology.[64]

Howard Carter in the Pharaon Tutankhamen's tomb, 1924

Soon the early archaeologists began to investigate various areas around the world, with the study of ancient Aegean civilization being stimulated by the excavations of Heinrich Schliemann at Troy, and of Arthur Evans at Crete, whilst John Lloyd Stephens was a pivotal figure in the rediscovery of Maya civilization throughout Central America. However, the methodologies employed by these archaeologists were highly flawed by today's standards, often having a eurocentric bias, and many early European archaeologists often relied on anthropological and ethnographic accounts provided by the likes of Edward Tylor and Lewis Henry Morgan, thereby comparing contemporary "savage" peoples like the Native Americans with the historical peoples of Europe who lived in similar societies.[65] Soon the new discipline of archaeology spread to North America, where it was taken up by figures like Samuel Haven and William Henry Holmes, who excavated ancient Native American monuments.[66]

Further advancements in archaeological field methodology arose in the late 19th century. One of the pioneering figures in this was Augustus Pitt Rivers, who meticulously excavated on Cranborne Chase in southern England, emphasising that it was not only items of beauty or value that should be recorded but mundane items as well; he therefore helped to differentiate archaeology from antiquarianism. Other important archaeologists who further refined the discipline in the late 19th and early 20th centuries were Flinders Petrie (who excavated in Egypt and Palestine), Sir Mortimer Wheeler (India), Dorothy Garrod (the Middle East), Max Uhle (Peru) and Alfred Kidder (Mexico).[67] Further adaptation and innovation in archaeology continued throughout the 20th century, in particular in the 1960s, when maritime archaeology was popularised by George Bass, urban archaeology became more prevalent with redevelopment in many European cities, and rescue archaeology was developed as a result of increasing commercial development.[67]

## Popular views of archaeology

Extensive excavations at Beit She'an, Israel

Early archaeology was largely an attempt to uncover spectacular artifacts and features, or to explore vast and mysterious abandoned cities. Such pursuits continue to fascinate the public. Books, films, and video games, such as *The City of Brass*, *King Solomon's Mines*, *Indiana Jones*, *Tomb Raider*, *The Mummy* and *Relic Hunter* all testify to the public's interest in the discovery aspect of archaeology.

Much thorough and productive research has indeed been conducted in dramatic locales such as Copán and the Valley of the Kings, but the bulk of activities and finds of modern archaeology is not so sensational. Archaeological adventure stories tend to ignore the painstaking work involved in carrying out modern survey, excavation, and data processing. Some archaeologists refer to such off the mark portrayals as "pseudoarchaeology".[68]

Archaeology has been portrayed in the mainstream media in sensational ways. This has its advantages and disadvantages. Many practitioners point to the childhood excitement of Indiana Jones films as the inspiration for them to enter the field.[69] [70] Archaeologists are also very much reliant on public support, the question of exactly who they are doing their work for is often discussed.[71]

## Current issues and controversy

### Public archaeology

Motivated by a desire to halt looting, curb pseudoarchaeology, and to help preserve archaeological sites through education and fostering public appreciation for the importance of archaeological heritage, archaeologists are mounting public-outreach campaigns.[72] They seek to stop looting by combatting people who illegally take artifacts from protected sites, and by alerting people who live near archaeological sites of the threat of looting. Common methods of public outreach include press releases, and the encouragement of school field trips to sites under excavation by professional archaeologists. Public appreciation of the significance of archaeology and archaeological sites often leads to improved protection from encroaching development or other threats.

One audience for archaeologists' work is the public. They increasingly realize that their work can benefit non-academic and non-archaeological audiences, and that they have a responsibility to educate and inform the public about archaeology. Local heritage awareness is aimed at increasing civic and individual pride through projects such as community excavation projects, and better public presentations of archaeological sites and knowledge. The U.S.Dept. of Agriculture, Forest Service(USFS) operates a volunteer archaeology and historic preservation program called the Passport in Time (PIT). Volunteers work with professional USFS archaeologists and historians on national forests throughout the U.S. Volunteers are involved in all aspects of professional archaeology under expert supervision.[73]

In the UK, popular archaeology programs such as *Time Team* and *Meet the Ancestors* have resulted in a huge upsurge in public interest. Where possible, archaeologists now make more provisions for public involvement and outreach in larger projects than they once did, and many local archaeological organizations operate within the Community archaeology framework to expand public involvement in smaller-scale, more local projects. Archaeological excavation, however, is best undertaken by well-trained staff that can work quickly and accurately. Often this requires observing the necessary health and safety and indemnity insurance issues involved in working on a modern building site with tight deadlines. Certain charities and local government bodies sometimes offer places on research projects either as part of academic work or as a defined community project. There is also a flourishing industry selling places on commercial training excavations and archaeological holiday tours.

Archaeologists prize local knowledge and often liaise with local historical and archaeological societies, which is one reason why Community archaeology projects are starting to become more common. Often archaeologists are assisted by the public in the locating of archaeological sites, which professional archaeologists have neither the funding, nor the time to do.

### Pseudoarchaeology

Pseudoarchaeology is an umbrella term for all activities that claim to be archaeological but in fact violate commonly accepted and scientific archaeological practices. It includes much fictional archaeological work (discussed above), as well as some actual activity. Many non-fiction authors have ignored the scientific methods of processual archaeology, or the specific critiques of it contained in post-processualism.

An example of this type is the writing of Erich von Däniken. His 1968 book, *Chariots of the Gods?*, together with many subsequent lesser-known works, expounds a theory of ancient contacts between human civilisation on Earth and more technologically advanced extraterrestrial civilisations. This theory, known as palaeocontact theory, or Ancient astronaut theory, is not exclusively Däniken's, nor did the idea originate with him. Works of this nature are usually marked by the renunciation of well-established theories on the basis of limited evidence and the interpretation of evidence with a preconceived theory in mind.

## Looting

A looter's pit on the morning following its excavation, taken at Rontoy, Huaura Valley, Peru in June 2007. Several small holes left by looters' prospecting probes can be seen, as well as their footprints.

Looting of archaeological sites is an ancient problem. For instance, many of the tombs of the Egyptian pharaohs were looted during antiquity.[74] Archaeology stimulates interest in ancient objects, and people in search of artifacts or treasure cause damage to archaeological sites. The commercial and academic demand for artifacts unfortunately contributes directly to the illicit antiquities trade. Smuggling of antiquities abroad to private collectors has caused great cultural and economic damage in many countries whose governments lack the resources and or the will to deter it. Looters damage and destroy archaeological sites, denying future generations information about their ethnic and cultural heritage. Indigenous peoples especially lose access to and control over their 'cultural resources', ultimately denying them the opportunity to know their past.[75]

Popular consciousness often associates looting with poor Third World countries, but this is a false assumption.[75] A lack of financial resources and political will are chronic worldwide problems inhibiting more effective protection of archaeological sites. Many Native American Indians today, such as Vine Deloria, Jr., consider any removal of cultural artifacts from a Native American Indian site to be theft, and much of professional archaeology as academic looting.

Stela of a king named Adad-Nirari. Object stolen from the Iraq National Museum in the looting in connection with the Iraq war of 2003.

In 1937 W. F. Hodge the Director of the Southwest Museum in Los Angeles CA, released a statement that the museum would no longer purchase or accept collections from looted contexts.[76] The first conviction of the transport of artifacts illegally removed from private property under the Archaeological Resources Protection Act (ARPA; Public Law 96-95; 93 Statute 721; [[Title 16 of the United States Code|16 U.S.C. [77]] § 470aamm [78])] was in 1992 in the State of Indiana.[79]

## Descendant peoples

In the United States, examples such as the case of Kennewick Man have illustrated the tensions between Native Americans and archaeologists, which can be summarized as a conflict between a need to remain respectful toward sacred burial sites and the academic benefit from studying them. For years, American archaeologists dug on Indian burial grounds and other places considered sacred, removing artifacts and human remains to storage facilities for further study. In some cases human remains were not even thoroughly studied but instead archived rather than reburied. Furthermore, Western archaeologists' views of the past often differ from those of tribal peoples. The West views time as linear; for many natives, it is cyclic. From a Western perspective, the past is long-gone; from a native perspective, disturbing the past can have dire consequences in the present.

As a consequence of this, American Indians attempted to prevent archaeological excavation of sites inhabited by their ancestors, while American archaeologists believed that the advancement of scientific knowledge was a valid reason to continue their studies. This contradictory situation was addressed by the Native American Graves

Protection and Repatriation Act (NAGPRA, 1990), which sought to reach a compromise by limiting the right of research institutions to possess human remains. Due in part to the spirit of postprocessualism, some archaeologists have begun to actively enlist the assistance of indigenous peoples likely to be descended from those under study.

Archaeologists have also been obliged to re-examine what constitutes an archaeological site in view of what native peoples believe to constitute sacred space. To many native peoples, natural features such as lakes, mountains or even individual trees have cultural significance. Australian archaeologists especially have explored this issue and attempted to survey these sites to give them some protection from being developed. Such work requires close links and trust between archaeologists and the people they are trying to help and at the same time study.

While this cooperation presents a new set of challenges and hurdles to fieldwork, it has benefits for all parties involved. Tribal elders cooperating with archaeologists can prevent the excavation of areas of sites that they consider sacred, while the archaeologists gain the elders' aid in interpreting their finds. There have also been active efforts to recruit aboriginal peoples directly into the archaeological profession.

### Repatriation

*See Repatriation and reburial of human remains*

A new trend in the heated controversy between First Nations groups and scientists is the repatriation of native artifacts to the original descendants. An example of this occurred June 21, 2005, when community members and elders from a number of the 10 Algonquian nations in the Ottawa area convened on the Kitigan Zibi reservation near Maniwaki, Quebec, to inter ancestral human remains and burial goods — some dating back 6,000 years. It was not determined, however, if the remains were directly related to the Algonquin people who now inhabit the region. The remains may be of Iroquoian ancestry, since Iroquoian people inhabited the area before the Algonquin. Moreover, the oldest of these remains might have no relation at all to the Algonquin or Iroquois, and belong to an earlier culture who previously inhabited the area.

The remains and artifacts, including jewelry, tools and weapons, were originally excavated from various sites in the Ottawa Valley, including Morrison and the Allumette Islands. They had been part of the Canadian Museum of Civilization's research collection for decades, some since the late 19th century. Elders from various Algonquin communities conferred on an appropriate reburial, eventually deciding on traditional redcedar and birchbark boxes lined with redcedar chips, muskrat and beaver pelts.

Now, an inconspicuous rock mound marks the reburial site where close to 80 boxes of various sizes are buried, no further scientific study is possible. Although negotiations were at times tense between the Kitigan Zibi community and museum, they were able to reach agreement.[80]

Kennewick Man is another repatriation candidate that has been the source of heated debate.

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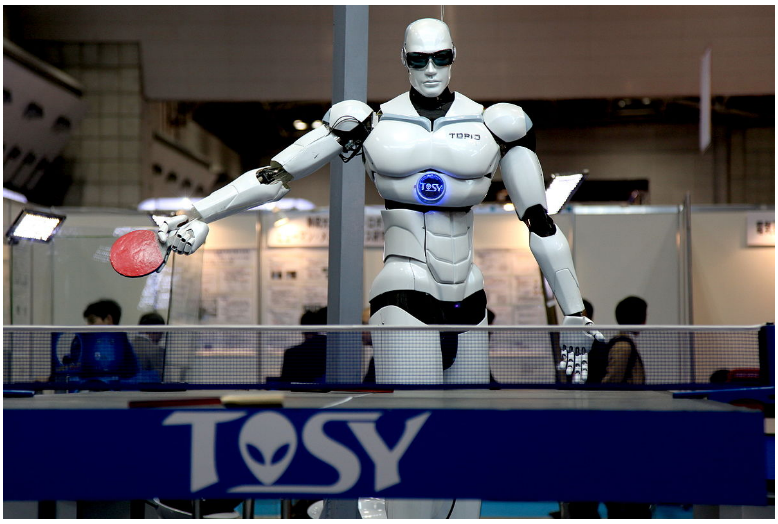
# Artificial intelligence

**Artificial intelligence** (**AI**) is the intelligence of machines and the branch of computer science that aims to create it. AI textbooks define the field as "the study and design of intelligent agents"[2] where an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success.[3] John McCarthy, who coined the term in 1956,[4] defines it as "the science and engineering of making intelligent machines."[5]




TOPIO, a humanoid robot, played table tennis at Tokyo International Robot Exhibition (IREX) 2009.[1]

The field was founded on the claim that a central property of humans, intelligence—the sapience of *Homo sapiens*—can be so precisely described that it can be simulated by a machine.[6] This raises philosophical issues about the nature of the mind and the ethics of creating artificial beings, issues which have been addressed by myth, fiction and philosophy since antiquity.[7] Artificial intelligence has been the subject of optimism,[8] but has also suffered setbacks[9] and, today, has become an essential part of the technology industry, providing the heavy lifting for many of the most difficult problems in computer science.[10]

AI research is highly technical and specialized, *deeply* divided into subfields that often fail in the task of communicating with each other.[11] Subfields have grown up around particular institutions, the work of individual researchers, the solution of specific problems, longstanding differences of opinion about how AI should be done and the application of widely differing tools. The central problems of AI include such traits as reasoning, knowledge, planning, learning, communication, perception and the ability to move and manipulate objects.[12] General intelligence (or "strong AI") is still among the field's long term goals.[13]

## History

Thinking machines and artificial beings appear in Greek myths, such as Talos of Crete, the bronze robot of Hephaestus, and Pygmalion's Galatea.[14] Human likenesses believed to have intelligence were built in every major civilization: animated cult images were worshipped in Egypt and Greece[15] and humanoid automatons were built by Yan Shi, Hero of Alexandria and Al-Jazari.[16] It was also widely believed that artificial beings had been created by Jābir ibn Hayyān, Judah Loew and Paracelsus.[17] By the 19th and 20th centuries, artificial beings had become a common feature in fiction, as in Mary Shelley's *Frankenstein* or Karel Čapek's *R.U.R. (Rossum's Universal Robots)*.[18] Pamela McCorduck argues that all of these are examples of an ancient urge, as she describes it, "to forge the gods".[7] Stories of these creatures and their fates discuss many of the same hopes, fears and ethical concerns that are presented by artificial intelligence.

Mechanical or "formal" reasoning has been developed by philosophers and mathematicians since antiquity. The study of logic led directly to the invention of the programmable digital electronic computer, based on the work of mathematician Alan Turing and others. Turing's theory of computation suggested that a machine, by shuffling symbols as simple as "0" and "1", could simulate any conceivable act of mathematical deduction.[19] [20] This, along with concurrent discoveries in neurology, information theory and cybernetics, inspired a small group of researchers to begin to seriously consider the possibility of building an electronic brain.[21]

The field of AI research was founded at a conference on the campus of Dartmouth College in the summer of 1956.[22] The attendees, including John McCarthy, Marvin Minsky, Allen Newell and Herbert Simon, became the leaders of AI research for many decades.[23] They and their students wrote programs that were, to most people, simply astonishing:[24] Computers were solving word problems in algebra, proving logical theorems and speaking English.[25] By the middle of the 1960s, research in the U.S. was heavily funded by the Department of Defense[26] and laboratories had been established around the world.[27] AI's founders were profoundly optimistic about the future of the new field: Herbert Simon predicted that "machines will be capable, within twenty years, of doing any work a man can do" and Marvin Minsky agreed, writing that "within a generation ... the problem of creating 'artificial intelligence' will substantially be solved".[28]

They had failed to recognize the difficulty of some of the problems they faced.[29] In 1974, in response to the criticism of Sir James Lighthill and ongoing pressure from the US Congress to fund more productive projects, both the U.S. and British governments cut off all undirected exploratory research in AI. The next few years, when funding for projects was hard to find, would later be called the "AI winter".[30]

In the early 1980s, AI research was revived by the commercial success of expert systems,[31] a form of AI program that simulated the knowledge and analytical skills of one or more human experts. By 1985 the market for AI had reached over a billion dollars. At the same time, Japan's fifth generation computer project inspired the U.S and British governments to restore funding for academic research in the field.[32] However, beginning with the collapse of the Lisp Machine market in 1987, AI once again fell into disrepute, and a second, longer lasting AI winter began.[33]

In the 1990s and early 21st century, AI achieved its greatest successes, albeit somewhat behind the scenes. Artificial intelligence is used for logistics, data mining, medical diagnosis and many other areas throughout the technology industry.[10] The success was due to several factors: the increasing computational power of computers (see Moore's law), a greater emphasis on solving specific subproblems, the creation of new ties between AI and other fields working on similar problems, and a new commitment by researchers to solid mathematical methods and rigorous scientific standards.[34]

On 11 May 1997, Deep Blue became the first computer chess-playing system to beat a reigning world chess champion, Garry Kasparov.[35] In 2005, a Stanford robot won the DARPA Grand Challenge by driving autonomously for 131 miles along an unrehearsed desert trail.[36] Two years later, a team from CMU won the DARPA Urban Challenge by autonomously navigating 55 miles in an Urban environment while adhering to traffic hazards and all traffic laws.[37] In February 2011, in a Jeopardy! quiz show exhibition match, IBM's question answering system, Watson, defeated the two greatest Jeopardy! champions, Brad Rutter and Ken Jennings, by a significant margin.[38]

The leading-edge definition of artificial intelligence research is changing over time. One pragmatic definition is: "AI research is that which computing scientists do not know how to do cost-effectively today." For example, in 1956 optical character recognition (OCR) was considered AI, but today, sophisticated OCR software with a context-sensitive spell checker and grammar checker software comes for free with most image scanners. No one would any longer consider already-solved computing science problems like OCR "artificial intelligence" today.

Low-cost entertaining chess-playing software is commonly available for tablet computers. DARPA no longer provides significant funding for chess-playing computing system development. The Kinect which provides a 3D body–motion interface for the Xbox 360 uses algorithms that emerged from lengthy AI research,[39] but few consumers realize the technology source.

AI applications are no longer the exclusive domain of Department of defense R&D, but are now common place consumer items and inexpensive intelligent toys.

In common usage, the term "AI" no longer seems to apply to off-the-shelf solved computing-science problems, which may have originally emerged out of years of AI research.

## Problems

"Can a machine act intelligently?" is still an open problem. Taking "A machine can act intelligently" as a working hypothesis, many researchers have attempted to build such a machine.

The general problem of simulating (or creating) intelligence has been broken down into a number of specific sub-problems. These consist of particular traits or capabilities that researchers would like an intelligent system to display. The traits described below have received the most attention.[12]

### Deduction, reasoning, problem solving

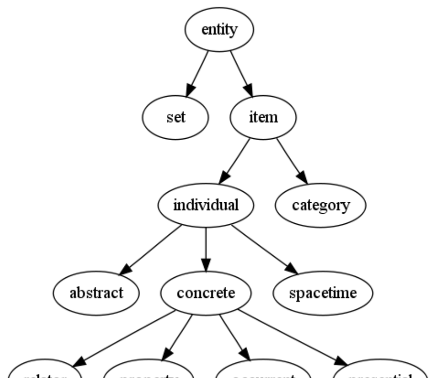
Early AI researchers developed algorithms that imitated the step-by-step reasoning that humans use when they solve puzzles or make logical deductions.[40] By the late 1980s and '90s, AI research had also developed highly successful methods for dealing with uncertain or incomplete information, employing concepts from probability and economics.[41]

For difficult problems, most of these algorithms can require enormous computational resources — most experience a "combinatorial explosion": the amount of memory or computer time required becomes astronomical when the problem goes beyond a certain size. The search for more efficient problem-solving algorithms is a high priority for AI research.[42]

Human beings solve most of their problems using fast, intuitive judgments rather than the conscious, step-by-step deduction that early AI research was able to model.[43] AI has made some progress at imitating this kind of "sub-symbolic" problem solving: embodied agent approaches emphasize the importance of sensorimotor skills to higher reasoning; neural net research attempts to simulate the structures inside human and animal brains that give rise to this skill.

### Knowledge representation

Knowledge representation[44] and knowledge engineering[45] are central to AI research. Many of the problems machines are expected to solve will require extensive knowledge about the world. Among the things that AI needs to represent are: objects, properties, categories and relations between objects;[46] situations, events, states and time;[47] causes and effects;[48] knowledge about knowledge (what we know about what other people know);[49] and many other, less well researched domains. A representation of "what exists" is an ontology (borrowing a word from traditional philosophy), of which the most general are called upper ontologies.[50]



An ontology represents knowledge as a set of concepts within a domain and the relationships between those concepts.

Among the most difficult problems in knowledge representation are:

Default reasoning and the qualification problem

Many of the things people know take the form of "working assumptions." For example, if a bird comes up in conversation, people typically picture an animal that is fist sized, sings, and flies. None of these things are true about all birds. John McCarthy identified this problem in 1969[51] as the qualification problem: for any commonsense rule that AI researchers care to represent, there tend to be a huge number of exceptions. Almost nothing is simply true or false in the way that abstract logic requires. AI research has explored a number of solutions to this problem.[52]

The breadth of commonsense knowledge

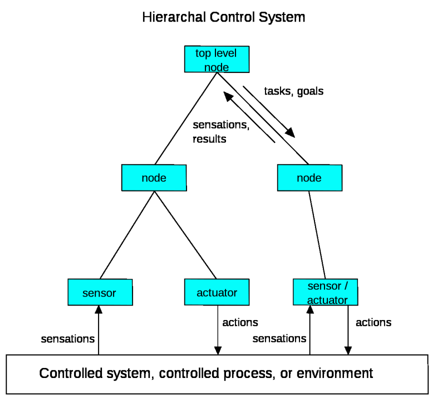
The number of atomic facts that the average person knows is astronomical. Research projects that attempt to build a complete knowledge base of commonsense knowledge (e.g., Cyc) require enormous amounts of laborious ontological engineering — they must be built, by hand, one complicated concept at a time.[53] A major goal is to have the computer understand enough concepts to be able to learn by reading from sources like the internet, and thus be able to add to its own ontology.

The subsymbolic form of some commonsense knowledge

Much of what people know is not represented as "facts" or "statements" that they could express verbally. For example, a chess master will avoid a particular chess position because it "feels too exposed"[54] or an art critic can take one look at a statue and instantly realize that it is a fake.[55] These are intuitions or tendencies that are represented in the brain non-consciously and sub-symbolically.[56] Knowledge like this informs, supports and provides a context for symbolic, conscious knowledge. As with the related problem of sub-symbolic reasoning, it is hoped that situated AI or computational intelligence will provide ways to represent this kind of knowledge.[56]

## Planning

Intelligent agents must be able to set goals and achieve them.[57] They need a way to visualize the future (they must have a representation of the state of the world and be able to make predictions about how their actions will change it) and be able to make choices that maximize the utility (or "value") of the available choices.[58]




A hierarchical control system is a form of control system in which a set of devices and governing software is arranged in a hierarchy.

In classical planning problems, the agent can assume that it is the only thing acting on the world and it can be certain what the consequences of its actions may be.[59] However, if this is not true, it must periodically check if the world matches its predictions and it must change its plan as this becomes necessary, requiring the agent to reason under uncertainty.[60]

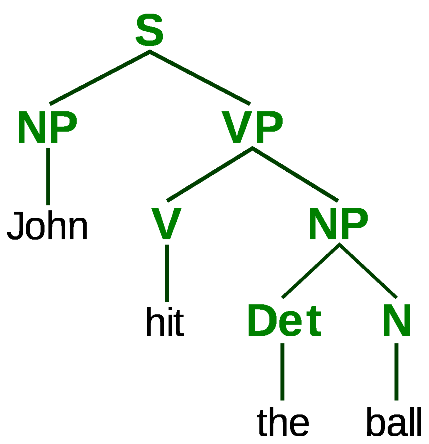
Multi-agent planning uses the cooperation and competition of many agents to achieve a given goal. Emergent behavior such as this is used by evolutionary algorithms and swarm intelligence.[61]

## Learning

Machine learning[62] has been central to AI research from the beginning.[63] In 1956, at the original Dartmouth AI summer conference, Ray Solomonoff wrote a report on unsupervised probabilistic machine learning: "An Inductive Inference Machine".[64] Unsupervised learning is the ability to find patterns in a stream of input. Supervised learning includes both classification and numerical regression. Classification is used to determine what category something belongs in, after seeing a number of examples of things from several categories. Regression is the attempt to produce a function that describes the relationship between inputs and outputs and predicts how the outputs should change as the inputs change. In reinforcement learning[65] the agent is rewarded for good responses and punished for bad ones. These can be analyzed in terms of decision theory, using concepts like utility. The mathematical analysis of machine learning algorithms and their performance is a branch of theoretical computer science known as computational learning theory.[66]

## Natural language processing

Natural language processing[67] gives machines the ability to read and understand the languages that humans speak. Many researchers hope that a sufficiently powerful natural language processing system would be able to acquire knowledge on its own, by reading the existing text available over the internet. Some straightforward applications of natural language processing include information retrieval (or text mining) and machine translation.[68]



A parse tree represents the syntactic structure of a sentence according to some formal grammar.

## Motion and manipulation

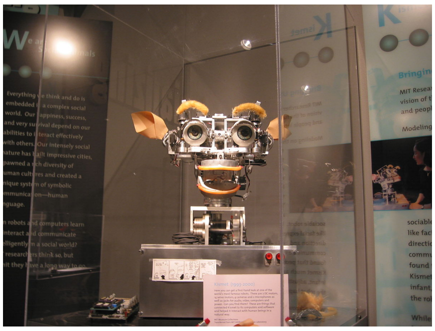
The field of robotics[69] is closely related to AI. Intelligence is required for robots to be able to handle such tasks as object manipulation[70] and navigation, with sub-problems of localization (knowing where you are), mapping (learning what is around you) and motion planning (figuring out how to get there).[71]

## Perception

Machine perception[72] is the ability to use input from sensors (such as cameras, microphones, sonar and others more exotic) to deduce aspects of the world. Computer vision[73] is the ability to analyze visual input. A few selected subproblems are speech recognition,[74] facial recognition and object recognition.[75]

## Social intelligence

Emotion and social skills[76] play two roles for an intelligent agent. First, it must be able to predict the actions of others, by understanding their motives and emotional states. (This involves elements of game theory, decision theory, as well as the ability to model human emotions and the perceptual skills to detect emotions.) Also, for good human-computer interaction, an intelligent machine also needs to *display* emotions. At the very least it must appear polite and sensitive to the humans it interacts with. At best, it should have normal emotions itself.


Kismet, a robot with rudimentary social skills

## Creativity

A sub-field of AI addresses creativity both theoretically (from a philosophical and psychological perspective) and practically (via specific implementations of systems that generate outputs that can be considered creative, or systems that identify and assess creativity). A related area of computational research is Artificial intuition and Artificial imagination.

### General intelligence

Most researchers hope that their work will eventually be incorporated into a machine with *general* intelligence (known as strong AI), combining all the skills above and exceeding human abilities at most or all of them.[13] A few believe that anthropomorphic features like artificial consciousness or an artificial brain may be required for such a project.[77] [78]

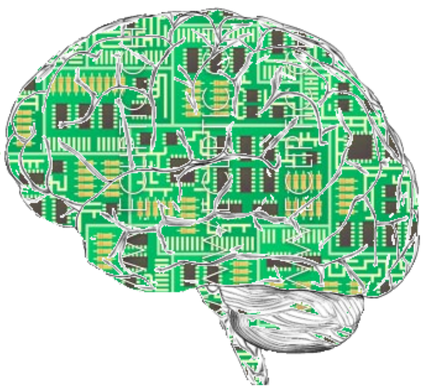
Many of the problems above are considered AI-complete: to solve one problem, you must solve them all. For example, even a straightforward, specific task like machine translation requires that the machine follow the author's argument (reason), know what is being talked about (knowledge), and faithfully reproduce the author's intention (social intelligence). Machine translation, therefore, is believed to be AI-complete: it may require strong AI to be done as well as humans can do it.[79]

## Approaches

There is no established unifying theory or paradigm that guides AI research. Researchers disagree about many issues.[80] A few of the most long standing questions that have remained unanswered are these: should artificial intelligence simulate natural intelligence by studying psychology or neurology? Or is human biology as irrelevant to AI research as bird biology is to aeronautical engineering?[81] Can intelligent behavior be described using simple, elegant principles (such as logic or optimization)? Or does it necessarily require solving a large number of completely unrelated problems?[82] Can intelligence be reproduced using high-level symbols, similar to words and ideas? Or does it require "sub-symbolic" processing?[83] John Haugeland, who coined the term GOFAI (Good Old-Fashioned Artificial Intelligence), also proposed that AI should more properly be referred to as synthetic intelligence,[84] a term which has since been adopted by some non-GOFAI researchers.[85] [86]

### Cybernetics and brain simulation

In the 1940s and 1950s, a number of researchers explored the connection between neurology, information theory, and cybernetics. Some of them built machines that used electronic networks to exhibit rudimentary intelligence, such as W. Grey Walter's turtles and the Johns Hopkins Beast. Many of these researchers gathered for meetings of the Teleological Society at Princeton University and the Ratio Club in England.[21] By 1960, this approach was largely abandoned, although elements of it would be revived in the 1980s.



There is currently no consensus on how closely the brain should be simulated.

### Symbolic

When access to digital computers became possible in the middle 1950s, AI research began to explore the possibility that human intelligence could be reduced to symbol manipulation. The research was centered in three institutions: CMU, Stanford and MIT, and each one developed its own style of research. John Haugeland named these approaches to AI "good old fashioned AI" or "GOFAI".[87]

Cognitive simulation

> Economist Herbert Simon and Allen Newell studied human problem-solving skills and attempted to formalize them, and their work laid the foundations of the field of artificial intelligence, as well as cognitive science, operations research and management science. Their research team used the results of psychological experiments to develop programs that simulated the techniques that people used to solve problems. This tradition, centered at Carnegie Mellon University would eventually culminate in the development of the Soar architecture in the middle 80s.[88] [89]

Logic-based

Unlike Newell and Simon, John McCarthy felt that machines did not need to simulate human thought, but should instead try to find the essence of abstract reasoning and problem solving, regardless of whether people used the same algorithms.[81] His laboratory at Stanford (SAIL) focused on using formal logic to solve a wide variety of problems, including knowledge representation, planning and learning.[90] Logic was also focus of the work at the University of Edinburgh and elsewhere in Europe which led to the development of the programming language Prolog and the science of logic programming.[91]

"Anti-logic" or "scruffy"

Researchers at MIT (such as Marvin Minsky and Seymour Papert)[92] found that solving difficult problems in vision and natural language processing required ad-hoc solutions – they argued that there was no simple and general principle (like logic) that would capture all the aspects of intelligent behavior. Roger Schank described their "anti-logic" approaches as "scruffy" (as opposed to the "neat" paradigms at CMU and Stanford).[82] Commonsense knowledge bases (such as Doug Lenat's Cyc) are an example of "scruffy" AI, since they must be built by hand, one complicated concept at a time.[93]

Knowledge-based

When computers with large memories became available around 1970, researchers from all three traditions began to build knowledge into AI applications.[94] This "knowledge revolution" led to the development and deployment of expert systems (introduced by Edward Feigenbaum), the first truly successful form of AI software.[31] The knowledge revolution was also driven by the realization that enormous amounts of knowledge would be required by many simple AI applications.

## Sub-symbolic

During the 1960s, symbolic approaches had achieved great success at simulating high-level thinking in small demonstration programs. Approaches based on cybernetics or neural networks were abandoned or pushed into the background.[95] By the 1980s, however, progress in symbolic AI seemed to stall and many believed that symbolic systems would never be able to imitate all the processes of human cognition, especially perception, robotics, learning and pattern recognition. A number of researchers began to look into "sub-symbolic" approaches to specific AI problems.[83]

Bottom-up, embodied, situated, behavior-based or nouvelle AI

Researchers from the related field of robotics, such as Rodney Brooks, rejected symbolic AI and focused on the basic engineering problems that would allow robots to move and survive.[96] Their work revived the non-symbolic viewpoint of the early cybernetics researchers of the 50s and reintroduced the use of control theory in AI. This coincided with the development of the embodied mind thesis in the related field of cognitive science: the idea that aspects of the body (such as movement, perception and visualization) are required for higher intelligence.

Computational Intelligence

Interest in neural networks and "connectionism" was revived by David Rumelhart and others in the middle 1980s.[97] These and other sub-symbolic approaches, such as fuzzy systems and evolutionary computation, are now studied collectively by the emerging discipline of computational intelligence.[98]

### Statistical

In the 1990s, AI researchers developed sophisticated mathematical tools to solve specific subproblems. These tools are truly scientific, in the sense that their results are both measurable and verifiable, and they have been responsible for many of AI's recent successes. The shared mathematical language has also permitted a high level of collaboration with more established fields (like mathematics, economics or operations research). Stuart Russell and Peter Norvig describe this movement as nothing less than a "revolution" and "the victory of the neats."[34] Critiques argue that these techniques are too focussed on particular problems and have failed to address the long term goal of general intelligence.

### Integrating the approaches

Intelligent agent paradigm

> An intelligent agent is a system that perceives its environment and takes actions which maximize its chances of success. The simplest intelligent agents are programs that solve specific problems. More complicated agents include human beings and organizations of human beings (such as firms). The paradigm gives researchers license to study isolated problems and find solutions that are both verifiable and useful, without agreeing on one single approach. An agent that solves a specific problem can use any approach that works — some agents are symbolic and logical, some are sub-symbolic neural networks and others may use new approaches. The paradigm also gives researchers a common language to communicate with other fields—such as decision theory and economics—that also use concepts of abstract agents. The intelligent agent paradigm became widely accepted during the 1990s.[3]

Agent architectures and cognitive architectures

> Researchers have designed systems to build intelligent systems out of interacting intelligent agents in a multi-agent system.[99] A system with both symbolic and sub-symbolic components is a hybrid intelligent system, and the study of such systems is artificial intelligence systems integration. A hierarchical control system provides a bridge between sub-symbolic AI at its lowest, reactive levels and traditional symbolic AI at its highest levels, where relaxed time constraints permit planning and world modelling.[100] Rodney Brooks' subsumption architecture was an early proposal for such a hierarchical system.[101]

## Tools

In the course of 50 years of research, AI has developed a large number of tools to solve the most difficult problems in computer science. A few of the most general of these methods are discussed below.

### Search and optimization

Many problems in AI can be solved in theory by intelligently searching through many possible solutions:[102] Reasoning can be reduced to performing a search. For example, logical proof can be viewed as searching for a path that leads from premises to conclusions, where each step is the application of an inference rule.[103] Planning algorithms search through trees of goals and subgoals, attempting to find a path to a target goal, a process called means-ends analysis.[104] Robotics algorithms for moving limbs and grasping objects use local searches in configuration space.[70] Many learning algorithms use search algorithms based on optimization.

Simple exhaustive searches[105] are rarely sufficient for most real world problems: the search space (the number of places to search) quickly grows to astronomical numbers. The result is a search that is too slow or never completes. The solution, for many problems, is to use "heuristics" or "rules of thumb" that eliminate choices that are unlikely to lead to the goal (called "pruning the search tree"). Heuristics supply the program with a "best guess" for the path on which the solution lies.[106]

A very different kind of search came to prominence in the 1990s, based on the mathematical theory of optimization. For many problems, it is possible to begin the search with some form of a guess and then refine the guess incrementally until no more refinements can be made. These algorithms can be visualized as blind hill climbing: we begin the search at a random point on the landscape, and then, by jumps or steps, we keep moving our guess uphill, until we reach the top. Other optimization algorithms are simulated annealing, beam search and random optimization.[107]

Evolutionary computation uses a form of optimization search. For example, they may begin with a population of organisms (the guesses) and then allow them to mutate and recombine, selecting only the fittest to survive each generation (refining the guesses). Forms of evolutionary computation include swarm intelligence algorithms (such as ant colony or particle swarm optimization)[108] and evolutionary algorithms (such as genetic algorithms and genetic programming).[109]

## Logic

Logic[110] is used for knowledge representation and problem solving, but it can be applied to other problems as well. For example, the satplan algorithm uses logic for planning[111] and inductive logic programming is a method for learning.[112]

Several different forms of logic are used in AI research. Propositional or sentential logic[113] is the logic of statements which can be true or false. First-order logic[114] also allows the use of quantifiers and predicates, and can express facts about objects, their properties, and their relations with each other. Fuzzy logic,[115] is a version of first-order logic which allows the truth of a statement to be represented as a value between 0 and 1, rather than simply True (1) or False (0). Fuzzy systems can be used for uncertain reasoning and have been widely used in modern industrial and consumer product control systems. Subjective logic[116] models uncertainty in a different and more explicit manner than fuzzy-logic: a given binomial opinion satisfies belief + disbelief + uncertainty = 1 within a Beta distribution. By this method, ignorance can be distinguished from probabilistic statements that an agent makes with high confidence.

Default logics, non-monotonic logics and circumscription[52] are forms of logic designed to help with default reasoning and the qualification problem. Several extensions of logic have been designed to handle specific domains of knowledge, such as: description logics;[46] situation calculus, event calculus and fluent calculus (for representing events and time);[47] causal calculus;[48] belief calculus; and modal logics.[49]

## Probabilistic methods for uncertain reasoning

Many problems in AI (in reasoning, planning, learning, perception and robotics) require the agent to operate with incomplete or uncertain information. AI researchers have devised a number of powerful tools to solve these problems using methods from probability theory and economics.[117]

Bayesian networks[118] are a very general tool that can be used for a large number of problems: reasoning (using the Bayesian inference algorithm),[119] learning (using the expectation-maximization algorithm),[120] planning (using decision networks)[121] and perception (using dynamic Bayesian networks).[122] Probabilistic algorithms can also be used for filtering, prediction, smoothing and finding explanations for streams of data, helping perception systems to analyze processes that occur over time (e.g., hidden Markov models or Kalman filters).[122]

A key concept from the science of economics is "utility": a measure of how valuable something is to an intelligent agent. Precise mathematical tools have been developed that analyze how an agent can make choices and plan, using decision theory, decision analysis,[123] information value theory.[58] These tools include models such as Markov decision processes,[124] dynamic decision networks,[122] game theory and mechanism design.[125]

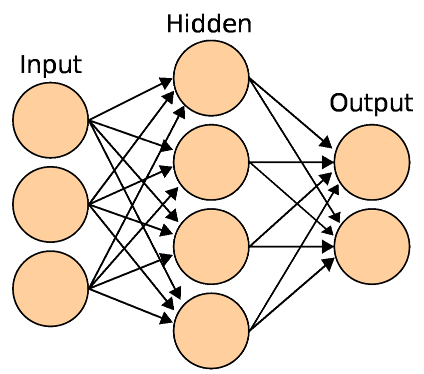
## Classifiers and statistical learning methods

The simplest AI applications can be divided into two types: classifiers ("if shiny then diamond") and controllers ("if shiny then pick up"). Controllers do however also classify conditions before inferring actions, and therefore classification forms a central part of many AI systems. Classifiers are functions that use pattern matching to determine a closest match. They can be tuned according to examples, making them very attractive for use in AI. These examples are known as observations or patterns. In supervised learning, each pattern belongs to a certain predefined class. A class can be seen as a decision that has to be made. All the observations combined with their class labels are known as a data set. When a new observation is received, that observation is classified based on previous experience.[126]

A classifier can be trained in various ways; there are many statistical and machine learning approaches. The most widely used classifiers are the neural network,[127] kernel methods such as the support vector machine,[128] k-nearest neighbor algorithm,[129] Gaussian mixture model,[130] naive Bayes classifier,[131] and decision tree.[132] The performance of these classifiers have been compared over a wide range of tasks. Classifier performance depends greatly on the characteristics of the data to be classified. There is no single classifier that works best on all given problems; this is also referred to as the "no free lunch" theorem. Determining a suitable classifier for a given problem is still more an art than science.[133]

## Neural networks

The study of artificial neural networks[127] began in the decade before the field AI research was founded, in the work of Walter Pitts and Warren McCullough. Other important early researchers were Frank Rosenblatt, who invented the perceptron and Paul Werbos who developed the backpropagation algorithm.[134]



A neural network is an interconnected group of nodes, akin to the vast network of neurons in the human brain.

The main categories of networks are acyclic or feedforward neural networks (where the signal passes in only one direction) and recurrent neural networks (which allow feedback). Among the most popular feedforward networks are perceptrons, multi-layer perceptrons and radial basis networks.[135] Among recurrent networks, the most famous is the Hopfield net, a form of attractor network, which was first described by John Hopfield in 1982.[136] Neural networks can be applied to the problem of intelligent control (for robotics) or learning, using such techniques as Hebbian learning and competitive learning.[137]

Hierarchical temporal memory is an approach that models some of the structural and algorithmic properties of the neocortex.[138]

### Control theory

Control theory, the grandchild of cybernetics, has many important applications, especially in robotics.[139]

### Languages

AI researchers have developed several specialized languages for AI research, including Lisp[140] and Prolog.[141]

## Evaluating progress

In 1950, Alan Turing proposed a general procedure to test the intelligence of an agent now known as the Turing test. This procedure allows almost all the major problems of artificial intelligence to be tested. However, it is a very difficult challenge and at present all agents fail.[142]

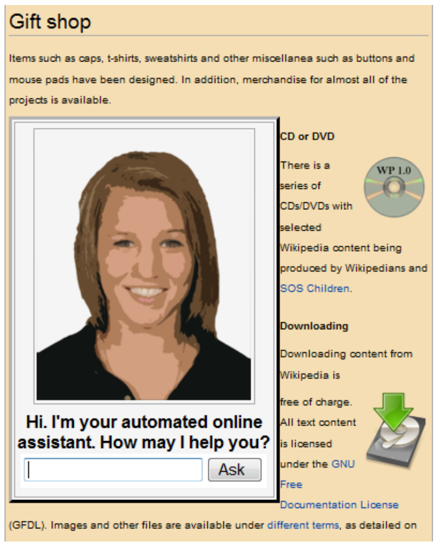
Artificial intelligence can also be evaluated on specific problems such as small problems in chemistry, hand-writing recognition and game-playing. Such tests have been termed subject matter expert Turing tests. Smaller problems provide more achievable goals and there are an ever-increasing number of positive results.[143]

The broad classes of outcome for an AI test are: (1) Optimal: it is not possible to perform better. (2) Strong super-human: performs better than all humans. (3) Super-human: performs better than most humans. (4) Sub-human: performs worse than most humans. For example, performance at draughts is optimal,[144] performance at chess is super-human and nearing strong super-human (see Computer chess#Computers versus humans) and performance at many everyday tasks (such as recognizing a face or crossing a room without bumping into something) is sub-human.

A quite different approach measures machine intelligence through tests which are developed from *mathematical* definitions of intelligence. Examples of these kinds of tests start in the late nineties devising intelligence tests using notions from Kolmogorov complexity and data compression.[145] Two major advantages of mathematical definitions are their applicability to nonhuman intelligences and their absence of a requirement for human testers.

## Applications

Artificial intelligence techniques are pervasive and are too numerous to list. Frequently, when a technique reaches mainstream use, it is no longer considered artificial intelligence; this phenomenon is described as the AI effect.[146]




An automated online assistant providing customer service on a web page - one of many applications of artificial intelligence.

### Competitions and prizes

There are a number of competitions and prizes to promote research in artificial intelligence. The main areas promoted are: general machine intelligence, conversational behavior, data-mining, driverless cars, robot soccer and games.

### Platforms

A platform (or "computing platform") is defined as "some sort of hardware architecture or software framework (including application frameworks), that allows software to run." As Rodney Brooks[147] pointed out many years ago, it is not just the artificial intelligence software that defines the AI features of the platform, but rather the actual platform itself that affects the AI that results, i.e., we need to be working out AI problems on real-world platforms rather than in isolation.

A wide variety of platforms has allowed different aspects of AI to develop, ranging from expert systems, albeit PC-based but still an entire real-world system, to various robot platforms such as the widely available Roomba with open interface.[148]

## Philosophy

Artificial intelligence, by claiming to be able to recreate the capabilities of the human mind, is both a challenge and an inspiration for philosophy. Are there limits to how intelligent machines can be? Is there an essential difference between human intelligence and artificial intelligence? Can a machine have a mind and consciousness? A few of the most influential answers to these questions are given below.[149]

Turing's "polite convention": We need not decide if a machine can "think"; we need only decide if a machine can act as intelligently as a human being. This approach to the philosophical problems associated with artificial intelligence forms the basis of the Turing test.[142]

The Dartmouth proposal: "Every aspect of learning or any other feature of intelligence can be so precisely described that a machine can be made to simulate it." This conjecture was printed in the proposal for the Dartmouth Conference of 1956, and represents the position of most working AI researchers.[150]

Newell and Simon's physical symbol system hypothesis: "A physical symbol system has the necessary and sufficient means of general intelligent action." Newell and Simon argue that intelligences consist of formal operations on symbols.[151] Hubert Dreyfus argued that, on the contrary, human expertise depends on unconscious instinct rather than conscious symbol manipulation and on having a "feel" for the situation rather than explicit symbolic knowledge. (See Dreyfus' critique of AI.)[152] [153]

Gödel's incompleteness theorem: A formal system (such as a computer program) cannot prove all true statements.[154] Roger Penrose is among those who claim that Gödel's theorem limits what machines can do. (See *The Emperor's New Mind*.)[155]

Searle's strong AI hypothesis: "The appropriately programmed computer with the right inputs and outputs would thereby have a mind in exactly the same sense human beings have minds."[156] John Searle counters this assertion with his Chinese room argument, which asks us to look *inside* the computer and try to find where the "mind" might be.[157]

The artificial brain argument: The brain can be simulated. Hans Moravec, Ray Kurzweil and others have argued that it is technologically feasible to copy the brain directly into hardware and software, and that such a simulation will be essentially identical to the original.[78]

## Predictions and ethics

Artificial Intelligence is a common topic in both science fiction and projections about the future of technology and society. The existence of an artificial intelligence that rivals human intelligence raises difficult ethical issues, and the potential power of the technology inspires both hopes and fears.

In fiction, Artificial Intelligence has appeared fulfilling many roles, including a servant (R2D2 in *Star Wars*), a law enforcer (K.I.T.T. "Knight Rider"), a comrade (Lt. Commander Data in *Star Trek: The Next Generation*), a conqueror/overlord (*The Matrix*), a dictator (*With Folded Hands*), a benevolent provider/de facto ruler (*The Culture*), an assassin (*Terminator*), a sentient race (*Battlestar Galactica*/Transformers), an extension to human abilities (*Ghost in the Shell*) and the savior of the human race (R. Daneel Olivaw in the *Asimov's Robot Series*).

Mary Shelley's *Frankenstein* considers a key issue in the ethics of artificial intelligence: if a machine can be created that has intelligence, could it also *feel*? If it can feel, does it have the same rights as a human? The idea also appears in modern science fiction, including the films *I Robot*, *Blade Runner* and *A.I.: Artificial Intelligence*, in which humanoid machines have the ability to feel human emotions. This issue, now known as "robot rights", is currently being considered by, for example, California's Institute for the Future, although many critics believe that the discussion is premature.[158] The subject is profoundly discussed in the 2010 documentary film *Plug & Pray*.[159]

Martin Ford, author of *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future*,[160] and others argue that specialized artificial intelligence applications, robotics and other forms of automation will ultimately result in significant unemployment as machines begin to match and exceed the capability of workers to perform most routine and repetitive jobs. Ford predicts that many knowledge-based occupations—and in particular entry level jobs—will be increasingly susceptible to automation via expert systems, machine learning[161] and other AI-enhanced applications. AI-based applications may also be used to amplify the capabilities of low-wage offshore workers, making it more feasible to outsource knowledge work.[162]

Joseph Weizenbaum wrote that AI applications can not, by definition, successfully simulate genuine human empathy and that the use of AI technology in fields such as customer service or psychotherapy[163] was deeply misguided. Weizenbaum was also bothered that AI researchers (and some philosophers) were willing to view the human mind as nothing more than a computer program (a position now known as computationalism). To Weizenbaum these points suggest that AI research devalues human life.[164]

Many futurists believe that artificial intelligence will ultimately transcend the limits of progress. Ray Kurzweil has used Moore's law (which describes the relentless exponential improvement in digital technology) to calculate that desktop computers will have the same processing power as human brains by the year 2029. He also predicts that by 2045 artificial intelligence will reach a point where it is able to improve *itself* at a rate that far exceeds anything conceivable in the past, a scenario that science fiction writer Vernor Vinge named the "singularity".[165]

Robot designer Hans Moravec, cyberneticist Kevin Warwick and inventor Ray Kurzweil have predicted that humans and machines will merge in the future into cyborgs that are more capable and powerful than either.[166] This idea, called transhumanism, which has roots in Aldous Huxley and Robert Ettinger, has been illustrated in fiction as well, for example in the manga *Ghost in the Shell* and the science-fiction series *Dune*.

Edward Fredkin argues that "artificial intelligence is the next stage in evolution," an idea first proposed by Samuel Butler's "Darwin among the Machines" (1863), and expanded upon by George Dyson in his book of the same name in 1998.[167]

Pamela McCorduck writes that all these scenarios are expressions of the ancient human desire to, as she calls it, "forge the gods".[7]

# References

## Notes

[1] TOPIO:

- "A Ping-Pong-Playing Terminator" (http://www.popsci.com/technology/article/2010-02/ping-pong-playing-terminator). Popular Science. .
- "Best robot 2009" (http://www.gadgetrivia.com/8164-best_robot_international_robot_exhibition). www.gadgetrivia.com. .

[2] Definition of AI as the study of intelligent agents:

- Poole, Mackworth & Goebel 1998, p. 1 (http://people.cs.ubc.ca/~poole/ci/ch1.pdf), which provides the version that is used in this article. Note that they use the term "computational intelligence" as a synonym for artificial intelligence.
- Russell & Norvig (2003) (who prefer the term "rational agent") and write "The whole-agent view is now widely accepted in the field" (Russell & Norvig 2003, p. 55).
- Nilsson 1998

[3] The intelligent agent paradigm:

- Russell & Norvig 2003, pp. 27, 32–58, 968–972
- Poole, Mackworth & Goebel 1998, pp. 7–21
- Luger & Stubblefield 2004, pp. 235–240

The definition used in this article, in terms of goals, actions, perception and environment, is due to Russell & Norvig (2003). Other definitions also include knowledge and learning as additional criteria.

[4] Although there is some controversy on this point (see Crevier (1993, p. 50)), McCarthy states unequivocally "I came up with the term" in a c|net interview. (Skillings 2006)

[5] McCarthy's definition of AI:

- McCarthy 2007

[6] See the Dartmouth proposal, under Philosophy, below.

[7] This is a central idea of Pamela McCorduck's *Machines That Think*. She writes: "I like to think of artificial intelligence as the scientific apotheosis of a venerable cultural tradition." (McCorduck 2004, p. 34) "Artificial intelligence in one form or another is an idea that has pervaded Western intellectual history, a dream in urgent need of being realized." (McCorduck 2004, p. xviii) "Our history is full of attempts—nutty, eerie, comical, earnest, legendary and real—to make artificial intelligences, to reproduce what is the essential us—bypassing the ordinary means. Back and forth between myth and reality, our imaginations supplying what our workshops couldn't, we have engaged for a long time in this odd form of self-reproduction." (McCorduck 2004, p. 3) She traces the desire back to its Hellenistic roots and calls it the urge to "forge the Gods." (McCorduck 2004, pp. 340–400)

[8] The optimism referred to includes the predictions of early AI researchers (see optimism in the history of AI) as well as the ideas of modern transhumanists such as Ray Kurzweil.

[9] The "setbacks" referred to include the ALPAC report of 1966, the abandonment of perceptrons in 1970, the Lighthill Report of 1973 and the collapse of the lisp machine market in 1987.

[10] AI applications widely used behind the scenes:

- Russell & Norvig 2003, p. 28
- Kurzweil 2005, p. 265
- NRC 1999, pp. 216–222

[11] Pamela McCorduck (2004, pp. 424) writes of "the rough shattering of AI in subfields—vision, natural language, decision theory, genetic algorithms, robotics ... and these with own sub-subfield—that would hardly have anything to say to each other."

[12] This list of intelligent traits is based on the topics covered by the major AI textbooks, including:

- Russell & Norvig 2003
- Luger & Stubblefield 2004
- Poole, Mackworth & Goebel 1998
- Nilsson 1998

[13] General intelligence (strong AI) is discussed in popular introductions to AI:

- Kurzweil 1999 and Kurzweil 2005

[14] AI in myth:

- McCorduck 2004, pp. 4–5
- Russell & Norvig 2003, p. 939

[15] Cult images as artificial intelligence:

- Crevier (1993, p. 1) (statue of Amun)
- McCorduck (2004, pp. 6–9)

These were the first machines to be believed to have true intelligence and consciousness. Hermes Trismegistus expressed the common belief that with these statues, craftsman had reproduced "the true nature of the gods", their *sensus* and *spiritus*. McCorduck makes the connection between sacred automatons and Mosaic law (developed around the same time), which expressly forbids the worship of robots (McCorduck 2004, pp. 6–9)

[16] Humanoid automata:

Yan Shi:

- Needham 1986, p. 53

Hero of Alexandria:

- McCorduck 2004, p. 6

Al-Jazari:

- "A Thirteenth Century Programmable Robot" (http://www.shef.ac.uk/marcoms/eview/articles58/robot.html). Shef.ac.uk. . Retrieved 2009-04-25.

Wolfgang von Kempelen:

- McCorduck 2004, p. 17

[17] Artificial beings:

Jābir ibn Hayyān's Takwin:

- O'Connor, Kathleen Malone (1994). *The alchemical creation of life (takwin) and other concepts of Genesis in medieval Islam* (http://repository.upenn.edu/dissertations/AAI9503804). University of Pennsylvania. . Retrieved 2007-01-10.

Judah Loew's Golem:

- McCorduck 2004, pp. 15–16
- Buchanan 2005, p. 50

Paracelsus' Homunculus:

- McCorduck 2004, pp. 13–14

[18] AI in early science fiction.

- McCorduck 2004, pp. 17–25

[19] This insight, that digital computers can simulate any process of formal reasoning, is known as the Church–Turing thesis.

[20] Formal reasoning:

- Berlinski, David (2000). *The Advent of the Algorithm*. Harcourt Books. ISBN 0-15-601391-6. OCLC 46890682.

[21] AI's immediate precursors:

- McCorduck 2004, pp. 51–107
- Crevier 1993, pp. 27–32
- Russell & Norvig 2003, pp. 15, 940
- Moravec 1988, p. 3

See also Cybernetics and early neural networks (in History of artificial intelligence). Among the researchers who laid the foundations of AI were Alan Turing, John Von Neumann, Norbert Wiener, Claude Shannon, Warren McCullough, Walter Pitts and Donald Hebb.

[22] Dartmouth conference:

- McCorduck 2004, pp. 111–136
- Crevier 1993, pp. 47–49, who writes "the conference is generally recognized as the official birthdate of the new science."
- Russell & Norvig 2003, p. 17, who call the conference "the birth of artificial intelligence."
- NRC 1999, pp. 200–201

[23] Hegemony of the Dartmouth conference attendees:

- Russell & Norvig 2003, p. 17, who write "for the next 20 years the field would be dominated by these people and their students."
- McCorduck 2004, pp. 129–130

[24] Russell and Norvig write "it was astonishing whenever a computer did anything kind of smartish." Russell & Norvig 2003, p. 18

[25] "Golden years" of AI (successful symbolic reasoning programs 1956-1973):

- McCorduck 2004, pp. 243–252
- Crevier 1993, pp. 52–107
- Moravec 1988, p. 9
- Russell & Norvig 2003, pp. 18–21

The programs described are Daniel Bobrow's STUDENT, Newell and Simon's Logic Theorist and Terry Winograd's SHRDLU.

[26] DARPA pours money into undirected pure research into AI during the 1960s:

- McCorduck 2004, pp. 131
- Crevier 1993, pp. 51, 64–65
- NRC 1999, pp. 204–205

[27] AI in England:

- Howe 1994

[28] Optimism of early AI:

- Herbert Simon quote: Simon 1965, p. 96 quoted in Crevier 1993, p. 109.
- Marvin Minsky quote: Minsky 1967, p. 2 quoted in Crevier 1993, p. 109.

[29] See The problems (in History of artificial intelligence)

[30] First AI Winter, Mansfield Amendment, Lighthill report

- Crevier 1993, pp. 115–117
- Russell & Norvig 2003, p. 22
- NRC 1999, pp. 212–213
- Howe 1994

[31] Expert systems:

- ACM 1998, I.2.1,
- Russell & Norvig 2003, pp. 22–24
- Luger & Stubblefield 2004, pp. 227–331,
- Nilsson 1998, chpt. 17.4
- McCorduck 2004, pp. 327–335, 434–435
- Crevier 1993, pp. 145–62, 197–203

[32] Boom of the 1980s: rise of expert systems, Fifth Generation Project, Alvey, MCC, SCI:

- McCorduck 2004, pp. 426–441
- Crevier 1993, pp. 161–162,197–203, 211, 240
- Russell & Norvig 2003, p. 24
- NRC 1999, pp. 210–211

[33] Second AI winter:

- McCorduck 2004, pp. 430–435

- Crevier 1993, pp. 209–210
- NRC 1999, pp. 214–216

[34] Formal methods are now preferred ("Victory of the neats"):

- Russell & Norvig 2003, pp. 25–26
- McCorduck 2004, pp. 486–487

[35] McCorduck 2004, pp. 480–483

[36] DARPA Grand Challenge – home page (http://www.darpa.mil/grandchallenge/)

[37] "Welcome" (http://archive.darpa.mil/grandchallenge/). Archive.darpa.mil. . Retrieved 2011-10-31.

[38] Markoff, John (16 February 2011). "On 'Jeopardy!' Watson Win Is All but Trivial" (http://www.nytimes.com/2011/02/17/science/17jeopardy-watson.html). *The New York Times*. .

[39] Kinect's AI breakthrough explained (http://www.i-programmer.info/news/105-artificial-intelligence/2176-kinects-ai-breakthrough-explained.html)

[40] Problem solving, puzzle solving, game playing and deduction:

- Russell & Norvig 2003, chpt. 3-9,
- Poole, Mackworth & Goebel 1998, chpt. 2,3,7,9,
- Luger & Stubblefield 2004, chpt. 3,4,6,8,
- Nilsson 1998, chpt. 7-12

[41] Uncertain reasoning:

- Russell & Norvig 2003, pp. 452–644,
- Poole, Mackworth & Goebel 1998, pp. 345–395,
- Luger & Stubblefield 2004, pp. 333–381,
- Nilsson 1998, chpt. 19

[42] Intractability and efficiency and the combinatorial explosion:

- Russell & Norvig 2003, pp. 9, 21–22

[43] Psychological evidence of sub-symbolic reasoning:

- Wason & Shapiro (1966) showed that people do poorly on completely abstract problems, but if the problem is restated to allow the use of intuitive social intelligence, performance dramatically improves. (See Wason selection task)
- Kahneman, Slovic & Tversky (1982) have shown that people are terrible at elementary problems that involve uncertain reasoning. (See list of cognitive biases for several examples).
- Lakoff & Núñez (2000) have controversially argued that even our skills at mathematics depend on knowledge and skills that come from "the body", i.e. sensorimotor and perceptual skills. (See Where Mathematics Comes From)

[44] Knowledge representation:

- ACM 1998, I.2.4,
- Russell & Norvig 2003, pp. 320–363,
- Poole, Mackworth & Goebel 1998, pp. 23–46, 69–81, 169–196, 235–277, 281–298, 319–345,
- Luger & Stubblefield 2004, pp. 227–243,
- Nilsson 1998, chpt. 18

[45] Knowledge engineering:

- Russell & Norvig 2003, pp. 260–266,
- Poole, Mackworth & Goebel 1998, pp. 199–233,
- Nilsson 1998, chpt. ~17.1-17.4

[46] Representing categories and relations: Semantic networks, description logics, inheritance (including frames and scripts):

- Russell & Norvig 2003, pp. 349–354,
- Poole, Mackworth & Goebel 1998, pp. 174–177,
- Luger & Stubblefield 2004, pp. 248–258,
- Nilsson 1998, chpt. 18.3

[47] Representing events and time:Situation calculus, event calculus, fluent calculus (including solving the frame problem):

- Russell & Norvig 2003, pp. 328–341,
- Poole, Mackworth & Goebel 1998, pp. 281–298,
- Nilsson 1998, chpt. 18.2

[48] Causal calculus:

- Poole, Mackworth & Goebel 1998, pp. 335–337

[49] Representing knowledge about knowledge: Belief calculus, modal logics:

- Russell & Norvig 2003, pp. 341–344,
- Poole, Mackworth & Goebel 1998, pp. 275–277

[50] Ontology:

- Russell & Norvig 2003, pp. 320–328

[51] Qualification problem:

- McCarthy & Hayes 1969
- Russell & Norvig 2003

While McCarthy was primarily concerned with issues in the logical representation of actions, Russell & Norvig 2003 apply the term to the more general issue of default reasoning in the vast network of assumptions underlying all our commonsense knowledge.

[52] Default reasoning and default logic, non-monotonic logics, circumscription, closed world assumption, abduction (Poole *et al.* places abduction under "default reasoning". Luger *et al.* places this under "uncertain reasoning"):

- Russell & Norvig 2003, pp. 354–360,
- Poole, Mackworth & Goebel 1998, pp. 248–256, 323–335,
- Luger & Stubblefield 2004, pp. 335–363,
- Nilsson 1998, ~18.3.3

[53] Breadth of commonsense knowledge:

- Russell & Norvig 2003, p. 21,
- Crevier 1993, pp. 113–114,
- Moravec 1988, p. 13,
- Lenat & Guha 1989 (Introduction)

[54] Dreyfus & Dreyfus 1986

[55] Gladwell 2005

[56] Expert knowledge as embodied intuition:

- Dreyfus & Dreyfus 1986 (Hubert Dreyfus is a philosopher and critic of AI who was among the first to argue that most useful human knowledge was encoded sub-symbolically. See Dreyfus' critique of AI)
- Gladwell 2005 (Gladwell's *Blink* is a popular introduction to sub-symbolic reasoning and knowledge.)
- Hawkins & Blakeslee 2005 (Hawkins argues that sub-symbolic knowledge should be the primary focus of AI research.)

[57] Planning:

- ACM 1998, ~I.2.8,
- Russell & Norvig 2003, pp. 375–459,
- Poole, Mackworth & Goebel 1998, pp. 281–316,
- Luger & Stubblefield 2004, pp. 314–329,
- Nilsson 1998, chpt. 10.1-2, 22

[58] Information value theory:

- Russell & Norvig 2003, pp. 600–604

[59] Classical planning:

- Russell & Norvig 2003, pp. 375–430,
- Poole, Mackworth & Goebel 1998, pp. 281–315,
- Luger & Stubblefield 2004, pp. 314–329,
- Nilsson 1998, chpt. 10.1-2, 22

[60] Planning and acting in non-deterministic domains: conditional planning, execution monitoring, replanning and continuous planning:

- Russell & Norvig 2003, pp. 430–449

[61] Multi-agent planning and emergent behavior:

- Russell & Norvig 2003, pp. 449–455

[62] Learning:

- ACM 1998, I.2.6,
- Russell & Norvig 2003, pp. 649–788,
- Poole, Mackworth & Goebel 1998, pp. 397–438,
- Luger & Stubblefield 2004, pp. 385–542,
- Nilsson 1998, chpt. 3.3 , 10.3, 17.5, 20

[63] Alan Turing discussed the centrality of learning as early as 1950, in his classic paper Computing Machinery and Intelligence. (Turing 1950)

[64] (pdf scanned copy of the original) (http://world.std.com/~rjs/indinf56.pdf) (version published in 1957, An Inductive Inference Machine," IRE Convention Record, Section on Information Theory, Part 2, pp. 56-62)

[65] Reinforcement learning:

- Russell & Norvig 2003, pp. 763–788
- Luger & Stubblefield 2004, pp. 442–449

[66] Computational learning theory:

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[67] Natural language processing:

- ACM 1998, I.2.7
- Russell & Norvig 2003, pp. 790–831
- Poole, Mackworth & Goebel 1998, pp. 91–104
- Luger & Stubblefield 2004, pp. 591–632

[68] Applications of natural language processing, including information retrieval (i.e. text mining) and machine translation:

- Russell & Norvig 2003, pp. 840–857,
- Luger & Stubblefield 2004, pp. 623–630

[69] Robotics:

- ACM 1998, I.2.9,
- Russell & Norvig 2003, pp. 901–942,
- Poole, Mackworth & Goebel 1998, pp. 443–460

[70] Moving and configuration space:

- Russell & Norvig 2003, pp. 916–932

[71] Robotic mapping (localization, etc):

- Russell & Norvig 2003, pp. 908–915

[72] Machine perception:

- Russell & Norvig 2003, pp. 537–581, 863–898
- Nilsson 1998, ~chpt. 6

[73] Computer vision:

- ACM 1998, I.2.10
- Russell & Norvig 2003, pp. 863–898
- Nilsson 1998, chpt. 6

[74] Speech recognition:

- ACM 1998, ~I.2.7
- Russell & Norvig 2003, pp. 568–578

[75] Object recognition:

- Russell & Norvig 2003, pp. 885–892

[76] Emotion and affective computing:

- Minsky 2006

[77] Gerald Edelman, Igor Aleksander and others have both argued that artificial consciousness is required for strong AI. (Aleksander 1995; Edelman 2007)

[78] Artificial brain arguments: AI requires a simulation of the operation of the human brain

- Russell & Norvig 2003, p. 957
- Crevier 1993, pp. 271 and 279

A few of the people who make some form of the argument:

- Moravec 1988
- Kurzweil 2005, p. 262
- Hawkins & Blakeslee 2005

The most extreme form of this argument (the brain replacement scenario) was put forward by Clark Glymour in the mid-70s and was touched on by Zenon Pylyshyn and John Searle in 1980.

[79] AI complete: Shapiro 1992, p. 9

[80] Nils Nilsson writes: "Simply put, there is wide disagreement in the field about what AI is all about" (Nilsson 1983, p. 10).

[81] Biological intelligence vs. intelligence in general:

- Russell & Norvig 2003, pp. 2–3, who make the analogy with aeronautical engineering.
- McCorduck 2004, pp. 100–101, who writes that there are "two major branches of artificial intelligence: one aimed at producing intelligent behavior regardless of how it was accomplioshed, and the other aimed at modeling intelligent processes found in nature, particularly human ones."
- Kolata 1982, a paper in *Science*, which describes McCathy's indifference to biological models. Kolata quotes McCarthy as writing: "This is AI, so we don't care if it's psychologically real" (http://books.google.com/books?id=PEkqAAAAMAAJ&q="we+don't+care+if+it's+psychologically+real"&dq="we+don't+care+if+it's+psychologically+real"&output=html&pgis=1). McCarthy recently reiterated his position at the AI@50 conference where he said "Artificial intelligence is not, by definition, simulation of human intelligence" (Maker 2006).

[82] Neats vs. scruffies:

- McCorduck 2004, pp. 421–424, 486–489
- Crevier 1993, pp. 168
- Nilsson 1983, pp. 10–11

[83] Symbolic vs. sub-symbolic AI:

- Nilsson (1998, p. 7), who uses the term "sub-symbolic".

[84] Haugeland 1985, p. 255.

[85] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.38.8384&rep=rep1&type=pdf

[86] Pei Wang (2008). *Artificial general intelligence, 2008: proceedings of the First AGI Conference* (http://books.google.com/books?id=a_ZR81Z25z0C&pg=PA63). IOS Press. p. 63. ISBN 978-1-58603-833-5. . Retrieved 31 October 2011.

[87] Haugeland 1985, pp. 112–117

[88] Cognitive simulation, Newell and Simon, AI at CMU (then called Carnegie Tech):

- McCorduck 2004, pp. 139–179, 245–250, 322–323 (EPAM)
- Crevier 1993, pp. 145–149

[89] Soar (history):

- McCorduck 2004, pp. 450–451
- Crevier 1993, pp. 258–263

[90] McCarthy and AI research at SAIL and SRI International:

- McCorduck 2004, pp. 251–259
- Crevier 1993

[91] AI research at Edinburgh and in France, birth of Prolog:

- Crevier 1993, pp. 193–196
- Howe 1994

[92] AI at MIT under Marvin Minsky in the 1960s :

- McCorduck 2004, pp. 259–305
- Crevier 1993, pp. 83–102, 163–176
- Russell & Norvig 2003, p. 19

[93] Cyc:

- McCorduck 2004, p. 489, who calls it "a determinedly scruffy enterprise"
- Crevier 1993, pp. 239–243
- Russell & Norvig 2003, p. 363–365
- Lenat & Guha 1989

[94] Knowledge revolution:

- McCorduck 2004, pp. 266–276, 298–300, 314, 421
- Russell & Norvig 2003, pp. 22–23

[95] The most dramatic case of sub-symbolic AI being pushed into the background was the devastating critique of perceptrons by Marvin Minsky and Seymour Papert in 1969. See History of AI, AI winter, or Frank Rosenblatt.

[96] Embodied approaches to AI:

- McCorduck 2004, pp. 454–462
- Brooks 1990
- Moravec 1988

[97] Revival of connectionism:

- Crevier 1993, pp. 214–215
- Russell & Norvig 2003, p. 25

[98] Computational intelligence

- IEEE Computational Intelligence Society (http://www.ieee-cis.org/)

[99] Agent architectures, hybrid intelligent systems:

- Russell & Norvig (2003, pp. 27, 932, 970–972)
- Nilsson (1998, chpt. 25)

[100] Hierarchical control system:

- Albus, J. S. 4-D/RCS reference model architecture for unmanned ground vehicles. (http://www.isd.mel.nist.gov/documents/albus/4DRCS.pdf) In G Gerhart, R Gunderson, and C Shoemaker, editors, Proceedings of the SPIE AeroSense Session on Unmanned Ground Vehicle Technology, volume 3693, pages 11—20

[101] Subsumption architecture:

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[102] Search algorithms:

- Russell & Norvig 2003, pp. 59–189
- Poole, Mackworth & Goebel 1998, pp. 113–163
- Luger & Stubblefield 2004, pp. 79–164, 193–219

- Nilsson 1998, chpt. 7-12

[103] Forward chaining, backward chaining, Horn clauses, and logical deduction as search:

- Russell & Norvig 2003, pp. 217–225, 280–294
- Poole, Mackworth & Goebel 1998, pp. ~46–52
- Luger & Stubblefield 2004, pp. 62–73
- Nilsson 1998, chpt. 4.2, 7.2

[104] State space search and planning:

- Russell & Norvig 2003, pp. 382–387
- Poole, Mackworth & Goebel 1998, pp. 298–305
- Nilsson 1998, chpt. 10.1-2

[105] Uninformed searches (breadth first search, depth first search and general state space search):

- Russell & Norvig 2003, pp. 59–93
- Poole, Mackworth & Goebel 1998, pp. 113–132
- Luger & Stubblefield 2004, pp. 79–121
- Nilsson 1998, chpt. 8

[106] Heuristic or informed searches (e.g., greedy best first and A*):

- Russell & Norvig 2003, pp. 94–109,
- Poole, Mackworth & Goebel 1998, pp. pp. 132–147,
- Luger & Stubblefield 2004, pp. 133–150,
- Nilsson 1998, chpt. 9

[107] Optimization searches:

- Russell & Norvig 2003, pp. 110–116,120–129
- Poole, Mackworth & Goebel 1998, pp. 56–163
- Luger & Stubblefield 2004, pp. 127–133

[108] Artificial life and society based learning:

- Luger & Stubblefield 2004, pp. 530–541

[109] Genetic programming and genetic algorithms:

- Luger & Stubblefield 2004, pp. 509–530,
- Nilsson 1998, chpt. 4.2.
- Holland, John H. (1975). *Adaptation in Natural and Artificial Systems*. University of Michigan Press. ISBN 0262581116.
- Koza, John R. (1992). *Genetic Programming*. MIT Press. ISBN 0262111705.
- Poli, R., Langdon, W. B., McPhee, N. F. (2008). *A Field Guide to Genetic Programming*. Lulu.com, freely available from http://www.gp-field-guide.org.uk/. ISBN 978-1-4092-0073-4.

[110] Logic:

- ACM 1998, ~I.2.3,
- Russell & Norvig 2003, pp. 194–310,
- Luger & Stubblefield 2004, pp. 35–77,
- Nilsson 1998, chpt. 13-16

[111] Satplan:

- Russell & Norvig 2003, pp. 402–407,
- Poole, Mackworth & Goebel 1998, pp. 300–301,
- Nilsson 1998, chpt. 21

[112] Explanation based learning, relevance based learning, inductive logic programming, case based reasoning:

- Russell & Norvig 2003, pp. 678–710,
- Poole, Mackworth & Goebel 1998, pp. 414–416,
- Luger & Stubblefield 2004, pp. ~422–442,
- Nilsson 1998, chpt. 10.3, 17.5

[113] Propositional logic:

- Russell & Norvig 2003, pp. 204–233,
- Luger & Stubblefield 2004, pp. 45–50
- Nilsson 1998, chpt. 13

[114] First-order logic and features such as equality:

- ACM 1998, ~I.2.4,
- Russell & Norvig 2003, pp. 240–310,
- Poole, Mackworth & Goebel 1998, pp. 268–275,
- Luger & Stubblefield 2004, pp. 50–62,

- Nilsson 1998, chpt. 15

[115] Fuzzy logic:

- Russell & Norvig 2003, pp. 526–527

[116] Subjective logic:

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[117] Stochastic methods for uncertain reasoning:

- ACM 1998, ~I.2.3,
- Russell & Norvig 2003, pp. 462–644,
- Poole, Mackworth & Goebel 1998, pp. 345–395,
- Luger & Stubblefield 2004, pp. 165–191, 333–381,
- Nilsson 1998, chpt. 19

[118] Bayesian networks:

- Russell & Norvig 2003, pp. 492–523,
- Poole, Mackworth & Goebel 1998, pp. 361–381,
- Luger & Stubblefield 2004, pp. ~182–190, ~363–379,
- Nilsson 1998, chpt. 19.3-4

[119] Bayesian inference algorithm:

- Russell & Norvig 2003, pp. 504–519,
- Poole, Mackworth & Goebel 1998, pp. 361–381,
- Luger & Stubblefield 2004, pp. ~363–379,
- Nilsson 1998, chpt. 19.4 & 7

[120] Bayesian learning and the expectation-maximization algorithm:

- Russell & Norvig 2003, pp. 712–724,
- Poole, Mackworth & Goebel 1998, pp. 424–433,
- Nilsson 1998, chpt. 20

[121] Bayesian decision theory and Bayesian decision networks:

- Russell & Norvig 2003, pp. 597–600

[122] Stochastic temporal models:

- Russell & Norvig 2003, pp. 537–581

Dynamic Bayesian networks:

- Russell & Norvig 2003, pp. 551–557

Hidden Markov model:

- (Russell & Norvig 2003, pp. 549–551)

Kalman filters:

- Russell & Norvig 2003, pp. 551–557

[123] decision theory and decision analysis:

- Russell & Norvig 2003, pp. 584–597,
- Poole, Mackworth & Goebel 1998, pp. 381–394

[124] Markov decision processes and dynamic decision networks:

- Russell & Norvig 2003, pp. 613–631

[125] Game theory and mechanism design:

- Russell & Norvig 2003, pp. 631–643

[126] Statistical learning methods and classifiers:

- Russell & Norvig 2003, pp. 712–754,
- Luger & Stubblefield 2004, pp. 453–541

[127] Neural networks and connectionism:

- Russell & Norvig 2003, pp. 736–748,
- Poole, Mackworth & Goebel 1998, pp. 408–414,
- Luger & Stubblefield 2004, pp. 453–505,
- Nilsson 1998, chpt. 3

[128] kernel methods such as the support vector machine, Kernel methods:

- Russell & Norvig 2003, pp. 749–752

[129] K-nearest neighbor algorithm:

- Russell & Norvig 2003, pp. 733–736

[130] Gaussian mixture model:

- Russell & Norvig 2003, pp. 725–727

[131] Naive Bayes classifier:

- Russell & Norvig 2003, pp. 718

[132] Decision tree:

- Russell & Norvig 2003, pp. 653–664,
- Poole, Mackworth & Goebel 1998, pp. 403–408,
- Luger & Stubblefield 2004, pp. 408–417

[133] Classifier performance:

- van der Walt & Bernard 2006

[134] Backpropagation:

- Russell & Norvig 2003, pp. 744–748,
- Luger & Stubblefield 2004, pp. 467–474,
- Nilsson 1998, chpt. 3.3

[135] Feedforward neural networks, perceptrons and radial basis networks:

- Russell & Norvig 2003, pp. 739–748, 758
- Luger & Stubblefield 2004, pp. 458–467

[136] Recurrent neural networks, Hopfield nets:

- Russell & Norvig 2003, p. 758
- Luger & Stubblefield 2004, pp. 474–505

[137] Competitive learning, Hebbian coincidence learning, Hopfield networks and attractor networks:

- Luger & Stubblefield 2004, pp. 474–505

[138] Hierarchical temporal memory:

- Hawkins & Blakeslee 2005

[139] Control theory:

- ACM 1998, ~I.2.8,
- Russell & Norvig 2003, pp. 926–932

[140] Lisp:

- Luger & Stubblefield 2004, pp. 723–821
- Crevier 1993, pp. 59–62,
- Russell & Norvig 2003, p. 18

[141] Prolog:

- Poole, Mackworth & Goebel 1998, pp. 477–491,
- Luger & Stubblefield 2004, pp. 641–676, 575–581

[142] The Turing test:

Turing's original publication:

- Turing 1950

Historical influence and philosophical implications:

- Haugeland 1985, pp. 6–9
- Crevier 1993, p. 24
- McCorduck 2004, pp. 70–71
- Russell & Norvig 2003, pp. 2–3 and 948

[143] Subject matter expert Turing test:

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[144] Game AI:

- CITATION IN PROGRESS.

[145] Mathematical definitions of intelligence:

- Jose Hernandez-Orallo (2000). "Beyond the Turing Test" (http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.44.8943). *Journal of Logic, Language and Information* **9** (4): 447–466. doi:10.1023/A:1008367325700. . Retrieved 2009-07-21.
- D L Dowe and A R Hajek (1997). "A computational extension to the Turing Test" (http://www.csse.monash.edu.au/publications/1997/tr-cs97-322-abs.html). *Proceedings of the 4th Conference of the Australasian Cognitive Science jSociety*. . Retrieved 2009-07-21.
- J Hernandez-Orallo and D L Dowe (2010). "Measuring Universal Intelligence: Towards an Anytime Intelligence Test". *Artificial Intelligence Journal* **174** (18): 1508–1539. doi:10.1016/j.artint.2010.09.006.

[146] "AI set to exceed human brain power" (http://www.cnn.com/2006/TECH/science/07/24/ai.bostrom/) (web article). CNN.com. 2006-07-26. . Retrieved 2008-02-26.

[147] Brooks, R.A., "How to build complete creatures rather than isolated cognitive simulators," in K. VanLehn (ed.), Architectures for Intelligence, pp. 225–239, Lawrence Erlbaum Associates, Hillsdale, NJ, 1991.

[148] Hacking Roomba » Search Results » atmel (http://hackingroomba.com/?s=atmel)

[149] Philosophy of AI. All of these positions in this section are mentioned in standard discussions of the subject, such as:

- Russell & Norvig 2003, pp. 947–960
- Fearn 2007, pp. 38–55

[150] Dartmouth proposal:

- McCarthy et al. 1955 (the original proposal)
- Crevier 1993, p. 49 (historical significance)

[151] The physical symbol systems hypothesis:

- Newell & Simon 1976, p. 116
- McCorduck 2004, p. 153
- Russell & Norvig 2003, p. 18

[152] Dreyfus criticized the necessary condition of the physical symbol system hypothesis, which he called the "psychological assumption": "The mind can be viewed as a device operating on bits of information according to formal rules". (Dreyfus 1992, p. 156)

[153] Dreyfus' critique of artificial intelligence:

- Dreyfus 1972, Dreyfus & Dreyfus 1986
- Crevier 1993, pp. 120–132
- McCorduck 2004, pp. 211–239
- Russell & Norvig 2003, pp. 950–952,

[154] This is a paraphrase of the relevant implication of Gödel's theorems.

[155] The Mathematical Objection:

- Russell & Norvig 2003, p. 949
- McCorduck 2004, pp. 448–449

Making the Mathematical Objection:

- Lucas 1961
- Penrose 1989

Refuting Mathematical Objection:

- Turing 1950 under "(2) The Mathematical Objection"
- Hofstadter 1979

Background:

- Gödel 1931, Church 1936, Kleene 1935, Turing 1937

[156] This version is from Searle (1999), and is also quoted in Dennett 1991, p. 435. Searle's original formulation was "The appropriately programmed computer really is a mind, in the sense that computers given the right programs can be literally said to understand and have other cognitive states." (Searle 1980, p. 1). Strong AI is defined similarly by Russell & Norvig (2003, p. 947): "The assertion that machines could possibly act intelligently (or, perhaps better, act as if they were intelligent) is called the 'weak AI' hypothesis by philosophers, and the assertion that machines that do so are actually thinking (as opposed to simulating thinking) is called the 'strong AI' hypothesis."

[157] Searle's Chinese Room argument:

- Searle 1980. Searle's original presentation of the thought experiment.
- Searle 1999.

Discussion:

- Russell & Norvig 2003, pp. 958–960
- McCorduck 2004, pp. 443–445
- Crevier 1993, pp. 269–271

[158] Robot rights:

- Russell & Norvig 2003, p. 964
- "Robots could demand legal rights" (http://news.bbc.co.uk/2/hi/technology/6200005.stm). *BBC News*. 21 December 2006. . Retrieved 3 February 2011.

Prematurity of:

- Henderson, Mark (24 April 2007). "Human rights for robots? We're getting carried away" (http://www.timesonline.co.uk/tol/news/uk/science/article1695546.ece). *The Times Online* (London). .

In fiction:

- McCorduck (2004, p. 190-25) discusses *Frankenstein* and identifies the key ethical issues as scientific hubris and the suffering of the monster, i.e. robot rights.

[159] Independent documentary Plug & Pray, featuring Joseph Weizenbaum and Raymond Kurzweil (http://www.plugandpray-film.de/en/content.html)

[160] Ford, Martin R. (2009), *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future* (http://www.thelightsinthetunnel.com), Acculant Publishing, ISBN 978-1448659814, . *( e-book available free online* (http://www.thelightsinthetunnel.com/)*.)*

[161] "Machine Learning: A Job Killer?" (http://econfuture.wordpress.com/2011/04/14/machine-learning-a-job-killer/)

[162] AI could decrease the demand for human labor:

- Russell & Norvig 2003, pp. 960–961
- Ford, Martin (2009). *The Lights in the Tunnel: Automation, Accelerating Technology and the Economy of the Future* (http://www.thelightsinthetunnel.com). Acculant Publishing. ISBN 978-1-4486-5981-4. .

[163] In the early 70s, Kenneth Colby presented a version of Weizenbaum's ELIZA known as DOCTOR which he promoted as a serious therapeutic tool. (Crevier 1993, pp. 132–144)

[164] Joseph Weizenbaum's critique of AI:

- Weizenbaum 1976
- Crevier 1993, pp. 132–144
- McCorduck 2004, pp. 356–373
- Russell & Norvig 2003, p. 961

Weizenbaum (the AI researcher who developed the first chatterbot program, ELIZA) argued in 1976 that the misuse of artificial intelligence has the potential to devalue human life.

[165] Technological singularity:

- Vinge 1993
- Kurzweil 2005
- Russell & Norvig 2003, p. 963

[166] Transhumanism:

- Moravec 1988
- Kurzweil 2005
- Russell & Norvig 2003, p. 963

[167] AI as evolution:

- Edward Fredkin is quoted in McCorduck (2004, p. 401).
- Butler, Samuel (13 June 1863). *the Press* (Christchurch, New Zealand). http://www.nzetc.org/tm/scholarly/tei-ButFir-t1-g1-t1-g1-t4-body.html, Letter to the Editor.
- Dyson, George (1998). *Darwin among the Machiens*. Allan Lane Science. ISBN 0738200301.

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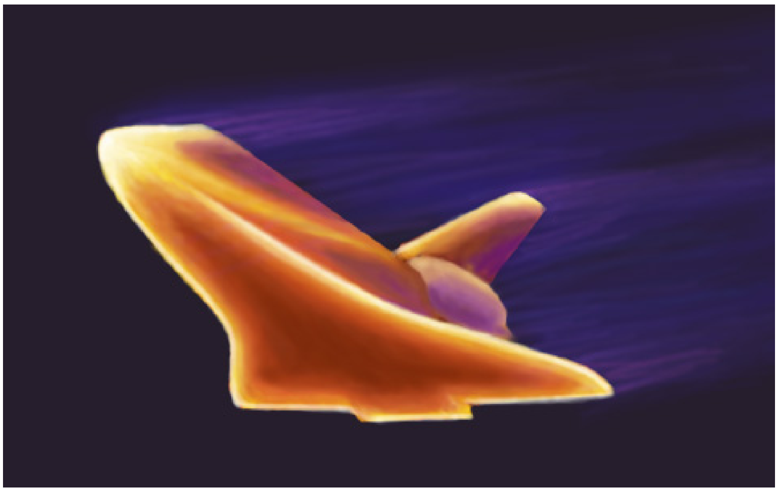
- Artificial Intelligence Discussion group (https://www.researchgate.net/group/Artificial_Intelligence)

# Ceramic engineering

**Ceramic engineering** is the science and technology of creating objects from inorganic, non-metallic materials. This is done either by the action of heat, or at lower temperatures using precipitation reactions from high purity chemical solutions. The term includes the purification of raw materials, the study and production of the chemical compounds concerned, their formation into components and the study of their structure, composition and properties.



Simulation of the outside of the Space Shuttle as it heats up to over 1500 °C (2730 °F) during re-entry into the Earth's atmosphere

Ceramic materials may have a crystalline or partly crystalline structure, with long-range order on atomic scale. Glass ceramics may have an amorphous or glassy structure, with limited or short-range atomic order. They are either formed from a molten mass that solidifies on cooling, formed and matured by the action of heat, or chemically synthesized at low temperatures using, for example, hydrothermal or sol-gel synthesis.

The special character of ceramic materials gives rise to many applications in materials engineering, electrical engineering, chemical engineering and mechanical engineering. As ceramics are heat resistant, they can be used for many tasks that materials like metal and polymers are unsuitable for. Ceramic materials are used in a wide range of industries, including mining, aerospace, medicine, refinery, food and chemical industries, packaging science, electronics, industrial and transmission electricity, and guided lightwave transmission. [1]

## History

The word "ceramic" is derived from the Greek word κεραμικός (*keramikos*) meaning pottery. It is related to the older Indo-European language root "to burn", [2] "Ceramic" may be used as a noun in the singular to refer to a ceramic material or the product of ceramic manufacture, or as an adjective. The plural "ceramics" may be used to refer the making of things out of ceramic materials. Ceramic engineering, like many sciences, evolved from a different discipline by today's standards. Materials science engineering is grouped with ceramics engineering to this day.

Bearing components made from 100% silicon nitride $Si_3N_4$


Ceramic bread knife

Leo Morandi's tile glazing line (circa 1945)

Abraham Darby first used coke in 1709 in Shropshire, England, to improve the yield of a smelting process. Coke is now widely used to produce carbide ceramics. Potter Josiah Wedgwood opened the first modern ceramics factory in Stoke-on-Trent, England, in 1759. Austrian chemist Karl Bayer, working for the textile industry in Russia, developed a process to separate alumina from bauxite ore in 1888. The Bayer process is still used to purify alumina for the ceramic and aluminum industries. Brothers Pierre and Jacques Curie discovered piezoelectricity in Rochelle salt circa 1880. Piezoelectricity is one of the key properties of electroceramics.

E.G. Acheson heated a mixture of coke and clay in 1893, and invented carborundum, or synthetic silicon carbide. Henri Moissan also synthesized SiC and tungsten carbide in his electric arc furnace in Paris about the same time as Acheson. Karl Schröter used liquid-phase sintering to bond or "cement" Moissan's tungsten carbide particles with cobalt in 1923 in Germany. Cemented (metal-bonded) carbide edges greatly increase the durability of hardened steel cutting tools. W.H. Nernst developed cubic-stabilized zirconia in the 1920s in Berlin. This material is used as an oxygen sensor in exhaust systems. The main limitation on the use of ceramics in engineering is brittleness. [1]

## Military

The military requirements of World War II (1939–1945) encouraged developments, which created a need for high-performance materials and helped speed the development of ceramic science and engineering. Throughout the 1960s and 1970s, new types of ceramics were developed in response to advances in atomic energy, electronics, communications, and space travel. The discovery of ceramic superconductors in 1986 has spurred intense research to develop superconducting ceramic parts for electronic devices, electric motors, and transportation equipment.


Soldiers pictured during the 2003 Iraq War seen through IR transparent Night Vision Goggles

There is an increasing need in the military sector for high-strength, robust materials which have the capability to transmit light around the visible (0.4–0.7 micrometers) and mid-infrared (1–5 micrometers) regions of the spectrum. These materials are needed for applications requiring transparent armor. Transparent armor is a material or system of materials designed to be optically transparent, yet protect from fragmentation or ballistic impacts. The primary requirement for a transparent armor system is to not only defeat the designated threat but also provide a multi-hit capability with minimized distortion of surrounding areas. Transparent armor windows must also be compatible with night vision equipment. New materials that are thinner, lightweight, and offer better ballistic performance are being sought. [3] Such solid-state components have found widespread use for various applications in the electro-optical field including: optical fibers for guided lightwave transmission, optical switches, laser amplifiers and lenses, hosts for solid-state lasers and optical window materials for gas lasers, and infrared (IR) heat seeking devices for missile guidance systems and IR night vision. [4]

## Education

### India

- **Indian Institute Of Technology**, Banaras Hindu University, Varanasi[5]

The founder of Banaras Hindu University, Pandit Madan Mohan Malviyaji instituted a course in Ceramic Technology as early as 1924 with the noble objective of advancing glass and ceramic technology in India.

In the Year 1956, Department of Glass Technology and Department of Ceramic Technology were merged to form the Department of Silicate Technology, offering a four year degree course by injecting into its curriculum balanced engineering and scientific contents. In the year 1968 the Department was renamed as Department of Ceramic Engineering. Presently this department is unique in the country which offers B.Tech., M.Tech. and PhD Programmes in the areas of Ceramic Engineering and Technology. The Department has so far produced more than 1000 graduates, 100 postgraduates and 30 PhDs.

The Department is pursuing active research in the emerging areas of glass, glass ceramics, refractories, electronic ceramic, cement and pottery & porcelain. Research papers are being published in reputed national and international journals regularly. Considering the important role that the department of Ceramic Engineering has played, the University Grants Commission has granted funds under 'Special Assistance and COSIST' Programmes. Many R& D projects have been sponsored by AICTE, DST, CSIR and UGC. The Department celebrated its Platinum Jubilee during 1999 for 75 years of Ceramic education and organized a ‘National Seminar on Challenges of 21st century’.[6]

**Czech Republic**

- The Secondary Technical School Of Ceramics was founded in 1872 in Znojmo. In 1922 it moved to Karlovy Vary.[7]
- The Ceramic Technical School At Bechyne was founded in 1884.[8]

**Japan** - The Ceramic Society of Japan was founded in 1891 in Tokyo.[9]

**Germany**

- The Ceramic Society Of Germany was founded in Berlin in 1919.
- Staatliche Fachschule fur Porzellan (Government Technical College for Porcelain) was founded in Selb in 1908. In 1973 it was transferred to Nuremberg Polytechnic, when it was incorporated into a professional training organisation for ceramics which also includes the Staatliche Fachschule fur Keramtechnik and a college for block release courses in ceramic trades, testing and laboratory work.[10] [11]

**France** - the "Ecole Nationale Supérieure de Céramique Industrielle" (ENSCI) funded in Sèvres (Paris) in 1893 and transferred to Limoges in 1979 educate students in engineered and traditionnal ceramic, glass and cement fields. This school proposes exchange programs with other European and International schools like Alfred University.

**Poland –** the Bunzlau Ceramic Technical College operated from 1887 to 1945.[12]

**Spain**

- The ‘Official Ceramic School’ open in Madrid in 1911.[13]
- The Ceramic School Of Manises – was founded in 1914.[14]

**United States** - the first ceramic engineering course and department in the USA were established by Edward Orton, Jr., a professor of geology and mining engineering, at Ohio State University in 1894. Orton and eight other refractory professionals founded the American Ceramic Society (ACerS) at the 1898 National Brick Manufacturers' Association convention in Pittsburgh. Orton was the first ACerS General Secretary, and his office at OSU served as the society headquarters in the beginning. Charles F. Binns established the New York State School of Clay-Working and Ceramics, now Alfred University, in 1900. Binns was the third ACerS president, and Orton the 32nd.[15] Significant contributions by Corning Incorporated a global leader of specialty glass and ceramics have been made and further committed to the update of the Sullivan Park Research and Development campus with $300 million in facility improvements with an estimated completion date of 2013. The largest known grant in history, localized to the education of Ceramic Engineering.

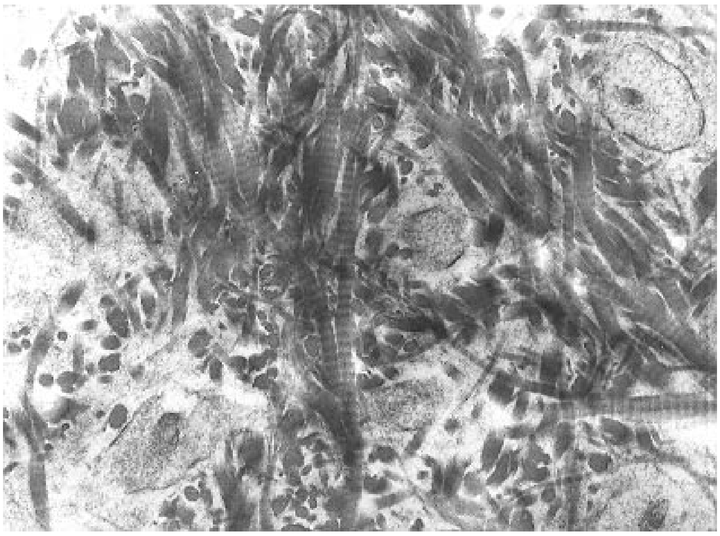
## Modern industry

Now a multi-billion dollar a year industry, ceramic engineering and research has established itself as an important field of science. Applications continue to expand as researchers develop new kinds of ceramics to serve different purposes. [1] [16]

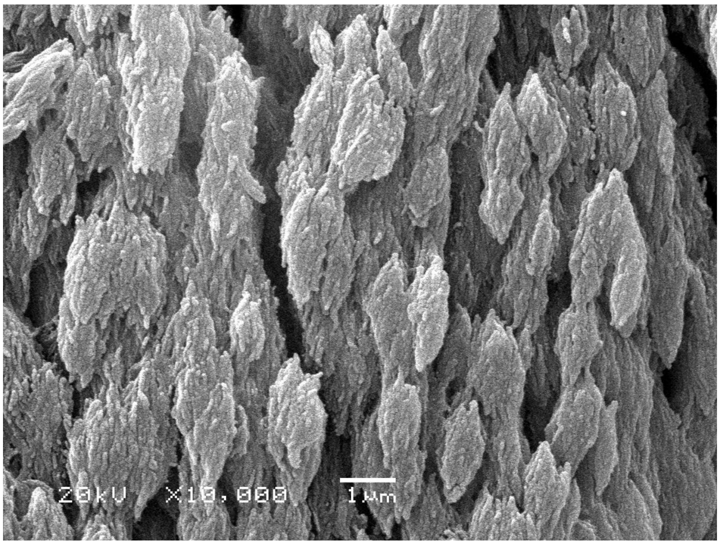
U.S. Army soldiers wearing bulletproof ballistic vests with an armored M3 Bradley.

- Zirconium dioxide ceramics are used in the manufacture of knives. The blade of the ceramic knife will stay sharp for much longer than that of a steel knife, although it is more brittle and can be snapped by dropping it on a hard surface.
- Ceramics such as alumina, boron carbide and silicon carbide have been used in bulletproof vests to repel large-caliber rifle fire. Such plates are known commonly as small-arms protective inserts (SAPI). Similar material is used to protect cockpits of some military airplanes, because of the low weight of the material.
- Silicon nitride parts are used in ceramic ball bearings. Their higher hardness means that they are much less susceptible to wear and can offer more than triple lifetimes. They also deform less under load meaning they have less contact with the bearing retainer walls and can roll faster. In very high speed applications, heat from friction during rolling can cause problems for metal bearings; problems which are reduced by the use of ceramics. Ceramics are also more chemically resistant and can be used in wet environments where steel bearings would rust. The major drawback to using ceramics is a significantly higher cost. In many cases their electrically insulating properties may also be valuable in bearings.
- In the early 1980s, Toyota researched production of an adiabatic ceramic engine which can run at a temperature of over 6000 °F (3300 °C). Ceramic engines do not require a cooling system and hence allow a major weight reduction and therefore greater fuel efficiency. Fuel efficiency of the engine is also higher at high temperature, as shown by Carnot's theorem. In a conventional metallic engine, much of the energy released from the fuel must be dissipated as waste heat in order to prevent a meltdown of the metallic parts. Despite all of these desirable properties, such engines are not in production because the manufacturing of ceramic parts in the requisite precision and durability is difficult. Imperfection in the ceramic leads to cracks, which can lead to potentially dangerous equipment failure. Such engines are possible in laboratory settings, but mass-production is not feasible with current technology.
- Work is being done in developing ceramic parts for gas turbine engines. Currently, even blades made of advanced metal alloys used in the engines' hot section require cooling and careful limiting of operating temperatures. Turbine engines made with ceramics could operate more efficiently, giving aircraft greater range and payload for a set amount of fuel.

- Recently, there have been advances in ceramics which include bio-ceramics, such as dental implants and synthetic bones. Hydroxyapatite, the natural mineral component of bone, has been made synthetically from a number of biological and chemical sources and can be formed into ceramic materials. Orthopedic implants made from these materials bond readily to bone and other tissues in the body without rejection or inflammatory reactions. Because of this, they are of great interest for gene delivery and tissue engineering scaffolds. Most hydroxy apatite ceramics are very porous and lack mechanical strength and are used to coat metal orthopedic devices to aid in forming a bond to bone or as bone fillers. They are also used as fillers for orthopedic plastic screws to aid in reducing the inflammation and increase absorption of these plastic materials. Work is being done to make strong, fully dense nano crystalline hydroxyapatite ceramic materials for orthopedic weight bearing devices, replacing foreign metal and plastic orthopedic materials with a synthetic, but naturally occurring, bone mineral. Ultimately these ceramic materials may be used as bone replacements or with the incorporation of protein collagens, synthetic bones.



Collagen fibers of woven bone




SEM 10,000x magnification of crystalline bone mineral.

- High-tech ceramic is used in watchmaking for producing watch cases. The material is valued by watchmakers for its light weight, scratch-resistance, durability and smooth touch. IWC is one of the brands that initiated the use of ceramic in watchmaking. The case of the IWC 2007 Top Gun edition of the Pilot's Watch Double chronograph is crafted in high-tech black ceramic.[17]

## Glass-ceramics

A high strength glass-ceramic cooktop with negligible thermal expansion.

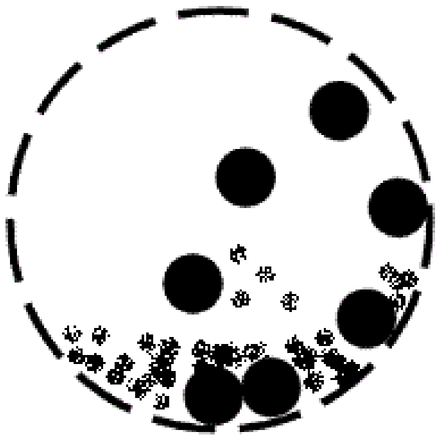
Glass-ceramic materials share many properties with both glasses and ceramics. Glass-ceramics have an amorphous phase and one or more crystalline phases and are produced by a so called "controlled crystallization", which is typically avoided in glass manufacturing. Glass-ceramics often contain a crystalline phase which constitutes anywhere from 30% [m/m] to 90% [m/m] of its composition by volume, yielding an array of materials with interesting thermomechanical properties.[16]

In the processing of glass-ceramics, molten glass is cooled down gradually before reheating and annealing. In this heat treatment the glass partly crystallizes. In many cases, so-called 'nucleation agents' are added in order to regulate and control the crystallization process. Because there is usually no pressing and sintering, glass-ceramics do not contain the volume fraction of porosity typically present in sintered ceramics.[1]

The term mainly refers to a mix of lithium and aluminosilicates which yields an array of materials with interesting thermomechanical properties. The most commercially important of these have the distinction of being impervious to thermal shock. Thus, glass-ceramics have become extremely useful for countertop cooking. The negative thermal expansion coefficient (TEC) of the crystalline ceramic phase can be balanced with the positive TEC of the glassy phase. At a certain point (~70% crystalline) the glass-ceramic has a net TEC near zero. This type of glass-ceramic exhibits excellent mechanical properties and can sustain repeated and quick temperature changes up to 1000 °C.[1] [16]

## Processing steps

The traditional ceramic process generally follows this sequence: Milling → Batching → Mixing → Forming → Drying → Firing → Assembly [18] [19] [20] [21]



Ball mill

- **Milling** is the process by which materials are reduced from a large size to a smaller size. Milling may involve breaking up cemented material (in which case individual particles retain their shape) or pulverization (which involves grinding the particles themselves to a smaller size). Milling is generally done by mechanical means, including *attrition* (which is particle-to-particle collision that results in agglomerate break up or particle shearing), *compression* (which applies a forces that results in fracturing), and *impact* (which employs a milling medium or the particles themselves to cause fracturing). Attrition milling equipment includes the wet scrubber (also called the planetary mill or wet attrition mill), which has paddles in water creating vortexes in which the material collides and break up. Compression mills include the jaw crusher, roller crusher and cone crusher. Impact mills include the ball mill, which has media that tumble and fracture the material. Shaft impactors cause particle-to particle attrition and compression.
- **Batching** is the process of weighing the oxides according to recipes, and preparing them for mixing and drying.
- **Mixing** occurs after batching and is performed with various machines, such as dry mixing ribbon mixers (a type of cement mixer), Mueller mixers, and pug mills. Wet mixing generally involves the same equipment.

- **Forming** is making the mixed material into shapes, ranging from toilet bowls to spark plug insulators. Forming can involve: (1) Extrusion, such as extruding "slugs" to make bricks, (2) Pressing to make shaped parts, (3) Slip casting, as in making toilet bowls, wash basins and ornamentals like ceramic statues. Forming produces a "green" part, ready for drying. Green parts are soft, pliable, and over time will lose shape. Handling the green product will change its shape. For example, a green brick can be "squeezed", and after squeezing it will stay that way.
- **Drying** is removing the water or binder from the formed material. Spray drying is widely used to prepare powder for pressing operations. Other dryers are tunnel dryers and periodic dryers. Controlled heat is applied in this two-stage process. First, heat removes water. This step needs careful control, as rapid heating causes cracks and surface defects. The dried part is smaller than the green part, and is brittle, necessitating careful handling, since a small impact will cause crumbling and breaking.
- **Firing** is where the dried parts pass through a controlled heating process, and the oxides are chemically changed to cause sintering and bonding. The fired part will be smaller than the dried part.

## Forming methods

Ceramic forming techniques include throwing, slipcasting, tape casting, injection molding, dry pressing, isostatic pressing, hot isostatic pressing (HIP) and others. Methods for forming ceramic powders into complex shapes are desirable in many areas of technology. Such methods are required for producing advanced, high-temperature structural parts such as heat engine components and turbines. Materials other than ceramics which are used in these processes may include: wood, metal, water, plaster and epoxy—most of which will be eliminated upon firing. [22]

These forming techniques are well known for providing tools and other components with dimensional stability, surface quality, high (near theoretical) density and microstructural uniformity. The increasing use and diversity of specialty forms of ceramics adds to the diversity of process technologies to be used.[22]

Thus, reinforcing fibers and filaments are mainly made by polymer, sol-gel, or CVD processes, but melt processing also has applicability. The most widely used specialty form is layered structures, with tape casting for electronic substrates and packages being preeminent. Photolithography is of increasing interest for precise patterning of conductors and other components for such packaging. Tape casting or forming processes are also of increasing interest for other applications, ranging from open structures such as fuel cells to ceramic composites.[22]

The other major layer structure is coating, where melt spraying is very important, but chemical and physical vapor deposition and chemical (e.g., sol-gel and polymer pyrolysis) methods are all seeing increased use. Besides open structures from formed tape, extruded structures, such as honeycomb catalyst supports, and highly porous structures, including various foams, for example, reticulated foam, are of increasing use.[22]

Densification of consolidated powder bodies continues to be achieved predominantly by (pressureless) sintering. However, the use of pressure sintering by hot pressing is increasing, especially for non-oxides and parts of simple shapes where higher quality (mainly microstructural homogeneity) is needed, and larger size or multiple parts per pressing can be an advantage.[22]

## The sintering process

The principles of sintering-based methods are simple ("sinter" has roots in the English "cinder"). The firing is done at a temperature below the melting point of the ceramic. Once a roughly-held-together object called a "green body" is made, it is baked in a kiln, where atomic and molecular diffusion processes give rise to significant changes in the primary microstructural features. This includes the gradual elimination of porosity, which is typically accompanied by a net shrinkage and overall densification of the component. Thus, the pores in the object may close up, resulting in a denser product of significantly greater strength and fracture toughness.

Another major change in the body during the firing or sintering process will be the establishment of the polycrystalline nature of the solid. This change will introduce some form of grain size distribution, which will have a significant impact on the ultimate physical properties of the material. The grain sizes will either be associated with the initial particle size, or possibly the sizes of aggregates or particle clusters which arise during the initial stages of processing.

The ultimate microstructure (and thus the physical properties) of the final product will be limited by and subject to the form of the structural template or precursor which is created in the initial stages of chemical synthesis and physical forming. Hence the importance of chemical powder and polymer processing as it pertains to the synthesis of industrial ceramics, glasses and glass-ceramics.

There are numerous possible refinements of the sintering process. Some of the most common involve pressing the green body to give the densification a head start and reduce the sintering time needed. Sometimes organic binders such as polyvinyl alcohol are added to hold the green body together; these burn out during the firing (at 200–350 °C). Sometimes organic lubricants are added during pressing to increase densification. It is common to combine these, and add binders and lubricants to a powder, then press. (The formulation of these organic chemical additives is an art in itself. This is particularly important in the manufacture of high performance ceramics such as those used by the billions for electronics, in capacitors, inductors, sensors, etc.)

A slurry can be used in place of a powder, and then cast into a desired shape, dried and then sintered. Indeed, traditional pottery is done with this type of method, using a plastic mixture worked with the hands. If a mixture of different materials is used together in a ceramic, the sintering temperature is sometimes above the melting point of one minor component - a *liquid phase* sintering. This results in shorter sintering times compared to solid state sintering. [23]

## Strength of ceramics

A material's strength is dependent on its microstructure. The engineering processes to which a material is subjected can alter this microstructure. The variety of strengthening mechanisms that alter the strength of a material include the mechanism of grain boundary strengthening. Thus, although yield strength is maximized with decreasing grain size, ultimately, very small grain sizes make the material brittle. Considered in tandem with the fact that the yield strength is the parameter that predicts plastic deformation in the material, one can make informed decisions on how to increase the strength of a material depending on its microstructural properties and the desired end effect.

The relation between yield stress and grain size is described mathematically by the Hall-Petch equation which is

$$\sigma_y = \sigma_0 + \frac{k_y}{\sqrt{d}}$$

where $k_y$ is the strengthening coefficient (a constant unique to each material), $\sigma_o$ is a materials constant for the starting stress for dislocation movement (or the resistance of the lattice to dislocation motion), $d$ is the grain diameter, and $\sigma_y$ is the yield stress.

Theoretically, a material could be made infinitely strong if the grains are made infinitely small. This is, unfortunately, impossible because the lower limit of grain size is a single unit cell of the material. Even then, if the grains of a material are the size of a single unit cell, then the material is in fact amorphous, not crystalline, since there is no long range order, and dislocations can not be defined in an amorphous material. It has been observed experimentally that the microstructure with the highest yield strength is a grain size of about 10 nanometers, because grains smaller than this undergo another yielding mechanism, grain boundary sliding.[24] Producing engineering materials with this ideal grain size is difficult because of the limitations of initial particle sizes inherent to nanomaterials and nanotechnology.

## Theory of chemical processing

### Microstructural uniformity

In the processing of fine ceramics, the irregular particle sizes and shapes in a typical powder often lead to non-uniform packing morphologies that result in packing density variations in the powder compact. Uncontrolled agglomeration of powders due to attractive van der Waals forces can also give rise to in microstructural inhomogeneities.[25] [26]

Differential stresses that develop as a result of non-uniform drying shrinkage are directly related to the rate at which the solvent can be removed, and thus highly dependent upon the distribution of porosity. Such stresses have been associated with a plastic-to-brittle transition in consolidated bodies,[27] and can yield to crack propagation in the unfired body if not relieved.

In addition, any fluctuations in packing density in the compact as it is prepared for the kiln are often amplified during the sintering process, yielding inhomogeneous densification.[28] [29] Some pores and other structural defects associated with density variations have been shown to play a detrimental role in the sintering process by growing and thus limiting end-point densities.[30] Differential stresses arising from inhomogeneous densification have also been shown to result in the propagation of internal cracks, thus becoming the strength-controlling flaws.[31]

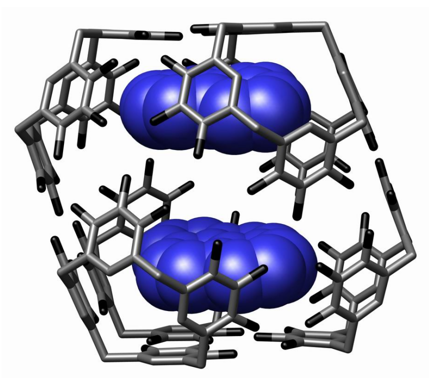
It would therefore appear desirable to process a material in such a way that it is physically uniform with regard to the distribution of components and porosity, rather than using particle size distributions which will maximize the green density. The containment of a uniformly dispersed assembly of strongly interacting particles in suspension requires total control over particle-particle interactions. Monodisperse colloids provide this potential.[32]

Monodisperse powders of colloidal silica, for example, may therefore be stabilized sufficiently to ensure a high degree of order in the colloidal crystal or polycrystalline colloidal solid which results from aggregation. The degree of order appears to be limited by the time and space allowed for longer-range correlations to be established.[33] [34]

Such defective polycrystalline colloidal structures would appear to be the basic elements of submicrometer colloidal materials science, and, therefore, provide the first step in developing a more rigorous understanding of the mechanisms involved in microstructural evolution in inorganic systems such as polycrystalline ceramics.

### Self-assembly

"Self-assembly" is the most common term in use in the modern scientific community to describe the spontaneous aggregation of particles (atoms, molecules, colloids, micelles, etc.) without the influence of any external forces. Large groups of such particles are known to assemble themselves into thermodynamically stable, structurally well-defined arrays, quite reminiscent of one of the 7 crystal systems found in metallurgy and mineralogy (e.g. face-centered cubic, body-centered cubic, etc.). The fundamental difference in equilibrium structure is in the spatial scale of the unit cell (or lattice parameter) in each particular case.



An example of a supramolecular assembly.[35]

Thus, self-assembly is emerging as a new strategy in chemical synthesis and nanotechnology. Molecular self-assembly has been observed in various biological systems and underlies the formation of a wide variety of complex biological structures. Molecular crystals, liquid crystals, colloids, micelles, emulsions, phase-separated polymers, thin films and self-assembled monolayers all represent examples of the types of highly ordered structures which are obtained using these techniques. The distinguishing feature of these methods is self-organization in the absence of any external forces.

In addition, the principal mechanical characteristics and structures of biological ceramics, polymer composites, elastomers, and cellular materials are being re-evaluated, with an emphasis on bioinspired materials and structures. Traditional approaches focus on design methods of biological materials using conventional synthetic materials. This includes an emerging class of mechanically superior biomaterials based on microstructural features and designs found in nature. The new horizons have been identified in the synthesis of bioinspired materials through processes that are characteristic of biological systems in nature. This includes the nanoscale self-assembly of the components and the development of hierarchical structures.[33] [34] [36]

## Ceramic composites

The Porsche Carrera GT's carbon-ceramic (silicon carbide) composite disc brake

Substantial interest has arisen in recent years in fabricating ceramic composites. While there is considerable interest in composites with one or more non-ceramic constituents, the greatest attention is on composites in which all constituents are ceramic. These typically comprise two ceramic constituents: a continuous matrix, and a dispersed phase of ceramic particles, whiskers, or short (chopped) or continuous ceramic fibers. The challenge, as in wet chemical processing, is to obtain a uniform or homogeneous distribution of the dispersed particle or fiber phase. [37] [38]

Consider first the processing of particulate composites. The particulate phase of greatest interest is tetragonal zirconia because of the toughening that can be achieved from the phase transformation from the metastable tetragonal to the monoclinic crystalline phase, aka transformation toughening. There is also substantial interest in dispersion of hard, non-oxide phases such as SiC, TiB, TiC, boron, carbon and especially oxide matrices like alumina and mullite. There is also interest too incorporating other ceramic particulates, especially those of highly anisotropic thermal expansion. Examples include $Al_2O_3$, $TiO_2$, graphite, and boron nitride.[37] [38]

Silicon carbide single crystal

In processing particulate composites, the issue is not only homogeneity of the size and spatial distribution of the dispersed and matrix phases, but also control of the matrix grain size. However, there is some built-in self-control due to inhibition of matrix grain growth by the dispersed phase. Particulate composites, though generally offer increased resistance to damage, failure, or both, are still quite sensitive to inhomogeneities of composition as well as other processing defects such as pores. Thus they need good processing to be effective.[1] [16]

Particulate composites have been made on a commercial basis by simply mixing powders of the two constituents. Although this approach is inherently limited in the homogeneity that can be achieved, it is the most readily adaptable for existing ceramic production technology. However, other approaches are of interest.[1] [16]

Tungsten carbide milling bits

From the technological standpoint, a particularly desirable approach to fabricating particulate composites is to coat the matrix or its precursor onto fine particles of the dispersed phase with good control of the starting dispersed particle size and the resultant matrix coating thickness. One should in principle be able to achieve the ultimate in homogeneity of distribution and thereby optimize composite performance. This can also have other ramifications, such as allowing more useful composite performance to be achieved in a body having porosity, which might be desired for other factors, such as limiting thermal conductivity.

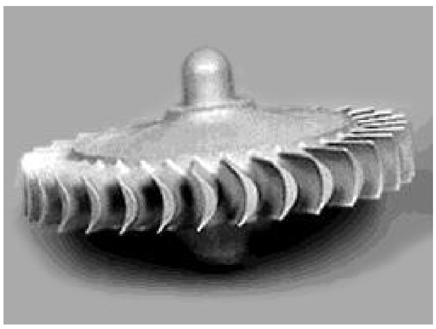
There are also some opportunities to utilize melt processing for fabrication of ceramic, particulate, whisker and short-fiber, and continuous-fiber composites. Clearly, both particulate and whisker composites are conceivable by solid-state precipitation after solidification of the melt. This can also be obtained in some cases by sintering, as for precipitation-toughened, partially stabilized zirconia. Similarly, it is known that one can directionally solidify ceramic eutectic mixtures and hence obtain uniaxially aligned fiber composites. Such composite processing has typically been limited to very simple shapes and thus suffers from serious economic problems due to high machining costs.[37] [38]

Clearly, there are possibilities of using melt casting for many of these approaches. Potentially even more desirable is using melt-derived particles. In this method, quenching is done in a solid solution or in a fine eutectic structure, in which the particles are then processed by more typical ceramic powder processing methods into a useful body. There have also been preliminary attempts to use melt spraying as a means of forming composites by introducing the dispersed particulate, whisker, or fiber phase in conjunction with the melt spraying process.

Other methods besides melt infiltration to manufacture ceramic composites with long fiber reinforcement are chemical vapor infiltration and the infiltration of fiber preforms with organic precursor, which after pyrolysis yield an amorphous ceramic matrix, initially with a low density. With repeated cycles of infiltration and pyrolysis one of those types of ceramic matrix composites is produced. Chemical vapor infiltration is used to manufacture carbon/carbon and silcon carbide reinforced with carbon or silicon carbide fibers.

Besides many process improvements, the first of two major needs for fiber composites is lower fiber costs. The second major need is fiber compositions or coatings, or composite processing, to reduce degradation that results from high-temperature composite exposure under oxidizing conditions.[37] [38]

## Applications



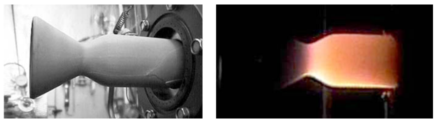
Radial rotor made from $Si_3N_4$ for a gas turbine engine

The products of technical ceramics include tiles used in the Space Shuttle program, gas burner nozzles, ballistic protection, nuclear fuel uranium oxide pellets, bio-medical implants, jet engine turbine blades, and missile nose cones.

Its products are often made from materials other than clay, chosen for their particular physical properties. These may be classified as follows:

- Oxides: silica, alumina, zirconia
- Non-oxides: carbides, borides, nitrides, silicides
- Composites: particulate or whisker reinforced matrices, combinations of oxides and non-oxides (e.g. polymers).

Ceramics can be used in many technological industries. One application are the ceramic tiles on NASA's Space Shuttle, used to protect it and the future supersonic space planes from the searing heat of reentry into the Earth's atmosphere. They are also used widely in electronics and optics. In addition to the applications listed here, ceramics are also used as a coating in various engineering cases. An example would be a ceramic bearing coating over a titanium frame used for an airplane. Recently the field has come to include the studies of single crystals or glass fibers, in addition to traditional polycrystalline materials, and the applications of these have been overlapping and changing rapidly.



Silicon nitride thruster. Left: Mounted in test stand. Right: Being tested with $H_2/O_2$ propellants

## Aerospace

- Engines; Shielding a hot running airplane engine from damaging other components.
- Airframes; Used as a high-stress, high-temp and lightweight bearing and structural component.
- Missile nose-cones; Shielding the missile internals from heat.
- Space Shuttle tiles
- Space-debris ballistic shields -- Ceramic fiber woven shields offer better protection to hypervelocity (~7 km/s) particles than aluminum shields of equal weight.[39]
- Rocket Nozzles; Withstands and focuses the exhaust of the rocket booster.

## Biomedical

- Artificial bone; Dentistry applications, teeth.
- Biodegradable splints; Reinforcing bones recovering from osteoporosis
- Implant material

A titanium hip prosthesis, with a ceramic head and polyethylene acetabular cup.

## Electronics

- Capacitors
- Integrated Circuit packages
- Transducers
- Insulators

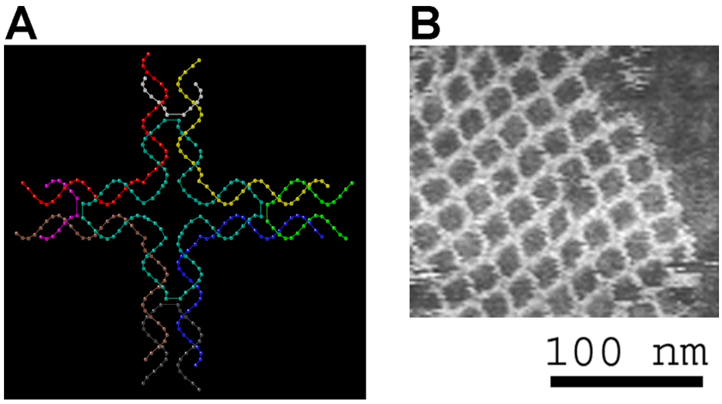
## Optical

- Optical fibers; Guided Lightwave Transmission
- Switches
- Laser amplifiers
- Lenses
- Infrared Heat Seeking Devices

### Automotive

- Heat shield
- Exhaust Heat Management

## Biomaterials



The DNA structure at left (schematic shown) will self-assemble into the structure visualized by atomic force microscopy at right.[40]

Silicification is quite common in the biological world and occurs in bacteria, single-celled organisms, plants, and animals (invertebrates and vertebrates). Crystalline minerals formed in such environment often show exceptional physical properties (e.g. strength, hardness, fracture toughness) and tend to form hierarchical structures that exhibit microstructural order over a range of length or spatial scales. The minerals are crystallized from an environment that is undersaturated with respect to silicon, and under conditions of neutral pH and low temperature (0-40 °C). Formation of the mineral may occur either within or outside of the cell wall of an organism, and specific biochemical reactions for mineral deposition exist that include lipids, proteins and carbohydrates. The significance of the cellular machinery cannot be overemphasized, and it is with advances in experimental techniques in cellular biology and the capacity to mimic the biological environment that significant progress is currently being reported.

Most natural (or biological) materials are complex composites whose mechanical properties are often outstanding, considering the weak constituents from which they are assembled. These complex structures, which have risen from hundreds of million years of evolution, are inspiring the design of novel materials with exceptional physical properties for high performance in adverse conditions. Their defining characteristics such as hierarchy, multifunctionality, and the capacity for self-healing, are currently being investigated.[41]

The basic building blocks begin with the 20 amino acids and proceed to polypeptides, polysaccharides, and polypeptides–saccharides. These, in turn, compose the basic proteins, which are the primary constituents of the ‘soft tissues’ common to most biominerals. With well over 1000 proteins possible, current research emphasizes the use of collagen, chitin, keratin, and elastin. The ‘hard’ phases are often strengthened by crystalline minerals, which nucleate and grow in a biomediated environment that determines the size, shape and distribution of individual crystals. The most important mineral phases have been identified as hydroxyapatite, silica, and aragonite. Using the classification of Wegst and Ashby, the principal mechanical characteristics and structures of biological ceramics, polymer composites, elastomers, and cellular materials have been presented. Selected systems in each class are being investigated with emphasis on the relationship between their microstructure over a range of length scales and their mechanical response.

Thus, the crystallization of inorganic materials in nature generally occurs at ambient temperature and pressure. Yet the vital organisms through which these minerals form are capable of consistently producing extremely precise and complex structures. Understanding the processes in which living organisms control the growth of crystalline minerals such as silica could lead to significant advances in the field of materials science, and open the door to novel synthesis techniques for nanoscale composite materials, or nanocomposites.


The iridescent nacre inside a Nautilus shell.

High-resolution SEM observations were performed of the microstructure of the mother-of-pearl (or nacre) portion of the abalone shell. Those shells exhibit the highest mechanical strength and fracture toughness of any non-metallic substance known. The nacre from the shell of the abalone has become one of the more intensively studied biological structures in materials science. Clearly visible in these images are the neatly stacked (or ordered) mineral tiles separated by thin organic sheets along with a macrostructure of larger periodic growth bands which collectively form what scientists are currently referring to as a hierarchical composite structure. (The term hierarchy simply implies that there are a range of structural features which exist over a wide range of length scales).[42]

Future developments reside in the synthesis of bio-inspired materials through processing methods and strategies that are characteristic of biological systems. These involve nanoscale self-assembly of the components and the development of hierarchical structures.[33] [34] [36] [43]

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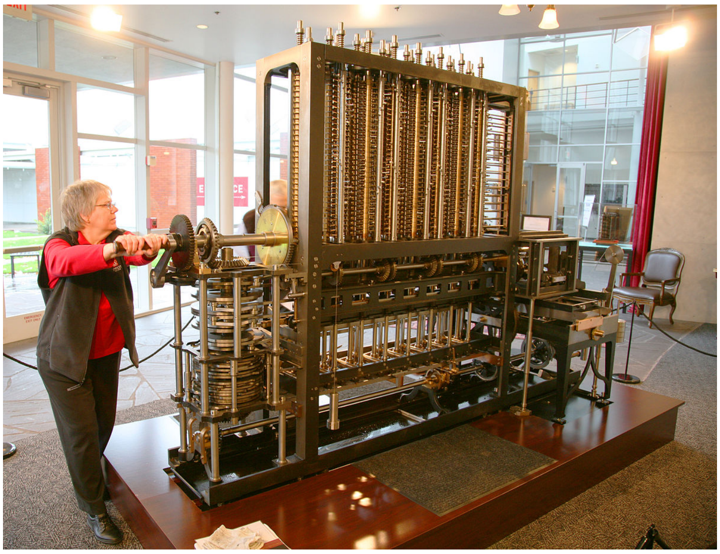
# External links

- The American Ceramic Society (http://www.ceramics.org)
- Ceramic Tile Institute of America (http://www.ctioa.org/)
- Ceramic Engineering Companies (http://www.ceramics-directory.com/CERAMIC-SERVICES/Engineering-Services/4-22-0.html)

# Computing

**Computing** is usually defined as the activity of using and improving computer hardware and software. It is the computer-specific part of information technology. Computer science (or computing science) is the study and the science of the theoretical foundations of information and computation and their implementation and application in computer systems.



A difference engine: computing the solution to a polynomial function

*Computing Curricula 2005*[1] defined "computing" as:

> "In a general way, we can define computing to mean any goal-oriented activity requiring, benefiting from, or creating computers. Thus, computing includes designing and building hardware and software systems for a wide range of purposes; processing, structuring, and managing various kinds of information; doing scientific studies using computers; making computer systems behave intelligently; creating and using communications and entertainment media; finding and gathering information relevant to any particular purpose, and so on. The list is virtually endless, and the possibilities are vast."

Computer laboratory, Moody Hall, James Madison University, 2003

A computer is a machine that manipulates data according to a set of instructions called a computer program. The program has an executable form that the computer can use directly to execute the instructions. The same program in its human-readable source code form, enables a programmer to study and develop the algorithm. Because the instructions can be carried out in different types of computers, a single set of source instructions converts to machine instructions according to the central processing unit type.


Wikimedia servers

The execution process carries out the instructions in a computer program. Instructions express the computations performed by the computer. They trigger sequences of simple actions on the executing machine. Those actions produce effects according to the semantics of the instructions.

Computer programming in general is the process of writing, testing, debugging, and maintaining the source code and documentation of computer programs. This source code is written in a programming language, which is an artificial language often more restrictive or demanding than natural languages, but easily translated by the computer. The purpose of programming is to invoke the desired behaviour (customization) from the machine. The process of writing high quality source code requires knowledge of both the application's domain *and* the computer science domain. The highest-quality software is thus developed by a team of various domain experts, each person a specialist in some area of development. But the term *programmer* may apply to a range of program quality, from hacker to open source contributor to professional. And a single programmer could do most or all of the computer programming needed to generate the proof of concept to launch a new "killer" application.

## Definitions

The term "computing" has sometimes been narrowly defined, as in a 1989 ACM report on *Computing as a Discipline*[2] :

> *The discipline of computing is the systematic study of algorithmic* processes that describe and transform information: their theory, analysis, design, efficiency, implementation, and application. The fundamental question underlying all computing is "What can be (efficiently) automated?"

*Computing Curricula 2005*[1] also recognizes that the meaning of "computing" depends on the context:

> *Computing also has other meanings that are more specific, based on the context in which the term is used. For example, an information systems specialist will view computing somewhat differently from a software engineer. Regardless of the context, doing computing well can be complicated and difficult. Because society needs people to do computing well, we must think of computing not only as a profession but also as a discipline.*

The term "computing" is also synonymous with counting and calculating. In earlier times, it was used in reference to mechanical computing machines.

A computer is a machine that reads, stores, manipulates and displays data. The most common example are the various personal computers. Other common examples include: mobile phones, mp3 players, or video game consoles.

## Science and theory

The Digital Bibliography & Library Project, as of July 2007, lists over 910,000 bibliographic entries on computer science and several thousand links to the home pages of computer scientists. Common topics include:

- Computer science
- Theory of computation
- Computational models
- Scientific computing
- Metacomputing
- Topological computing
- Autonomic Computing

## Hardware

See information processor for a high-level block diagram.

- Computer
- Computer Hardware Design
- Computer network
- Computer system
- History of computing hardware

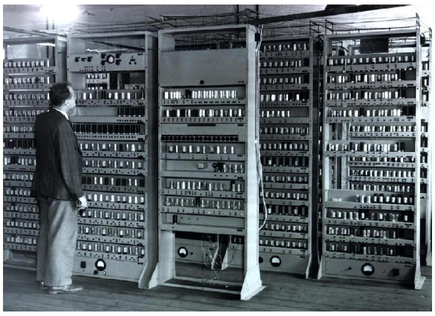
### Instruction-level taxonomies

After the commoditization of memory, attention turned to optimizing CPU performance at the instruction level. Various methods of speeding up the fetch-execute cycle include:

- designing instruction set architectures with simpler, faster instructions: RISC as opposed to CISC
- Superscalar instruction execution
- VLIW architectures, which make parallelism explicit

## Software

- Software engineering
- Computer programming
- Computational
- Software patent
- Firmware
- Operating systems
- Application Software
  - Databases
  - Geographic information system
  - Spreadsheet
  - Word processor
- Programming languages
  - interpreters
  - compilers
  - assemblers
- Speech recognition
- Speech synthesis



Part of an early computer, EDSAC.

## History of computing

- History of computing hardware from the tally stick to the quantum computer
- History of computer science
- Punched card
- Unit record equipment
- IBM 700/7000 series
- IBM 1400 series
- System/360
- Early IBM disk storage

## Business computing

- Accounting software
- Computer-aided design
- Computer-aided manufacturing
- Computer-assisted dispatch
- Customer relationship management
- Data warehouse
- Decision support system
- Electronic data processing
- Enterprise resource planning
- Geographic information system
- Management information system
- Material requirements planning
- Strategic enterprise management
- Supply chain management
- Product Lifecycle Management
- Utility Computing

## Human factors

- Accessible computing
- Computer-induced medical problems
- Computer user satisfaction
- Human-computer interaction
- Human-centered computing

## Computer network

### Wired and wireless computer network

- Types
  - Wide Area Network
  - Metropolitan Area Network
  - City Area Network
  - Village Area Network
  - Local Area Network
    - Wireless Local Area Network
- Mesh networking
- Collaborative workspace
- Internet
- Network Management

This notebook computer is connected to a wireless access point using a PC card wireless card.

### Computing technology based wireless networking (CbWN)

The main goal of CbWN is to optimize the system performance of the flexible wireless network.

- Source coding
  - Codebook design for side information based transmission techniques such as Precoding
  - Wyner-Ziv coding for cooperative wireless communications
- Security
  - Dirty paper coding for cooperative multiple antenna or user precoding
- Intelligence
  - Game theory for wireless networking
  - Cognitive communications
  - Flexible sectorization, Beamforming and SDMA
- Software
  - Software defined radio (SDR)
  - Programmable air-interface
  - Downloadable algorithm: e.g., downloadable codebook for Precoding

## Computer security

- Cryptology – cryptography – information theory
- Cracking – demon dialing – Hacking – war dialing – war driving
- Social engineering – Dumpster diving
- Physical security – Black bag job
- Computer insecurity
- Computer surveillance
- Defensive programming
- Malware
- Security engineering

## Data

### Numeric data

- integral data types – bit, byte, etc.
- real data types:
  - Floating point (Single precision, Double precision, etc.)
  - Fixed point
  - Rational number
- Decimal
  - Binary-coded decimal (BCD)
  - Excess-3 BCD (XS-3)
  - Biquinary-coded decimal
- representation: Binary – Octal – Decimal – Hexadecimal (hex)
- Computer mathematics – Computer numbering formats –

### Character data

- storage: Character – String – Plaintext
  - representation: ASCII – Unicode – Multibyte – EBCDIC (Widecharacter, Multicharacter) – Fieldata – Baudot

### Other data topics

- Data compression
- Digital signal processing
- Image processing
- Index (computer science)
- Data management
- Routing
- Data Protection Act

## Classes of computers

There are several terms which describe classes, or categories, of computers:


Polish analog computer AKAT-1

- Analog computer
- Calculator
- Desktop computer
- Desktop replacement computer
- Digital computer
- Embedded computer
- Home computer
- Laptop
- Mainframe
- Minicomputer
- Microcomputer
- Personal computer
- Portable computer
- Personal digital assistant (aka PDA, or Handheld computer)
- Programmable logic controller or PLC
- Server
- Supercomputer
- Tablet computer
- Video game console
- Workstation

## Companies – current

- Apple
- Asus
- Avaya
- Dell
- Fujitsu
- Gateway Computers
- Groupe Bull
- HCL
- Hewlett-Packard
- Hitachi, Ltd.
- Intel Corporation
- IBM
- Lenovo
- Microsoft
- NEC Corporation
- Novell
- Panasonic
- Red Hat
- Silicon Graphics
- Sun Microsystems
- Unisys

# Companies – historic

- Acorn, bought by Olivetti
- Amdahl Corporation, bought by Fujitsu
- Bendix Corporation
- Burroughs Corporation, merged with Sperry to become Unisys
- Compaq, bought by Hewlett-Packard
- Control Data
- Cray
- Data General
- Digital Equipment Corporation, bought by Compaq, later bought by Hewlett-Packard
- Digital Research – produced system software for early Intel microprocessor-based computers
- English Electric Company
- Ferranti
- General Electric, computer division bought by Honeywell, then Bull
- Honeywell, computer division bought by Bull
- ICL
- Leo
- Lisp Machines, Inc.
- Marconi
- Micro Instrumentation and Telemetry Systems produced the first widely sold microcomputer system (kit and assembled)
- Nixdorf Computer, bought by Siemens
- Norsk Data
- Olivetti
- Osborne
- Packard Bell
- PERQ
- Prime Computer
- Raytheon
- Royal McBee
- RCA
- Scientific Data Systems, sold to Xerox
- Siemens
- Sinclair Research, created the Sinclair ZX Spectrum, ZX80 and ZX81
- Southweat Technical products Corporation produced microcomputers systems (kit and assembled), peripherals, and software based on Motorola 6800 and 6809 microcomputer chips
- Sperry, which bought UNIVAC, and later merged with Burroughs to become Unisys
- Symbolics
- UNIVAC
- Varian Data Machines, a division of Varian Associates which was bought by Sperry
- Wang

# Organizations

## Professional

- Association for Computing Machinery (ACM)
- Association for Survey Computing [3] (ASC)
- British Computer Society (BCS)
- Canadian Information Processing Society (CIPS)
- Computer Measurement Group (CMG)
- Institute of Electrical and Electronics Engineers (IEEE), in particular the IEEE Computer Society

A computer Lab

- Institution of Electrical Engineers
- International Electrotechnical Commission (IEC)

### Standards bodies

*See also: Standardization and Standards organization*

- International Electrotechnical Commission (IEC)
- International Organization for Standardization (ISO)
- Institute of Electrical and Electronics Engineers (IEEE)
- Internet Engineering Task Force (IETF)
- World Wide Web Consortium (W3C)

### Open standards

*See also Open standard*

- Apdex Alliance – *Application Performance Index*
- Application Response Measurement (ARM)

## References

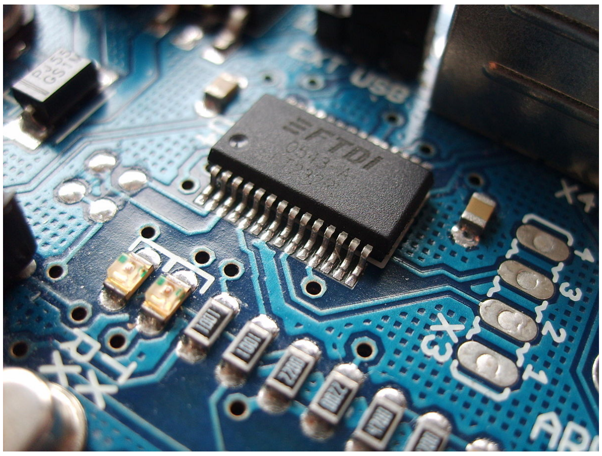
[1] The Joint Task Force for Computing Curricula 2005. Computing Curricula 2005: The Overview Report (pdf) (http://www.acm.org/education/curric_vols/CC2005-March06Final.pdf)
[2] Computing as a Discipline (pdf) (http://cs.gmu.edu/cne/pjd/GP/CompDisc.pdf)
[3] http://www.asc.org.uk/

## External links

http://foldoc.org/contents.html Free on-line dictionary of computing

http://pubs.doc.ic.ac.uk/ open-access repository of publications - Department of Computing - Imperial College London

# Electronics


Surface mount electronic components

**Electronics** is the branch of science, engineering and technology that deals with electrical circuits involving active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies. The nonlinear behaviour of active components and their ability to control electron flows makes amplification of weak signals possible and is usually applied to information and signal processing. Similarly, the ability of electronic devices to act as switches makes digital information processing possible. Interconnection technologies such as circuit boards, electronics packaging technology, and other varied forms of communication infrastructure complete circuit functionality and transform the mixed components into a working system.

Electronics is distinct from electrical and electro-mechanical science and technology, which deals with the generation, distribution, switching, storage and conversion of electrical energy to and from other energy forms using wires, motors, generators, batteries, switches, relays, transformers, resistors and other passive components. This distinction started around 1906 with the invention by Lee De Forest of the triode, which made electrical amplification of weak radio signals and audio signals possible with a non-mechanical device. Until 1950 this field was called "radio technology" because its principal application was the design and theory of radio transmitters, receivers and vacuum tubes.

Today, most electronic devices use semiconductor components to perform electron control. The study of semiconductor devices and related technology is considered a branch of solid state physics, whereas the design and construction of electronic circuits to solve practical problems come under electronics engineering. This article focuses on engineering aspects of electronics.

## Electronic devices and components

An electronic component is any physical entity in an electronic system used to affect the electrons or their associated fields in a desired manner consistent with the intended function of the electronic system. Components are generally intended to be connected together, usually by being soldered to a printed circuit board (PCB), to create an electronic circuit with a particular function (for example an amplifier, radio receiver, or oscillator). Components may be packaged singly or in more complex groups as integrated circuits. Some common electronic components are capacitors, inductors, resistors, diodes, transistors, etc. Components are often categorized as active (e.g. transistors and thyristors) or passive (e.g. resistors and capacitors).

## Early electronic components

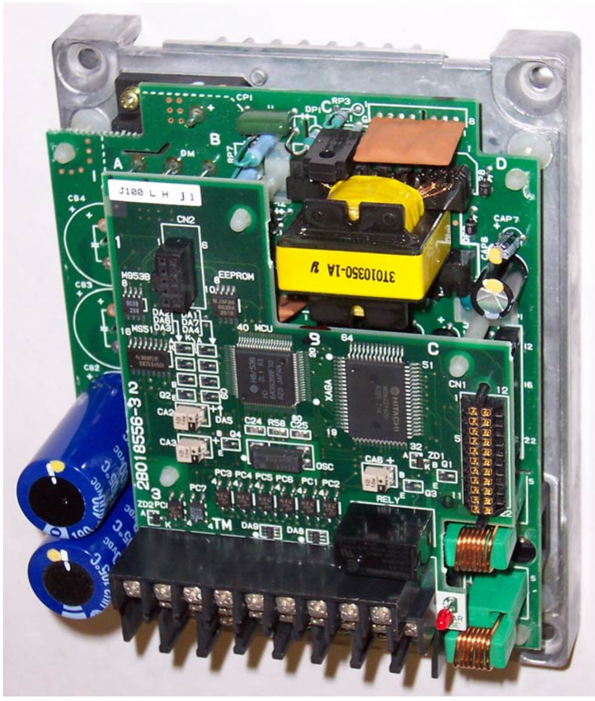
Vacuum tubes were one of the earliest electronic components. They dominated electronics until the 1950s. Since that time, solid state devices have all but completely taken over. Vacuum tubes are still used in some specialist applications such as high power RF amplifiers, cathode ray tubes, and some microwave devices.

## Types of circuits

Circuits and components can be divided into two groups: analog and digital. A particular device may consist of circuitry that has one or the other or a mix of the two types.

### Analog circuits

Most analog electronic appliances, such as radio receivers, are constructed from combinations of a few types of basic circuits. Analog circuits use a continuous range of voltage as opposed to discrete levels as in digital circuits.



Hitachi J100 adjustable frequency drive chassis.

The number of different analog circuits so far devised is huge, especially because a 'circuit' can be defined as anything from a single component, to systems containing thousands of components.

Analog circuits are sometimes called linear circuits although many non-linear effects are used in analog circuits such as mixers, modulators, etc. Good examples of analog circuits include vacuum tube and transistor amplifiers, operational amplifiers and oscillators.

One rarely finds modern circuits that are entirely analog. These days analog circuitry may use digital or even microprocessor techniques to improve performance. This type of circuit is usually called "mixed signal" rather than analog or digital.

Sometimes it may be difficult to differentiate between analog and digital circuits as they have elements of both linear and non-linear operation. An example is the comparator which takes in a continuous range of voltage but only outputs one of two levels as in a digital circuit. Similarly, an overdriven transistor amplifier can take on the characteristics of a controlled switch having essentially two levels of output.

### Digital circuits

Digital circuits are electric circuits based on a number of discrete voltage levels. Digital circuits are the most common physical representation of Boolean algebra and are the basis of all digital computers. To most engineers, the terms "digital circuit", "digital system" and "logic" are interchangeable in the context of digital circuits. Most digital circuits use a binary system with two voltage levels labeled "0" and "1". Often logic "0" will be a lower voltage and referred to as "Low" while logic "1" is referred to as "High". However, some systems use the reverse definition ("0" is "High") or are current based. Ternary (with three states) logic has been studied, and some prototype computers made. Computers, electronic clocks, and programmable logic controllers (used to control industrial processes) are constructed of digital circuits. Digital signal processors are another example.

Building blocks:

- Logic gates
- Adders
- Flip-Flops
- Counters
- Registers
- Multiplexers
- Schmitt triggers

Highly integrated devices:

- Microprocessors
- Microcontrollers
- Application-specific integrated circuit (ASIC)
- Digital signal processor (DSP)
- Field-programmable gate array (FPGA)

## Heat dissipation and thermal management

Heat generated by electronic circuitry must be dissipated to prevent immediate failure and improve long term reliability. Techniques for heat dissipation can include heat sinks and fans for air cooling, and other forms of computer cooling such as water cooling. These techniques use convection, conduction, & radiation of heat energy.

## Noise

Noise is associated with all electronic circuits. Noise is defined[1] as unwanted disturbances superposed on a useful signal that tend to obscure its information content. Noise is not the same as signal distortion caused by a circuit. Noise may be electromagnetically or thermally generated, which can be decreased by lowering the operating temperature of the circuit. Other types of noise, such as shot noise cannot be removed as they are due to limitations in physical properties.

## Electronics theory

Mathematical methods are integral to the study of electronics. To become proficient in electronics it is also necessary to become proficient in the mathematics of circuit analysis.

Circuit analysis is the study of methods of solving generally linear systems for unknown variables such as the voltage at a certain node or the current through a certain branch of a network. A common analytical tool for this is the SPICE circuit simulator.

Also important to electronics is the study and understanding of electromagnetic field theory.

## Electronics lab

Due to the empirical nature of electronics theory, laboratory experimentation is an important part of the study of electronics. These experiments are used to prove, verify, and reinforce laws and theorems such as Ohm's law, Kirchhoff's laws, etc. Historically, electronics labs have consisted of electronics devices and equipment located in a physical space, although in more recent years the trend has been towards electronics lab simulation software, such as CircuitLogix, Multisim, and PSpice.

## Computer aided design (CAD)

Today's electronics engineers have the ability to design circuits using premanufactured building blocks such as power supplies, semiconductors (such as transistors), and integrated circuits. Electronic design automation software programs include schematic capture programs and printed circuit board design programs. Popular names in the EDA software world are NI Multisim, Cadence (ORCAD), Eagle PCB and Schematic, Mentor (PADS PCB and LOGIC Schematic), Altium (Protel), LabCentre Electronics (Proteus), gEDA, KiCad and many others.

## Construction methods

Many different methods of connecting components have been used over the years. For instance, early electronics often used point to point wiring with components attached to wooden breadboards to construct circuits. Cordwood construction and wire wraps were other methods used. Most modern day electronics now use printed circuit boards made of materials such as FR4, or the cheaper (and less hard-wearing) Synthetic Resin Bonded Paper (SRBP, also known as Paxoline/Paxolin (trade marks) and FR2) - characterised by its light yellow-to-brown colour. Health and environmental concerns associated with electronics assembly have gained increased attention in recent years, especially for products destined to the European Union, with its Restriction of Hazardous Substances Directive (RoHS) and Waste Electrical and Electronic Equipment Directive (WEEE), which went into force in July 2006.

## References

[1] IEEE Dictionary of Electrical and Electronics Terms ISBN 978-0-471-42806-0

## Further reading

- *The Art of Electronics* ISBN 978-0-521-37095-0
- Online course on *Computational Electronics* (http://nanohub.org/resources/1500) on Nanohub.org

## External links

- Electrical and electronics web portal (http://www.electricalandelectronics.org)
- Electronics tutorials, projects and software (http://www.electroniq.net)
- Navy 1998 Navy Electricity and Electronics Training Series (NEETS) (http://www.phy.davidson.edu/instrumentation/NEETS.htm)
- DOE 1998 Electrical Science, Fundamentals Handbook, 4 vols.
  - Vol. 1, Basic Electrical Theory, Basic DC Theory (http://hss.energy.gov/nuclearsafety/ns/techstds/standard/hdbk1011/h1011v1.pdf)
  - Vol. 2, DC Circuits, Batteries, Generators, Motors (http://hss.energy.gov/nuclearsafety/ns/techstds/standard/hdbk1011/h1011v2.pdf)
  - Vol. 3, Basic AC Theory, Basic AC Reactive Components, Basic AC Power, Basic AC Generators (http://hss.energy.gov/nuclearsafety/ns/techstds/standard/hdbk1011/h1011v3.pdf)
  - Vol. 4, AC Motors, Transformers, Test Instruments & Measuring Devices, Electrical Distribution Systems (http://hss.energy.gov/nuclearsafety/ns/techstds/standard/hdbk1011/h1011v4.pdf)
- Electronics (http://www.dmoz.org/Science/Technology/Electronics//) at the Open Directory Project

# Energy


Lightning is the electric breakdown of air by strong electric fields, which produce a force on charges. When these charges move through a distance, a flow of energy occurs. The electric potential energy in the atmosphere then is transformed into thermal energy, light, and sound, which are other forms of energy.

In physics, **energy** (Ancient Greek: ἐνέργεια *energeia* "activity, operation"[1] ) is an indirectly observed quantity. It is often understood as the ability a physical system has to do work on other physical systems.[2][3] Since work is defined as a force acting through a distance (a length of space), energy is always equivalent to the ability to exert pulls or pushes against the basic forces of nature, along a path of a certain length.

The total energy contained in an object is identified with its mass, and energy (like mass), cannot be created or destroyed. When matter (ordinary material particles) is changed into energy (such as energy of motion, or into radiation), the **mass** of the system does not change through the transformation process. However, there may be mechanistic limits as to how much of the matter in an object may be changed into other types of energy and thus into work, on other systems. Energy, like mass, is a scalar physical quantity. In the International System of Units (SI), energy is measured in joules, but in many fields other units, such as kilowatt-hours and kilocalories, are customary. All of these units translate to units of work, which is always defined in terms of forces and the distances that the forces act through.

A system can transfer energy to another system by simply transferring matter to it (since matter is equivalent to energy, in accordance with its mass). However, when energy is transferred by means other than matter-transfer, the transfer produces changes in the second system, as a result of work done on it. This work manifests itself as the effect of force(s) applied through distances within the target system. For example, a system can emit energy to another by transferring (radiating) electromagnetic energy, but this creates forces upon the particles that absorb the radiation. Similarly, a system may transfer energy to another by physically impacting it, but in that case the energy of motion in an object, called kinetic energy, results in forces acting over distances (new energy) to appear in another object that is struck. Transfer of thermal energy by heat occurs by both of these mechanisms: heat can be transferred by electromagnetic radiation, or by physical contact in which direct particle-particle impacts transfer kinetic energy.

Energy may be stored in systems without being present as matter, or as kinetic or electromagnetic energy. Stored energy is created whenever a particle has been moved through a field it interacts with (requiring a force to do so), but the energy to accomplish this is stored as a new position of the particles in the field—a configuration that must be "held" or fixed by a different type of force (otherwise, the new configuration would resolve itself by the field pushing or pulling the particle back toward its previous position). This type of energy "stored" by force-fields and particles that have been forced into a new physical configuration in the field by doing work on them by another system, is referred to as potential energy. A simple example of potential energy is the work needed to lift an object in a gravity field, up to a support. Each of the basic forces of nature is associated with a different type of potential energy, and all types of potential energy (like all other types of energy) appears as system mass, whenever present. For example, a compressed spring will be slightly more massive than before it was compressed. Likewise, whenever energy is transferred between systems by any mechanism, an associated mass is transferred with it.

Any form of energy may be transformed into another form. For example, all types of potential energy are converted into kinetic energy when the objects are given freedom to move to different position (as for example, when an object falls off a support). When energy is in a form other than thermal energy, it may be transformed with good or even perfect efficiency, to any other type of energy, including electricity or production of new particles of matter. With thermal energy, however, there are often limits to the efficiency of the conversion to other forms of energy, as described by the second law of thermodynamics.

In all such energy transformation processes, the total energy remains the same, and a transfer of energy from one system to another, results in a loss to compensate for any gain. This principle, the conservation of energy, was first postulated in the early 19th century, and applies to any isolated system. According to Noether's theorem, the conservation of energy is a consequence of the fact that the laws of physics do not change over time.[4]

Although the total energy of a system does not change with time, its value may depend on the frame of reference. For example, a seated passenger in a moving airplane has zero kinetic energy relative to the airplane, but non-zero kinetic energy (and higher total energy) relative to the Earth.

## History

The word *energy* derives from the Greek ἐνέργεια *energeia*, which possibly appears for the first time in the work of Aristotle in the 4th century BCE.

The concept of energy emerged out of the idea of *vis viva* (living force), which Gottfried Leibniz defined as the product of the mass of an object and its velocity squared; he believed that total *vis viva* was conserved. To account for slowing due to friction, Leibniz theorized that thermal energy consisted of the random motion of the constituent parts of matter, a view shared by Isaac Newton, although it would be more than a century until this was generally accepted. In 1807, Thomas Young was possibly the first to use the term "energy" instead of *vis viva*, in its modern sense.[5] Gustave-Gaspard Coriolis described "kinetic energy" in 1829 in its modern sense, and in 1853, William Rankine coined the term "potential energy". It was argued for some years whether energy was a substance (the caloric) or merely a physical quantity, such as momentum.

William Thomson (Lord Kelvin) amalgamated all of these laws into the laws of thermodynamics, which aided in the rapid development of explanations of chemical processes by Rudolf Clausius, Josiah Willard Gibbs, and Walther Nernst. It also led to a mathematical formulation of the concept of entropy by Clausius and to the introduction of laws of radiant energy by Jožef Stefan.

During a 1961 lecture[6] for undergraduate students at the California Institute of Technology, Richard Feynman, a celebrated physics teacher and Nobel Laureate, said this about the concept of energy:

> There is a fact, or if you wish, a *law*, governing all natural phenomena that are known to date. There is no known exception to this law—it is exact so far as we know. The law is called the *conservation of energy*. It states that there is a certain quantity, which we call energy, that does not change in manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same.
>
> —*The Feynman Lectures on Physics*

Since 1918 it has been known that the law of conservation of energy is the direct mathematical consequence of the translational symmetry of the quantity conjugate to energy, namely time. That is, energy is conserved because the laws of physics do not distinguish between different instants of time (see Noether's theorem).

## Energy in various contexts

The concept of energy and its transformations is useful in explaining and predicting most natural phenomena. The *direction* of transformations in energy (what kind of energy is transformed to what other kind) is often described by entropy (equal energy spread among all available degrees of freedom) considerations, as in practice all energy transformations are permitted on a small scale, but certain larger transformations are not permitted because it is statistically unlikely that energy or matter will randomly move into more concentrated forms or smaller spaces.

The concept of energy is widespread in all sciences.

- In the context of chemistry, energy is an attribute of a substance as a consequence of its atomic, molecular or aggregate structure. Since a chemical transformation is accompanied by a change in one or more of these kinds of structure, it is invariably accompanied by an increase or decrease of energy of the substances involved. Some energy is transferred between the surroundings and the reactants of the reaction in the form of heat or light; thus the products of a reaction may have more or less energy than the reactants. A reaction is said to be exergonic if the final state is lower on the energy scale than the initial state; in the case of endergonic reactions the situation is the reverse. Chemical reactions are invariably not possible unless the reactants surmount an energy barrier known as the activation energy. The *speed* of a chemical reaction (at given temperature $T$) is related to the activation energy $E$, by the Boltzmann's population factor $e^{-E/kT}$ – that is the probability of molecule to have energy greater than or equal to $E$ at the given temperature $T$. This exponential dependence of a reaction rate on temperature is known as the Arrhenius equation.The activation energy necessary for a chemical reaction can be in the form of thermal energy.
- In biology, energy is an attribute of all biological systems from the biosphere to the smallest living organism. Within an organism it is responsible for growth and development of a biological cell or an organelle of a biological organism. Energy is thus often said to be stored by cells in the structures of molecules of substances such as carbohydrates (including sugars), lipids, and proteins, which release energy when reacted with oxygen in respiration. In human terms, the human equivalent (H-e) (Human energy conversion) indicates, for a given amount of energy expenditure, the relative quantity of energy needed for human metabolism, assuming an average human energy expenditure of 12,500kJ per day and a basal metabolic rate of 80 watts. For example, if our bodies run (on average) at 80 watts, then a light bulb running at 100 watts is running at 1.25 human equivalents (100 ÷ 80) i.e. 1.25 H-e. For a difficult task of only a few seconds' duration, a person can put out thousands of watts, many times the 746 watts in one official horsepower. For tasks lasting a few minutes, a fit human can generate perhaps 1,000 watts. For an activity that must be sustained for an hour, output drops to around 300; for an activity kept up all day, 150 watts is about the maximum.[7] The human equivalent assists understanding of energy flows in physical and biological systems by expressing energy units in human terms: it provides a “feel” for the use of a given amount of energy[8]
- In geology, continental drift, mountain ranges, volcanoes, and earthquakes are phenomena that can be explained in terms of energy transformations in the Earth's interior.,[9] while meteorological phenomena like wind, rain, hail, snow, lightning, tornadoes and hurricanes, are all a result of energy transformations brought about by solar energy on the atmosphere of the planet Earth.
- In cosmology and astronomy the phenomena of stars, nova, supernova, quasars and gamma ray bursts are the universe's highest-output energy transformations of matter. All stellar phenomena (including solar activity) are driven by various kinds of energy transformations. Energy in such transformations is either from gravitational collapse of matter (usually molecular hydrogen) into various classes of astronomical objects (stars, black holes, etc.), or from nuclear fusion (of lighter elements, primarily hydrogen).

Energy transformations in the universe over time are characterized by various kinds of potential energy that has been available since the Big Bang, later being "released" (transformed to more active types of energy such as kinetic or radiant energy), when a triggering mechanism is available.

Familiar examples of such processes include nuclear decay, in which energy is released that was originally "stored" in heavy isotopes (such as uranium and thorium), by nucleosynthesis, a process ultimately using the gravitational potential energy released from the gravitational collapse of supernovae, to store energy in the creation of these heavy elements before they were incorporated into the solar system and the Earth. This energy is triggered and released in nuclear fission bombs. In a slower process, **radioactive decay** of these atoms in the core of the Earth releases heat. This thermal energy drives plate tectonics and may lift mountains, via orogenesis. This slow lifting represents a kind of gravitational potential energy storage of the thermal energy, which may be later released to active kinetic energy in landslides, after a triggering event. Earthquakes also release stored elastic potential energy in rocks, a store that has been produced ultimately from the same radioactive heat sources. Thus, according to present understanding, familiar events such as landslides and earthquakes release energy that has been stored as potential energy in the Earth's gravitational field or elastic strain (mechanical potential energy) in rocks. Prior to this, they represent release of energy that has been stored in heavy atoms since the collapse of long-destroyed supernova stars created these atoms.

In another similar chain of transformations beginning at the dawn of the universe, **nuclear fusion** of hydrogen in the Sun also releases another store of potential energy which was created at the time of the Big Bang. At that time, according to theory, space expanded and the universe cooled too rapidly for hydrogen to completely fuse into heavier elements. This meant that hydrogen represents a store of potential energy that can be released by fusion. Such a fusion process is triggered by heat and pressure generated from gravitational collapse of hydrogen clouds when they produce stars, and some of the fusion energy is then transformed into sunlight. Such sunlight from our Sun may again be stored as gravitational potential energy after it strikes the Earth, as (for example) water evaporates from oceans and is deposited upon mountains (where, after being released at a hydroelectric dam, it can be used to drive turbines or generators to produce electricity). Sunlight also drives many weather phenomena, save those generated by volcanic events. An example of a solar-mediated weather event is a hurricane, which occurs when large unstable areas of warm ocean, heated over months, give up some of their thermal energy suddenly to power a few days of violent air movement. Sunlight is also captured by plants as *chemical potential energy* in photosynthesis, when carbon dioxide and water (two low-energy compounds) are converted into the high-energy compounds carbohydrates, lipids, and proteins. Plants also release oxygen during photosynthesis, which is utilized by living organisms as an electron acceptor, to release the energy of carbohydrates, lipids, and proteins. Release of the energy stored during photosynthesis as heat or light may be triggered suddenly by a spark, in a forest fire, or it may be made available more slowly for animal or human metabolism, when these molecules are ingested, and catabolism is triggered by enzyme action.

Through all of these transformation chains, potential energy stored at the time of the Big Bang is later released by intermediate events, sometimes being stored in a number of ways over time between releases, as more active energy. In all these events, one kind of energy is converted to other types of energy, including heat.

## Distinction between energy and power

Although in everyday usage the terms *energy* and *power* are essentially synonyms, scientists and engineers distinguish between them. In its technical sense, power is not at all the same as energy, but is the ***rate*** at which energy is converted (or, equivalently, at which work is performed). Thus a hydroelectric plant, by allowing the water above the dam to pass through turbines, converts the water's potential energy into kinetic energy and ultimately into electric energy, whereas the amount of electric energy that is generated ***per unit of time*** is the electric power generated. The same amount of energy converted through a shorter period of time is more power over that shorter time.

## Conservation of energy

Energy is subject to the **law of conservation of energy**. According to this law, energy can neither be created (produced) nor destroyed by itself. It can only be transformed.

Most kinds of energy (with gravitational energy being a notable exception)[10] are subject to strict local conservation laws as well. In this case, energy can only be exchanged between adjacent regions of space, and all observers agree as to the volumetric density of energy in any given space. There is also a global law of conservation of energy, stating that the total energy of the universe cannot change; this is a corollary of the local law, but not vice versa.[6][11] Conservation of energy is the mathematical consequence of translational symmetry of time (that is, the indistinguishability of time intervals taken at different time)[12] - see Noether's theorem.

According to Conservation of energy the total inflow of energy into a system must equal the total outflow of energy from the system, plus the change in the energy contained within the system.

This law is a fundamental principle of physics. It follows from the translational symmetry of time, a property of most phenomena below the cosmic scale that makes them independent of their locations on the time coordinate. Put differently, yesterday, today, and tomorrow are physically indistinguishable.

This is because energy is the quantity which is canonical conjugate to time. This mathematical entanglement of energy and time also results in the uncertainty principle - it is impossible to define the exact amount of energy during any definite time interval. The uncertainty principle should not be confused with energy conservation - rather it provides mathematical limits to which energy can in principle be defined and measured.

In quantum mechanics energy is expressed using the Hamiltonian operator. On any time scales, the uncertainty in the energy is by

$$\Delta E \Delta t \ge \frac{\hbar}{2}$$

which is similar in form to the Heisenberg uncertainty principle (but not really mathematically equivalent thereto, since *H* and *t* are not dynamically conjugate variables, neither in classical nor in quantum mechanics).

In particle physics, this inequality permits a qualitative understanding of virtual particles which carry momentum, exchange by which and with real particles, is responsible for the creation of all known fundamental forces (more accurately known as fundamental interactions). Virtual photons (which are simply lowest quantum mechanical energy state of photons) are also responsible for electrostatic interaction between electric charges (which results in Coulomb law), for spontaneous radiative decay of exited atomic and nuclear states, for the Casimir force, for van der Waals bond forces and some other observable phenomena.

## Applications of the concept of energy

Energy is subject to a strict global conservation law; that is, whenever one measures (or calculates) the total energy of a system of particles whose interactions do not depend explicitly on time, it is found that the total energy of the system always remains constant.[13]

- The total energy of a system can be subdivided and classified in various ways. For example, it is sometimes convenient to distinguish potential energy (which is a function of coordinates only) from kinetic energy (which is a function of coordinate time derivatives only). It may also be convenient to distinguish gravitational energy, electric energy, thermal energy, and other forms. These classifications overlap; for instance, thermal energy usually consists partly of kinetic and partly of potential energy.
- The *transfer* of energy can take various forms; familiar examples include work, heat flow, and advection, as discussed below.
- The word "energy" is also used outside of physics in many ways, which can lead to ambiguity and inconsistency. The vernacular terminology is not consistent with technical terminology. For example, while energy is always conserved (in the sense that the total energy does not change despite energy transformations), energy can be

converted into a form, e.g., thermal energy, that cannot be utilized to perform work. When one talks about "conserving energy by driving less," one talks about conserving fossil fuels and preventing useful energy from being lost as heat. This usage of "conserve" differs from that of the law of conservation of energy.[11]

In classical physics energy is considered a scalar quantity, the canonical conjugate to time. In special relativity energy is also a scalar (although not a Lorentz scalar but a time component of the energy-momentum 4-vector).[14] In other words, energy is invariant with respect to rotations of space, but not invariant with respect to rotations of space-time (= boosts).

## Energy transfer

Because energy is strictly conserved and is also locally conserved (wherever it can be defined), it is important to remember that by the definition of energy the transfer of energy between the "system" and adjacent regions is work. A familiar example is *mechanical work*. In simple cases this is written as the following equation:

$$\Delta E = W \quad \textbf{(1)}$$

if there are no other energy-transfer processes involved. Here $E$ is the amount of energy transferred, and $W$ represents the work done on the system.

More generally, the energy transfer can be split into two categories:

$$\Delta E = W + Q \quad \textbf{(2)}$$

where $Q$ represents the heat flow into the system.

There are other ways in which an open system can gain or lose energy. In chemical systems, energy can be added to a system by means of adding substances with different chemical potentials, which potentials are then extracted (both of these process are illustrated by fueling an auto, a system which gains in energy thereby, without addition of either work or heat). Winding a clock would be adding energy to a mechanical system. These terms may be added to the above equation, or they can generally be subsumed into a quantity called "energy addition term $E$ " which refers to *any* type of energy carried over the surface of a control volume or system volume. Examples may be seen above, and many others can be imagined (for example, the kinetic energy of a stream of particles entering a system, or energy from a laser beam adds to system energy, without either being either work-done or heat-added, in the classic senses).

$$\Delta E = W + Q + E \quad \textbf{(3)}$$

Where E in this general equation represents other additional advected energy terms not covered by work done on a system, or heat added to it.

Energy is also transferred from potential energy ( $E_p$) to kinetic energy ( $E_k$ ) and then back to potential energy constantly. This is referred to as conservation of energy. In this closed system, energy cannot be created or destroyed; therefore, the initial energy and the final energy will be equal to each other. This can be demonstrated by the following:

$$E_{pi} + E_{ki} = E_{pF} + E_{kF} \quad \textbf{(4)}$$

The equation can then be simplified further since $E_p = mgh$ (mass times acceleration due to gravity times the height) and $E_k = \frac{1}{2}mv^2$ (half mass times velocity squared). Then the total amount of energy can be found by adding $E_p + E_k = E_{total}$ .

## Energy and the laws of motion

In classical mechanics, energy is a conceptually and mathematically useful property, as it is a conserved quantity. Several formulations of mechanics have been developed using energy as a core concept.

### The Hamiltonian

The total energy of a system is sometimes called the Hamiltonian, after William Rowan Hamilton. The classical equations of motion can be written in terms of the Hamiltonian, even for highly complex or abstract systems. These classical equations have remarkably direct analogs in nonrelativistic quantum mechanics.[15]

### The Lagrangian

Another energy-related concept is called the Lagrangian, after Joseph Louis Lagrange. This is even more fundamental than the Hamiltonian, and can be used to derive the equations of motion. It was invented in the context of classical mechanics, but is generally useful in modern physics. The Lagrangian is defined as the kinetic energy *minus* the potential energy.

Usually, the Lagrange formalism is mathematically more convenient than the Hamiltonian for non-conservative systems (such as systems with friction).

### Noether's Theorem

Noether's (first) theorem (1918) states that any differentiable symmetry of the action of a physical system has a corresponding conservation law.

Noether's theorem has become a fundamental tool of modern theoretical physics and the calculus of variations. A generalization of the seminal formulations on constants of motion in Lagrangian and Hamiltonian mechanics (1788 and 1833, respectively), it does not apply to systems that cannot be modeled with a Lagrangian; for example, dissipative systems with continuous symmetries need not have a corresponding conservation law.

## Energy and thermodynamics

### Internal energy

Internal energy is the sum of all microscopic forms of energy of a system. It is the energy needed to create the system. It is related to the potential energy, e.g., molecular structure, crystal structure, and other geometric aspects, as well as the motion of the particles, in form of kinetic energy. Thermodynamics is chiefly concerned with changes in internal energy and not its absolute value, which is impossible to determine with thermodynamics alone.[16]

### The laws of thermodynamics

According to the second law of thermodynamics, work can be totally converted into heat, but not vice versa. This is a mathematical consequence of statistical mechanics. The first law of thermodynamics simply asserts that energy is conserved,[17] and that heat is included as a form of energy transfer. A commonly used corollary of the first law is that for a "system" subject only to pressure forces and heat transfer (e.g., a cylinder-full of gas), the differential change in energy of the system (with a *gain* in energy signified by a positive quantity) is given as the following equation:

$$\mathrm{d}E = T\mathrm{d}S - P\mathrm{d}V,$$

where the first term on the right is the heat transfer into the system, defined in terms of temperature $T$ and entropy $S$ (in which entropy increases and the change d$S$ is positive when the system is heated), and the last term on the right hand side is identified as "work" done on the system, where pressure is $P$ and volume $V$ (the negative sign results since compression of the system requires work to be done on it and so the volume change, d$V$, is negative when work is done on the system). Although this equation is the standard textbook example of energy conservation in classical thermodynamics, it is highly specific, ignoring all chemical, electric, nuclear, and gravitational forces, effects such as advection of any form of energy other than heat, and because it contains a term that depends on temperature. The most general statement of the first law (i.e., conservation of energy) is valid even in situations in which temperature is undefinable.

Energy is sometimes expressed as the following equation:

$$\mathrm{d}E = \delta Q + \delta W,$$

which is unsatisfactory[11] because there cannot exist any thermodynamic state functions *W* or *Q* that are meaningful on the right hand side of this equation, except perhaps in trivial cases.

## Equipartition of energy

The energy of a mechanical harmonic oscillator (a mass on a spring) is alternatively kinetic and potential. At two points in the oscillation cycle it is entirely kinetic, and alternatively at two other points it is entirely potential. Over the whole cycle, or over many cycles, net energy is thus equally split between kinetic and potential. This is called equipartition principle; total energy of a system with many degrees of freedom is equally split among all available degrees of freedom.

This principle is vitally important to understanding the behavior of a quantity closely related to energy, called entropy. Entropy is a measure of evenness of a distribution of energy between parts of a system. When an isolated system is given more degrees of freedom (i.e., given new available energy states that are the same as existing states), then total energy spreads over **all** available degrees equally without distinction between "new" and "old" degrees. This mathematical result is called the second law of thermodynamics.

## Oscillators, phonons, and photons

In an ensemble (connected collection) of unsynchronized oscillators, the average energy is spread equally between kinetic and potential types.

In a solid, thermal energy (often referred to loosely as heat content) can be accurately described by an ensemble of thermal phonons that act as mechanical oscillators. In this model, thermal energy is equally kinetic and potential.

In an ideal gas, the interaction potential between particles is essentially the delta function which stores no energy: thus, all of the thermal energy is kinetic.

Because an electric oscillator (LC circuit) is analogous to a mechanical oscillator, its energy must be, on average, equally kinetic and potential. It is entirely arbitrary whether the magnetic energy is considered kinetic and whether the electric energy is considered potential, or vice versa. That is, either the inductor is analogous to the mass while the capacitor is analogous to the spring, or vice versa.

1. By extension of the previous line of thought, in free space the electromagnetic field can be considered an ensemble of oscillators, meaning that radiation energy can be considered equally potential and kinetic. This model is useful, for example, when the electromagnetic Lagrangian is of primary interest and is interpreted in terms of potential and kinetic energy.

2. On the other hand, in the key equation $m^2c^4 = E^2 - p^2c^2$, the contribution $mc^2$ is called the rest energy, and all other contributions to the energy are called kinetic energy. For a particle that has mass, this implies that the kinetic energy is $0.5p^2/m$ at speeds much smaller than *c*, as can be proved by writing $E = mc^2$ √ $(1 + p^2m^{-2}c^{-2})$ and expanding the square root to lowest order. By this line of reasoning, the energy of a photon is entirely kinetic, because the photon is massless and has no rest energy. This expression is useful, for example, when the energy-versus-momentum relationship is of primary interest.

The two analyses are entirely consistent. The electric and magnetic degrees of freedom in item 1 are *transverse* to the direction of motion, while the speed in item 2 is *along* the direction of motion. For non-relativistic particles these two notions of potential versus kinetic energy are numerically equal, so the ambiguity is harmless, but not so for relativistic particles.

### Work and virtual work

Work, a form of energy, is force times distance.

$$W = \int_C \mathbf{F} \cdot \mathrm{d}\mathbf{s}$$

This says that the work ( $W$ ) is equal to the line integral of the force **F** along a path *C*; for details see the mechanical work article.

Work and thus energy is frame dependent. For example, consider a ball being hit by a bat. In the center-of-mass reference frame, the bat does no work on the ball. But, in the reference frame of the person swinging the bat, considerable work is done on the ball.

### Quantum mechanics

In quantum mechanics energy is defined in terms of the energy operator as a time derivative of the wave function. The Schrödinger equation equates the energy operator to the full energy of a particle or a system. In results can be considered as a definition of measurement of energy in quantum mechanics. The Schrödinger equation describes the space- and time-dependence of slow changing (non-relativistic) wave function of quantum systems. The solution of this equation for bound system is discrete (a set of permitted states, each characterized by an energy level) which results in the concept of quanta. In the solution of the Schrödinger equation for any oscillator (vibrator) and for electromagnetic waves in a vacuum, the resulting energy states are related to the frequency by the Planck equation $E = h\nu$ (where $h$ is the Planck's constant and $\nu$ the frequency). In the case of electromagnetic wave these energy states are called quanta of light or photons.

### Relativity

When calculating kinetic energy (work to accelerate a mass from zero speed to some finite speed) relativistically - using Lorentz transformations instead of Newtonian mechanics, Einstein discovered an unexpected by-product of these calculations to be an energy term which does not vanish at zero speed. He called it rest mass energy - energy which every mass must possess even when being at rest. The amount of energy is directly proportional to the mass of body:

$$E = mc^2,$$

where

*m* is the mass,

*c* is the speed of light in vacuum,

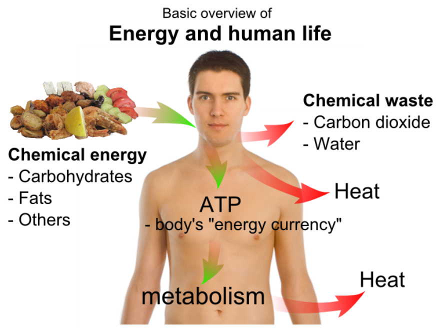
*E* is the rest mass energy.

For example, consider electron-positron annihilation, in which the rest mass of individual particles is destroyed, but the inertia equivalent of the system of the two particles (its invariant mass) remains (since all energy is associated with mass), and this inertia and invariant mass is carried off by photons which individually are massless, but as a system retain their mass. This is a reversible process - the inverse process is called pair creation - in which the rest mass of particles is created from energy of two (or more) annihilating photons. In this system the matter (electrons and positrons) is destroyed and changed to non-matter energy (the photons). However, the total system mass and energy do not change during this interaction.

In general relativity, the stress-energy tensor serves as the source term for the gravitational field, in rough analogy to the way mass serves as the source term in the non-relativistic Newtonian approximation.[14]

It is not uncommon to hear that energy is "equivalent" to mass. It would be more accurate to state that every energy has an inertia and gravity equivalent, and because mass is a form of energy, then mass too has inertia and gravity associated with it.

## Energy and life




Basic overview of energy and human life.

Any living organism relies on an external source of energy—radiation from the Sun in the case of green plants; chemical energy in some form in the case of animals—to be able to grow and reproduce. The daily 1500–2000 Calories (6–8 MJ) recommended for a human adult are taken as a combination of oxygen and food molecules, the latter mostly carbohydrates and fats, of which glucose ($C_6H_{12}O_6$) and stearin ($C_{57}H_{110}O_6$) are convenient examples. The food molecules are oxidised to carbon dioxide and water in the mitochondria

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

$$C_{57}H_{110}O_6 + 81.5O_2 \rightarrow 57CO_2 + 55H_2O$$

and some of the energy is used to convert ADP into ATP

$$\text{ADP} + HPO_4^{2-} \rightarrow \text{ATP} + H_2O$$

The rest of the chemical energy in the carbohydrate or fat is converted into heat: the ATP is used as a sort of "energy currency", and some of the chemical energy it contains when split and reacted with water, is used for other metabolism (at each stage of a metabolic pathway, some chemical energy is converted into heat). Only a tiny fraction of the original chemical energy is used for work:[18]

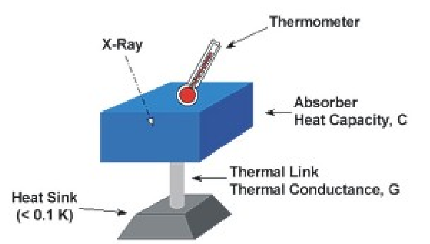
gain in kinetic energy of a sprinter during a 100 m race: 4 kJ

gain in gravitational potential energy of a 150 kg weight lifted through 2 metres: 3kJ

Daily food intake of a normal adult: 6–8 MJ

It would appear that living organisms are remarkably inefficient (in the physical sense) in their use of the energy they receive (chemical energy or radiation), and it is true that most real machines manage higher efficiencies. In growing organisms the energy that is converted to heat serves a vital purpose, as it allows the organism tissue to be highly ordered with regard to the molecules it is built from. The second law of thermodynamics states that energy (and matter) tends to become more evenly spread out across the universe: to concentrate energy (or matter) in one specific place, it is necessary to spread out a greater amount of energy (as heat) across the remainder of the universe ("the surroundings").[19] Simpler organisms can achieve higher energy efficiencies than more complex ones, but the complex organisms can occupy ecological niches that are not available to their simpler brethren. The conversion of a portion of the chemical energy to heat at each step in a metabolic pathway is the physical reason behind the pyramid of biomass observed in ecology: to take just the first step in the food chain, of the estimated 124.7 Pg/a of carbon that is fixed by photosynthesis, 64.3 Pg/a (52%) are used for the metabolism of green plants,[20] i.e. reconverted into carbon dioxide and heat.

# Measurement



A schematic diagram of a Calorimeter - An instrument used by physicists to measure energy

Because energy is defined as the ability to do work on objects, there is no absolute measure of energy. Only the transition of a system from one state into another can be defined and thus energy is measured in relative terms. The choice of a baseline or zero point is often arbitrary and can be made in whatever way is most convenient for a problem.

## Methods

The methods for the measurement of energy often deploy methods for the measurement of still more fundamental concepts of science, namely mass, distance, radiation, temperature, time, electric charge and electric current.

Conventionally the technique most often employed is calorimetry, a thermodynamic technique that relies on the measurement of temperature using a thermometer or of intensity of radiation using a bolometer.

## Units

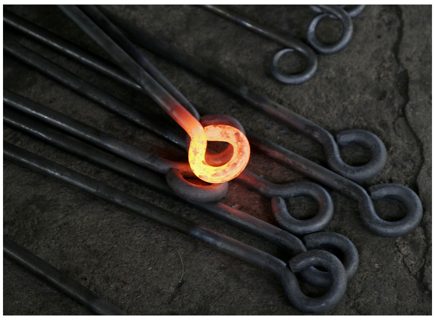
Throughout the history of science, energy has been expressed in several different units such as ergs and calories. At present, the accepted unit of measurement for energy is the SI unit of energy, the joule. In addition to the joule, other units of energy include the kilowatt hour (kWh) and the British thermal unit (Btu). These are both larger units of energy. One kWh is equivalent to exactly 3.6 million joules, and one Btu is equivalent to about 1055 joules.[21]

## Energy density

**Energy density** is a term used for the amount of useful energy stored in a given system or region of space per unit volume.

For fuels, the energy per unit volume is sometimes a useful parameter. In a few applications, comparing, for example, the effectiveness of hydrogen fuel to gasoline it turns out that hydrogen has a higher specific energy than does gasoline, but, even in liquid form, a much lower energy *density*.

# Forms of energy


Heat, a form of energy, is partly potential energy and partly kinetic energy.

In the context of physical sciences, several forms of energy have been defined. These include:

- Thermal energy, thermal energy in transit is called heat
- Chemical energy
- Electrical energy
- Radiant energy, the energy of electromagnetic radiation
- Nuclear energy
- Magnetic energy
- Elastic energy
- Sound energy
- Mechanical energy
- Luminous energy

These forms of energy may be divided into two main groups; kinetic energy and potential energy. Other familiar types of energy are a varying mix of both potential and kinetic energy.

Energy may be transformed between these forms, some with 100% energy conversion efficiency and others with less. Items that transform between these forms are called transducers.

The above list of the known possible forms of energy is not necessarily complete. Whenever physical scientists discover that a certain phenomenon appears to violate the law of energy conservation, new forms may be added, as is the case with dark energy, a hypothetical form of energy that permeates all of space and tends to increase the rate of expansion of the universe.

Classical mechanics distinguishes between potential energy, which is a function of the position of an object, and kinetic energy, which is a function of its movement. Both position and movement are relative to a frame of reference, which must be specified: this is often (and originally) an arbitrary fixed point on the surface of the Earth, the *terrestrial* frame of reference. It has been attempted to categorize *all* forms of energy as either kinetic or potential: this is not incorrect, but neither is it clear that it is a real simplification, as Feynman points out:

> These notions of potential and kinetic energy depend on a notion of length scale. For example, one can speak of *macroscopic* potential and kinetic energy, which do not include thermal potential and kinetic energy. Also what is called chemical potential energy (below) is a macroscopic notion, and closer examination shows that it is really the sum of the potential *and kinetic* energy on the atomic and subatomic scale. Similar remarks apply to nuclear "potential" energy and most other forms of energy. This dependence on length scale is non-problematic if the various length scales are decoupled, as is often the case ... but confusion can arise when different length scales are coupled, for instance when friction converts macroscopic work into microscopic thermal energy.

## Transformations of energy

One form of energy can often be readily transformed into another with the help of a device- for instance, a battery, from chemical energy to electric energy; a dam: gravitational potential energy to kinetic energy of moving water (and the blades of a turbine) and ultimately to electric energy through an electric generator. Similarly, in the case of a chemical explosion, chemical potential energy is transformed to kinetic energy and thermal energy in a very short time. Yet another example is that of a pendulum. At its highest points the kinetic energy is zero and the gravitational potential energy is at maximum. At its lowest point the kinetic energy is at maximum and is equal to the decrease of potential energy. If one (unrealistically) assumes that there is no friction, the conversion of energy between these processes is perfect, and the pendulum will continue swinging forever.

Energy gives rise to weight when it is trapped in a system with zero momentum, where it can be weighed. It is also equivalent to mass, and this mass is always associated with it. Mass is also equivalent to a certain amount of energy, and likewise always appears associated with it, as described in mass-energy equivalence. The formula $E = mc^2$, derived by Albert Einstein (1905) quantifies the relationship between rest-mass and rest-energy within the concept of special relativity. In different theoretical frameworks, similar formulas were derived by J. J. Thomson (1881), Henri Poincaré (1900), Friedrich Hasenöhrl (1904) and others (see Mass-energy equivalence#History for further information).

Matter may be destroyed and converted to energy (and vice versa), but mass cannot ever be destroyed; rather, mass remains a constant for both the matter and the energy, during any process when they are converted into each other. However, since $c^2$ is extremely large relative to ordinary human scales, the conversion of ordinary amount of matter (for example, 1 kg) to other forms of energy (such as heat, light, and other radiation) can liberate tremendous amounts of energy (~ $9x10^{16}$joules = 21 megatons of TNT), as can be seen in nuclear reactors and nuclear weapons. Conversely, the mass equivalent of a unit of energy is minuscule, which is why a loss of energy (loss of mass) from most systems is difficult to measure by weight, unless the energy loss is very large. Examples of energy transformation into matter (i.e., kinetic energy into particles with rest mass) are found in high-energy nuclear physics.

Transformation of energy into useful work is a core topic of thermodynamics. In nature, transformations of energy can be fundamentally classed into two kinds: those that are thermodynamically reversible, and those that are thermodynamically irreversible. A reversible process in thermodynamics is one in which no energy is dissipated (spread) into empty energy states available in a volume, from which it cannot be recovered into more concentrated forms (fewer quantum states), without degradation of even more energy. A reversible process is one in which this sort of dissipation does not happen. For example, conversion of energy from one type of potential field to another, is reversible, as in the pendulum system described above. In processes where heat is generated, quantum states of lower energy, present as possible excitations in fields between atoms, act as a reservoir for part of the energy, from which it cannot be recovered, in order to be converted with 100% efficiency into other forms of energy. In this case, the energy must partly stay as heat, and cannot be completely recovered as usable energy, except at the price of an increase in some other kind of heat-like increase in disorder in quantum states, in the universe (such as an expansion of matter, or a randomization in a crystal).

As the universe evolves in time, more and more of its energy becomes trapped in irreversible states (i.e., as heat or other kinds of increases in disorder). This has been referred to as the inevitable thermodynamic heat death of the universe. In this heat death the energy of the universe does not change, but the fraction of energy which is available to do work through a heat engine, or be transformed to other usable forms of energy (through the use of generators attached to heat engines), grows less and less.

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## External links

- Energy (http://www.dmoz.org/Science/Technology/Energy/) at the Open Directory Project

# Energy storage

**Energy storage** is accomplished by devices or physical media that store some form of energy to perform some useful operation at a later time. A device that stores energy is sometimes called an accumulator.

The Llyn Stwlan upper reservoir and dam of the Ffestiniog Pumped Storage Scheme in north Wales. The lower power station has four water turbines which can generate 360 MW of electricity within 60 seconds, an example of artificial energy storage and conversion.

All forms of energy are either potential energy (e.g. Chemical, gravitational, electrical energy, etc.) or kinetic energy (e.g. thermal energy). A wind-up clock stores potential energy (in this case mechanical, in the spring tension), a battery stores readily convertible chemical energy to operate a mobile phone, and a hydroelectric dam stores energy in a reservoir as gravitational potential energy. Ice storage tanks store ice (thermal energy) at night to meet peak demand for cooling. Fossil fuels such as coal and gasoline store ancient energy derived from sunlight by organisms that later died, became buried and over time were then converted into these fuels. Even food (which is made by the same process as fossil fuels) is a form of energy stored in chemical form.

## Early history

Energy storage as a natural process is as old as the universe itself - the energy present at the initial formation of the universe has been stored in stars such as the Sun, and is now being used by humans directly (e.g. through solar heating), or indirectly (e.g. by growing crops or conversion into electricity in solar cells).

As a purposeful activity, energy storage has existed since pre-history, though it was often not explicitly recognized as such. An example of deliberate mechanical energy storage is the use of logs or boulders as defensive measures in ancient forts—the logs or boulders were collected at the top of a hill or wall, and the energy thus stored used to attack invaders who came within range.

A more recent application is the control of waterways to drive water mills for processing grain or powering machinery. Complex systems of reservoirs and dams were constructed to store and release water (and the potential energy it contained) when required.

## Modern era developments

Storing energy allows humans to balance the supply and demand of energy. Energy storage systems in commercial use today can be broadly categorized as mechanical, electrical, chemical, biological and thermal.

Energy storage became a dominant factor in economic development with the widespread introduction of electricity and refined chemical fuels, such as gasoline, kerosene and natural gas in the late 19th century. Unlike other common energy storage in prior use such as wood or coal, electricity must be used as it is being generated, or converted immediately into another form of energy such as potential, kinetic or chemical. Until recently electrical energy has not been converted and stored on a major scale, however new efforts to that effect began in the 21st century.

In the U.S., the 2009 Stimulus Plan helped finance research into energy storage and its integration with smart electrical grids.[1] Electricity is transmitted in a closed circuit, and for essentially any practical purposes cannot be stored as electrical energy. This means that changes in demand can not be accommodated without either cutting supplies (as by brownouts or blackouts) or by storing the electric energy in another medium.

Even renewable energy must be stored in order to make it reliable. Wind blows intermittently and so some form of storage is required to compensate for calm periods. Solar energy is equally not available on cloudy days and during the nighttime, so stored energy must be available to compensate for the loss of sunlight.

An early solution to the problem of storing energy for electrical purposes was the development of the battery as an electrochemical storage device. Batteries have previously been of limited use in electric power systems due to their relatively small capacity and high cost, however since about the middle of the first decade of the 21st century newer battery technologies have been developed that can now provide significant utility scale load-leveling capabilities.[2] A similar possible solution to deal with the intermittency issue of solar and wind energy is found in the capacitor.

In the 1980s, a number of manufacturers carefully researched thermal energy storage (TES) to meet the growing demand for air conditioning during peak hours. Today, several companies manufacture TES systems.[3] The most popular form of thermal energy storage for cooling is ice storage, since it can store more energy in less space than water storage and it is also less costly than energy recovered via fuel cells or flywheels. Thermal storage has cost-effectively shifted gigawatts of power away from daytime peak usage periods, and in 2009 was used in over 3,300 buildings in over 35 countries. It works by creating ice at night when electricity is usually less costly, and then using the ice to cool the air in buildings during the hotter daytime periods.

Chemical fuels have become the dominant form of energy storage, both in electrical generation and energy transportation. Chemical fuels in common use are processed coal, gasoline, diesel fuel, natural gas, liquefied petroleum gas (LPG), propane, butane, ethanol and biodiesel. All of these materials are readily converted to mechanical energy and then to electrical energy using heat engines (via turbines or other internal combustion engines, or boilers or other external combustion engines) used for electrical power generation. Heat-engine-powered generators are nearly universal, ranging from small engines producing only a few kilowatts to utility-scale generators with ratings up to 800 megawatts. A key disadvantage to hydrocarbon fuels are their significant emissions of greenhouse gases that contribute to global warming, as well as other significant pollutants emitted by the dirtier fuel sources such as coal and gasoline.

Some areas of the world such as Washington and Oregon in the United States, and Wales in the United Kingdom, have used geographic features to store large quantities of water in elevated reservoirs, using excess electricity at times of low demand to pump water up to the reservoirs, then letting the water pass through turbine generators to retrieve the energy when electrical demands peak.[2]

Liquid hydrocarbon fuels are the most commonly used forms of energy storage for use in transportation, but because the byproducts of the reaction that utilizes these liquid fuels' energy (combustion) produce greenhouse gases other energy carriers like hydrogen can be used to avoid production of greenhouse gases.

## Advanced systems

Electrochemical devices called fuel cells were invented about the same time as the battery in the 19th Century. However, for many reasons, fuel cells were not well-developed until the advent of manned spaceflight (such as the Gemini Program in the U.S.) when lightweight, non-thermal (and therefore efficient) sources of electricity were required in spacecraft. Fuel cell development has increased in recent years due to an attempt to increase conversion efficiency of chemical energy stored in hydrocarbon or hydrogen fuels into electricity.

Several other technologies have also been investigated, such as flywheels, which can store kinetic energy, and compressed air storage that can be pumped into underground caverns and abandoned mines.[2]

Another method used at the Solar Project and the Solar Tres Power Tower uses molten salt to store solar power and then dispatch that power as needed. The system pumps molten salt through a tower heated by the sun's rays. Insulated containers store the hot salt solution, and when needed water is then used to create steam that is fed to turbines to generate electricity.

Research is being conducted on harnessing the quantum effects of nanoscale capacitors to create digital quantum batteries. Although this technology is still in the experimental stage, it theoretically has the potential to provide dramatic increases in energy storage capacity.[4] [5]

## Grid energy storage

Grid energy storage (or large-scale energy storage) lets energy producers send excess electricity over the electricity transmission grid to temporary electricity storage sites that become energy producers when electricity demand is greater. Grid energy storage is particularly important in matching supply and demand over a 24 hour period of time.

A proposed variant of grid energy storage is called Vehicle-to-Grid energy storage system, where modern electric vehicles that are plugged into the energy grid can release the stored electrical energy in their batteries back into the grid when needed.

## Storage methods

- Chemical
  - Hydrogen
  - Biofuels
  - Liquid nitrogen
  - Oxyhydrogen
  - Hydrogen peroxide
- Biological
  - Starch
  - Glycogen
- Electrochemical
  - Batteries
  - Flow batteries
  - Fuel cells
- Electrical
  - Capacitor
  - Supercapacitor
  - Superconducting magnetic energy storage (SMES)
- Mechanical
  - Compressed air energy storage (CAES)
  - Flywheel energy storage
  - Hydraulic accumulator
  - Hydroelectric energy storage
  - Spring
  - Gravitational potential energy (device)
- Thermal
  - Ice Storage
  - Molten salt
  - Cryogenic liquid air or nitrogen
  - Seasonal thermal store
  - Solar pond
  - Hot bricks
  - Steam accumulator
  - Fireless locomotive
  - Eutectic system
- Fuel Conservation storage

## Hydrogen

Hydrogen is also being developed as an electrical power storage medium. Hydrogen is not a primary energy source, but a portable energy storage method, because it must first be manufactured by other energy sources in order to be used. However, as a storage medium, it may be a significant factor in using renewable energies. See hydrogen storage.

Underground hydrogen storage is the practice of hydrogen storage in underground caverns, salt domes and depleted oil and gas fields. Large quantities of gaseous hydrogen are stored in underground caverns for many years without any difficulties.[6] The storage of large quantities of hydrogen underground can function as grid energy storage which is essential for the hydrogen economy. By using a turboexpander, the electricity needs for compressed storage at 200 bars amounts to 2.1% of the energy content.[7]

With intermittent renewables such as solar and wind, the output may be fed directly into an electricity grid. At penetrations below 20% of the grid demand, this does not severely change the economics; but beyond about 20% of the total demand, external storage will become important. If these sources are used for electricity to make hydrogen, then they can be utilized fully whenever they are available, opportunistically. Broadly speaking, it does not matter when they cut in or out, the hydrogen is simply stored and used as required. A community based pilot program using wind turbines and hydrogen generators is being undertaken from 2007 for five years in the remote community of Ramea, Newfoundland and Labrador.[8] A similar project has been going on since 2004 on Utsira, a small Norwegian island municipality.

Energy losses are involved in the hydrogen storage cycle of hydrogen production for vehicle applications with electrolysis of water, liquification or compression, and conversion back to electricity.[9] and the hydrogen storage cycle of production for the stationary fuel cell applications like microchp at 93 %[10] with biohydrogen or biological hydrogen production, and conversion to electricity.

About 50 kW·h (180 MJ) of solar energy is required to produce a kilogram of hydrogen, so the cost of the electricity clearly is crucial, even for hydrogen uses other than storage for electrical generation. At $0.03/kWh, common off-peak high-voltage line rate in the United States, this means hydrogen costs $1.50 a kilogram for the electricity, equivalent to $1.50 a U.S. gallon for gasoline if used in a fuel cell vehicle. Other costs would include the electrolyzer plant, hydrogen compressors or liquefaction, storage and transportation, which will be significant.

## Biofuels

Various biofuels such as biodiesel, straight vegetable oil, alcohol fuels, or biomass can be used to replace hydrocarbon fuels. Various chemical processes can convert the carbon and hydrogen in coal, natural gas, plant and animal biomass, and organic wastes into short hydrocarbons suitable as replacements for existing hydrocarbon fuels. Examples are Fischer-Tropsch diesel, methanol, dimethyl ether, or syngas. This diesel source was used extensively in World War II in Germany, with limited access to crude oil supplies. Today South Africa produces most of the country's diesel from coal for similar reasons.[11] A long term oil price above US$35/bbl may make such synthetic liquid fuels economical on a large scale (See coal). Some of the energy in the original source is lost in the conversion process. Historically, coal itself has been used directly for transportation purposes in vehicles and boats using steam engines. And compressed natural gas is being used in special circumstances fuel, for instance in busses for some mass transit agencies.

## Synthetic hydrocarbon fuel

Carbon dioxide in the atmosphere has been, experimentally, converted into hydrocarbon fuel with the help of energy from another source. To be useful industrially, the energy will probably have to come from sunlight using, perhaps, future artificial photosynthesis technology.[12] [13] Another alternative for the energy is electricity or heat from solar energy or nuclear power.[14] [15] Compared to hydrogen, many hydrocarbon fuels have the advantage of being immediately usable in existing engine technology and existing fuel distribution infrastructures. Manufacturing synthetic hydrocarbon fuel reduces the amount of carbon dioxide in the atmosphere until the fuel is burned, when the same amount of carbon dioxide returns to the atmosphere.

### Methane

Methane is the simplest hydrocarbon with the molecular formula $CH_4$. Methane could be produced from electricity of renewable energies. Methane can be stored more easily than hydrogen and the transportation, storage and combustion infrastructure are mature (pipelines, gasometers, power plants).

As hydrogen and oxygen are produced in the electrolysis of water,

$$2H_2O \rightarrow 2H_2 + O_2$$

hydrogen would then be reacted with carbon dioxide in Sabatier process, producing methane and water.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Methane would be stored and used to produce electricity later. Produced water would be recycled back to the electrolysis stage, reducing the need for new pure water. In the electrolysis stage oxygen would also be stored for methane combustion in a pure oxygen environment in an adjacent power plant, eliminating e.g. nitrogen oxides. In the combustion of methane, carbon dioxide and water are produced.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Produced carbon dioxide would be recycled back to boost the Sabatier process and water would be recycled back to the electrolysis stage. The carbon dioxide produced by methane combustion would be turned back to methane, thus producing no greenhouse gases. Methane production, storage and adjacent combustion would recycle all the reaction products, creating a cycle.

## Boron, silicon, and zinc

Boron,[16] silicon,[17] lithium, and zinc[18] have been proposed as energy storage solutions.

## Mechanical storage

Energy can be stored in water pumped to a higher elevation using pumped storage methods, in compressed air, or in spinning flywheels.

A mass of 1 kg, elevated to a height of 1000 m stores 9.8 kJ of gravitational energy, which is equivalent to 1 kg mass accelerated to 140 m/s. To store the same mass of water, if increased in temperature by 2.34 Celsius, requires the same amount of energy. Admittedly, this is a bit of an unfair comparison, but it makes it easy to see how it is possible to store more energy in 1 $m^3$ of cheap rock or sand than 1 $m^3$ of lead–acid battery, even if the battery is also moved to a higher elevation, not just charged.

Compressed air energy storage technology stores low cost off-peak energy, in the form of compressed air in an underground reservoir. The air is then released during peak load hours and heated with the exhaust heat of a standard combustion turbine. This heated air is converted to energy through expansion turbines to produce electricity. A CAES plant has been in existence in McIntosh, Alabama since 1991 and has run successfully. Other applications are possible. Walker Architects published the first $CO_2$ gas CAES application, proposing the use of sequestered $CO_2$ for Energy Storage on October 24, 2008.

Several companies have done preliminary design work for vehicles using compressed air power.[19] [20]

## Thermal storage


District heating accumulation tower from Theiss near Krems an der Donau in Lower Austria with a thermal capacity of 2 GWh

Thermal storage is the temporary storage or removal of heat for later use. An example of thermal storage is the storage of solar heat energy during the day to be used at a later time for heating at night. In the HVAC/R field, this type of application using thermal storage for heating is less common than using thermal storage for cooling. An example of the storage of "cold" heat removal for later use is ice made during the cooler night time hours for use during the hot daylight hours. This ice storage is produced when electrical utility rates are lower. This is often referred to as "off-peak" cooling.

When used for the proper application with the appropriate design, off-peak cooling systems can lower energy costs. The U.S. Green Building Council has developed the Leadership in Energy and Environmental Design (LEED) program to encourage the design of high-performance buildings that will help protect our environment. The increased levels of energy performance by utilizing off-peak cooling may qualify of credits toward LEED Certification.

The advantages of thermal storage are:

- Commercial electrical rates are lower at night.
- It takes less energy to make ice when the ambient temperature is cool at night. Source energy (energy from the power plant) is saved.
- A smaller, more efficient system can do the job of a much larger unit by running for more hours.[21]

For more information on thermal storage, see[22] [23] [24]

## Renewable energy storage

Further information: Wind power grid integration

Many renewable energy sources (most notably solar and wind) produce intermittent power.[2] Wherever intermittent power sources reach high levels of grid penetration, energy storage becomes one option to provide reliable energy supplies. Other options include recourse to peaking power plants, methane storage (excess renewable electricity to hydrogen via electrolysis, combine with CO2 (low to neutral CO2 system) to produce methane (synthetic natural gas sabatier process) with stockage in the natural gas network) [25] [26] and smart grids[27] with advanced energy demand management. The latter involves bringing "prices to devices",[27] i.e. making electrical equipment and appliances able to adjust their operation to seek the lowest spot price of electricity. On a grid with a high penetration of renewables, low spot prices would correspond to times of high availability of wind and/or sunshine.

## Economic Evaluation

For economic evaluation of large scale applications, pumped hydro storage, compressed air, the potential benefits that can be accounted are avoidance of wind curtailment, grid congestion avoidance, price arbitrage and carbon free energy delivery.[28]

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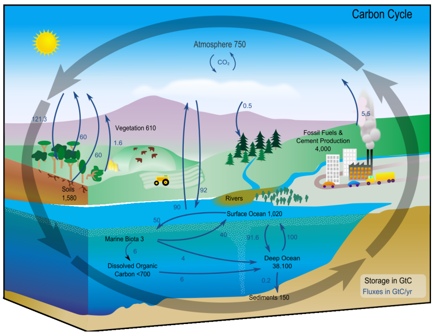
## External links

- U.S. Dept of Energy - Energy Storage Systems (http://www.sandia.gov/ess/index.html) Government research center on energy storage technology.
- Electricity Storage Association (http://www.electricitystorage.org/) Good comparison of technologies.

# Environmental engineering science

**Environmental engineering science** (EES) is a multidisciplinary field of engineering science that combines the biological, chemical and physical sciences with the field of engineering. This major traditionally requires the student to take many basic engineering classes in fields such as thermodynamics, advanced math, computer modeling and simulation as well as technical classes in subjects such as statics, mechanics, hydrology, and fluid dynamics. As the student progresses, the upper division elective classes define a specific field of study for the student with a choice in a wide range of science, technology and engineering related classes[1] :




Students in Environmental Engineering Science typically combine scientific studies of the biosphere with mathematical, analytical and design tools found in the engineering fields

## Difference with related fields

As a recently created program, environmental engineering science has not yet been incorporated into the terminology found among environmentally focused professionals . It should be noted in the few engineering colleges that offer this major, the curriculum shares more classes in common with environmental engineering than it does with environmental science. Typically, EES students follow a similar course curriculum with environmental engineers until their fields diverge during the last year of college. While, a majority of the environmental engineering students must take classes designed to connect their knowledge of the environment to modern building materials and construction methods. This is meant to steer the environmental engineer into a field where they will more than likely assist in building treatment facilities, preparing environmental impact assessments or helping to mitigate air pollution from specific point sources.

Graduates of Environmental Engineering Science can go on to work on the technical aspects of designing a Living Roof like the one pictured here at the California Academy of the Sciences

Meanwhile, the environmental engineering science student will choose a direction for their career. From the wide range of electives they have to choose from, these students can move into a wide range of fields in anything from the design of nuclear storage facilities, bacterial bioreactors or environmental policies. With this in mind, it is important to note that these students combine the practical design background of an engineer with the detailed theory found in many of the biological and physical sciences. In other words, these students have the capabilities to imagine, design and build ideas from many interconnected disciplines concerned with the healthy fate of our environment.

## Description at universities

### UC Berkeley

The College of Engineering at UC Berkeley defines Environmental Engineering Science as follows[1]

> This is a multidisciplinary field requiring an integration of physical, chemical and biological principles with engineering analysis for environmental protection and restoration. The program incorporates courses from many departments on campus to create a discipline that is rigorously based in science and engineering, while addressing a wide variety of environmental issues. Although an environmental engineering option exists within the civil engineering major, the engineering science curriculum provides a more broadly based foundation in the sciences than is possible in civil engineering. This major prepares the student for a career or graduate study in many environmental areas.

### Massachusetts Institute of Technology

At MIT, the major is described in their curriculum and says[2]

> The Bachelor of Science in Environmental Engineering Science emphasizes the fundamental physical, chemical, and biological processes necessary for understanding the interactions between man and the environment. Issues considered include the provision of clean and reliable water supplies, flood forecasting and protection, development of renewable and nonrenewable energy sources, causes and implications of climate change, and the impact of human activities on natural cycles. Both programs provide awareness of the sociopolitical context in which civil and environmental engineering problems are solved. Premedical students may satisfy medical school

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entrance requirements while earning the accredited degree in environmental engineering science with proper planning of their program.
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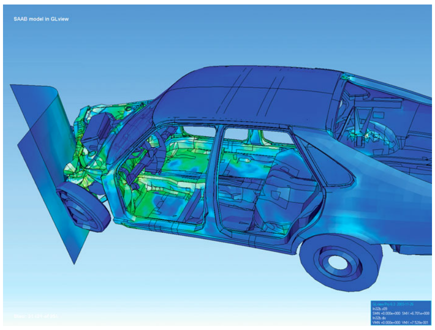
## Lower division coursework

Lower division coursework in this field requires the student to take several laboratory-based classes in calculus-based physics, chemistry, biology, programming and analysis. This is intended to give the student background information in order to introduce them to the engineering fields as well as prepare them for more technical information in their upper division coursework.

Wet labs are required as part of the lower division curriculum

## Upper division coursework



Students learn to integrate their advanced knowledge of math and statistics with software such to perform analysis of physical systems like the Finite Element Analysis shown above

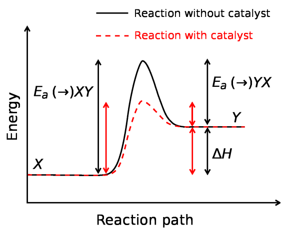
The upper division classes in Environmental Engineering Science prepares the student for work in the fields of engineering and science with coursework in (but not limited to) the following subjects[1]

- Fluid mechanics
- Mechanics of materials
- Thermodynamics
- Environmental engineering
- Advanced math and statistics
- Geology
- Physical, organic and atmospheric chemistry
- Biochemistry
- Microbiology
- Ecology

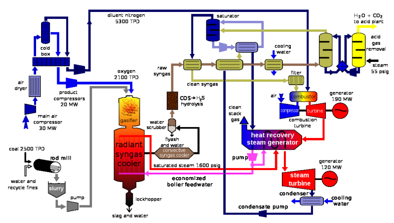
## Electives

### Process engineering

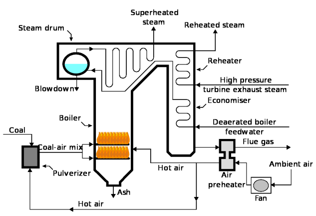
On this track, students are introduced to the fundamental reaction mechanisms in the field of chemical and biochemical engineering. See also Process engineering




Designing a better catalyst for use with biofuels



Considering a cleaner process for coal gasification




Using more waste heat from power plants with better heat exchangers

### Resource engineering

For this track, students are encouraged to take classes introducing them to various ways to conserve natural resources. This can include but is not limited to classes in water chemistry, sanitation, combustion, air pollution and radioactive waste management.

Using design knowledge to make better wastewater treatment facilities

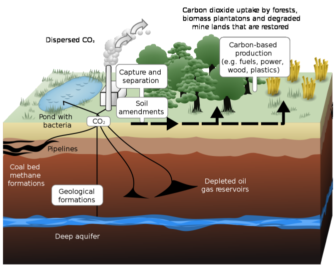
Designing a safe way to store nuclear waste

Design ways to effectively deal with industrial waste

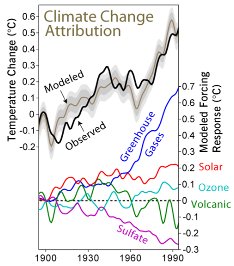
## Geoengineering

This gives the student an in-depth look at geoengineering.

Figuring out what to do with emissions in a large scale



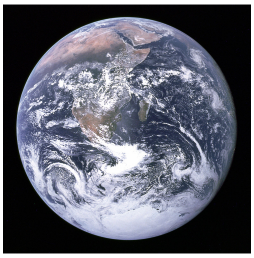

Sequestering carbon from the atmosphere



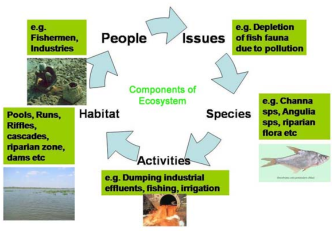

Figuring out what to do with rising levels of greenhouse gases in the atmosphere

## Ecology

Prepares the students for using their engineering and scientific know how to solve the interactions between plants, animals and the biosphere. See also Ecology



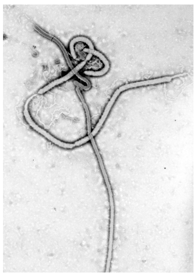
How to alter certain biologic interactions in order to optimize the survival of the system



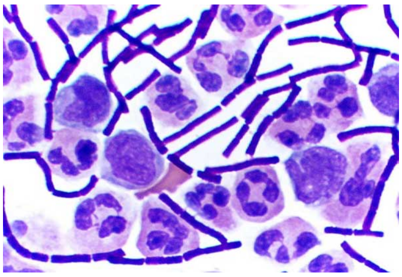

Examining how the harvesting of kelp effects the sea otter population

## Biology

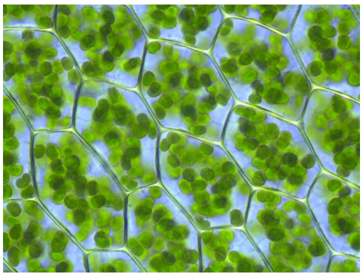
Gives the environmental engineering science student a more advanced knowledge of microbial, molecular and cell biology. Classes can include cell biology, virology, microbial and plant biology



Understanding the way in which viruses function in order to safely sanitize water supplies



Understanding the metabolism of bacteria in order to see how their proliferation effects the climate

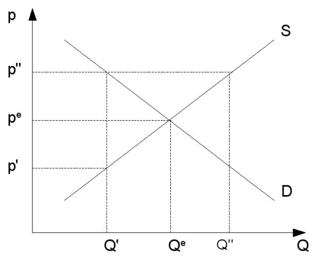


Using the biological design of chloroplasts to design a more effective way of turning solar energy into future sources of power

## Policy

Gives the students a more rigorous look at ways improve our environment through political means. This is done by introducing students to both qualitative and quantitative tools in classes such as economics, sociology, political science as well as energy and resources.

Studying politics in an effort to understand and influence environmental policy




Learning about economics to determine the financial burden it might take to implement an "environmentally friendly" technology

Observing groups and learning the way that "greener" ideas might get passed between people

## Post graduation work

The multidisciplinary approach in Environmental Engineering Science gives the student expertise in a wide variety of technical fields related to their own personal interest. While many graduates choose to use this major to go to graduate school [1] , students who choose to work often go into the fields of civil and environmental engineering, biotechnology, and research. However, the less technical math, programming and writing background gives the students opportunities to pursue IT work and technical writing.

Some graduates may go on to design hydrogen producing bioreactors for the alternative energy industry

## Notes

[1] "Engineering Announcement 2008-2009" (http://coe.berkeley.edu/students/EngAnn08.pdf). pp. 27–28. .

[2] "MIT Course Catalog: Department of Civil and Environmental Engineering." (http://web.mit.edu/catalogue/degre.engin.civil.shtml). .

## References

"MIT Course Catalog: Department of Civil and Environmental Engineering." Massachusetts Institute of Technology. <http://web.mit.edu/catalogue/degre.engin.civil.shtml>.

2008-2009 Announcement. Brochure. Berkeley, 2008. Engineering Announcement 2008-2009. University of California, Berkeley. <http://coe.berkeley.edu/students/EngAnn08.pdf>.

## External links

- Engineering Engineering and Science program at Stanford University (http://www.stanford.edu/group/ees/)
- What people go on to do in Engineering Science at UC Berkeley (http://career.berkeley.edu/Major2006/EngrSci.stm)
- Curriculum at University of Florida (http://www.ees.ufl.edu/prospective/undergrad/curriculum.asp)
- Curriculum at MIT (http://web.mit.edu/catalogue/degre.engin.ch1e.shtml)
- Curriculum at University of Illinois (http://cee.uiuc.edu/environmental/Academic/UndergradProgram.html)

# Engineering physics

**Engineering physics** is the study of the combined disciplines of physics, engineering and mathematics in order to develop an understanding of the interrelationships of these three disciplines. Fundamental physics is combined with problem solving and engineering skills, which then has broad applications. Career paths for Engineering physics is usually (broadly) "engineering, applied science or applied physics through research, teaching or entrepreneurial engineering". Coverage of Engineering physics can be one course, one curriculum, or one book. This interdisciplinary knowledge is designed for the continuous innovation occurring with technology. [1] [2] [3] [4]

## Overview

Unlike traditional engineering disciplines, engineering science/physics is not necessarily confined to a particular branch of science or physics. Instead, engineering science/physics is meant to provide a more thorough grounding in applied physics for a selected specialty such as optics, quantum physics, materials science, applied mechanics, nanotechnology, microfabrication, mechanical engineering, electrical engineering, biophysics, control theory, aerodynamics, energy, solid-state physics, etc. It is the discipline devoted to creating and optimizing engineering solutions through enhanced understanding and integrated application of mathematical, scientific, statistical, and engineering principles. The discipline is also meant for cross-functionality and bridges the gap between theoretical science and practical engineering with emphasis in research and development, design, and analysis.

Engineering physics or engineering science degrees are respected academic degrees awarded in many countries. It is notable that in many languages the term for "engineering physics" would be directly translated into English as "technical physics". In some countries, both what would be translated as "engineering physics" and what would be translated as "technical physics" are disciplines leading to academic degrees, with the former specializes in nuclear power research, and the latter closer to engineering physics.[5] In some institutions, engineering (or applied) physics major is a discipline or specialization within the scope of engineering science, or applied science.[6] [7]

In many universities, engineering science programs may be offered at the levels of B.Tech, B.Sc., M.Sc. and Ph.D. Usually, a core of basic and advanced courses in mathematics, physics, chemistry, and biology forms the foundation of the curriculum, while typical elective areas may include fluid dynamics, quantum physics, economics, plasma physics, relativity, solid mechanics, operations research, information technology and engineering, dynamical systems, bioengineering, environmental engineering, computational engineering, engineering mathematics and statistics, solid-state devices, materials science, electromagnetism, nanoscience, nanotechnology, energy, and optics. While typical undergraduate engineering programs generally focus on the application of established methods to the design and analysis of engineering solutions, undergraduate program in engineering science focuses on the creation and use of more advanced experimental or computational techniques where standard approaches are inadequate (i.e., development of engineering solutions to contemporary problems in the physical and life sciences by applying fundamental principles). Due to rigorous nature of the academic curriculum, an undergraduate major in engineering science is an honors program at some universities such as the University of Toronto[8] and Pennsylvania State University.[9]

## Areas of specialization

- Accelerator physics
- Acoustics
- Aerodynamics
- Agrophysics
- Analog electronics
- Applied mathematics
- Applied mechanics
- Force microscopy and imaging
- Ballistics
- Biomechanics
- Biosensors and bioelectronics
- Biophysics
- Bionanotechnology
- Communication physics
- Computational physics
- Composite materials
- Control theory
- Data mining
- Digital electronics
- Econophysics
- Quantum information
- Electrochemistry
- Electromagnetism
- Fiber optics
- Fluid dynamics
- Geophysics
- Laser physics
- Materials science and processing
- Medical physics
- Metallurgy
- Metamaterials
- Metrological physics
- Microfluidics, MEMS, and MOEMS
- Microfabrication
- Nanotechnology
- Neural engineering
- Nondestructive testing
- Nuclear engineering
- Nuclear technology
- Optics
- Optoelectronics
- Photovoltaics
- Photonics and Plasmonics
- Plasma physics
- Polymer science
- Quantum electronics
- Semiconductor physics and devices
- Soil physics
- Solid-state physics
- Space physics
- Spintronics, Spin engineering
- Systems biology
- Superconductors
- Thin films and nanostructured materials
- Vehicle dynamics

## Professional Societies and Organizations

- Society of Engineering Science Inc. [10].

## Notes and references

[1] "Major: Engineering Physics" (http://www.princetonreview.com/Majors.aspx?cip=141201&page=1). *The Princeton Review*: pp. 01. 2011. . Retrieved June 26, 2011.
[2] "Introduction" (http://www.princeton.edu/EngineeringPhysics/introduction.html) (online). Princeton University. . Retrieved June 26, 2011.
[3] Khare, P. ,; A. Swarup (January 2009 and 2010) (in English). *Engineering Physics: Fundamentals & Modern Applications* (http://books.google.com/books?id=UfztNNnSFckC&printsec=frontcover&dq=engineering+physics&cd=1#v=onepage&q&f=false) (13th ed.). Jones & Bartlett Learning. pp. xiii - Preface. ISBN 9780763773748. .
[4] "Engineering Physics" (http://books.google.com/books?sourceid=navclient&ie=UTF-8&rlz=1T4GWYA_enUS318US318&q=Engineering+Physics) (online). Google books. . Retrieved June 26, 2011.
[5] "2002 Applications for graduate study open in Shanghai Research Institute of Technical Physics (上海技术物理研究所2002年招生)" (http://web.archive.org/web/20080607130833/http://www.cas.ac.cn/html/Dir/2001/10/07/0655.htm). Chinese Academy of Sciences (中国科学院). 2001-10-07. Archived from the original (http://www.cas.ac.cn/html/Dir/2001/10/07/0655.htm) on 2008-06-07. . Retrieved 2008-09-16.
[6] Division of Engineering and Applied Science, California Institute of Technology (http://www.eas.caltech.edu/)
[7] Engineering Physics, Division of Engineering Science, University of Toronto (http://engsci.utoronto.ca/explore_our_program/majors/engineering_physics.htm)
[8] Engineering Science Honors Program at the University of Toronto (http://www.engsci.utoronto.ca/)

[9] Engineering Science Honors Program at Pennsylvania State University (http://www.esm.psu.edu/programs/undergraduate/esc/)
[10] http://www.sesinc.org/

## External links

- "US News Ranking of Undergraduate Programs in Engineering Science/Engineering Physics" (http://colleges.usnews.rankingsandreviews.com/best-colleges/rankings/engineering-doctorate-science-physics)

# Environmental technology

**Environmental technology** (abbreviated as *envirotech*) or green technology (abbreviated as *greentech*) or clean technology (abbreviated as *cleantech*) is the application of one or more of environmental science, green chemistry, environmental monitoring and electronic devices to monitor, model and conserve the natural environment and resources, and to curb the negative impacts of human involvement. Sustainable development is the core of *environmental technologies*. The term *environmental technologies* is also used to describe a class of electronic devices that can promote sustainable management of resources.

Sustainable urban design and innovation: Photovoltaic ombrière SUDI is an autonomous and mobile station that replenishes energy for electric vehicles using solar energy.

## Examples

- Biofiltration
- Biosphere Technology
- Bioremediation
- Composting toilet
- Desalination
- Doubly fed electric machine
- Energy Conservation
- Energy Saving Modules
- Environmental Devices
- Hydroelectricity
- Hydrogen fuel cell
- Ocean Thermal Energy Conversion
- Solar power
- Thermal depolymerization
- Wind power
- battery-powered cars

## Water Purification

Water purification: The whole idea/concept of having dirt/germ/pollution free water flowing throughout the environment. Many other phenomena lead from this concept of purification of water. Water pollution is the main enemy of this concept, and various campaigns and activists have been organized around the world to help purify water. Considering the amount of water usage that is under current consumptions, this Concept is of utter Importance.[1]

## Air Purification

Air Purification: basic and common green plants can be grown indoors to keep air fresh because all plants remove $CO_2$ and convert it into oxygen. The best examples are: *Dypsis lutescens*, *Sansevieria trifasciata*, and *Epipremnum aureum*.[2]

## Sewage treatment

Sewage treatment is conceptually similar to water purification. Sewage treatments are very important as they purify water per levels of its pollution. The more polluted water is not used for anything, and the least polluted water is supplied to places where water is used affluently. It may lead to vaious other concepts of environmental protection, sustainability etc.[3]

## Environmental remediation

Environmental remediation is the removal of pollutants or contaminants for the general protection of the environment. This is accomplished by various chemical, biological, and bulk movement methods, in conjunction with environmental monitoring. (encyclopedia of medical concepts)[4]

## Solid waste management

Solid waste management is the purification, consumption, reuse, disposal and treatment of solid waste that undertaken by the government or the ruling bodies of a city/town.[5]

## Renewable energy

Renewable energy is energy that can be replenished easily. For years we have been using sources like wood, sun, water, etc. for means for producing energy. Energy that can be produced by natural objects like wood, sun, wind, etc. is considered to be renewable.[6]

## eGain forecasting

Egain forecasting is a method using forecasting technology to predict the future weather's impact on a building.[7] By adjusting the heat based on the weather forecast, the system eliminates redundant use of heat, thus reducing the energy consumption and the emission of greenhouse gases.[8]

## Energy Conservation

Energy conservation is the utilization of devices that require smaller amounts of energy in order to reduce the consumption of electricity. Reducing the use of electricity causes less fossil fuels to be burned to provide that electricity.

## Alternative and clean power

Principles:

- Green syndicalism
- Sustainability
- Sustainable design
- Sustainable engineering

Scientists continue to search for clean energy alternatives to our current power production methods. Some technologies such as anaerobic digestion produce renewable energy from waste materials. The global reduction of greenhouse gases is dependent on the adoption of energy conservation technologies at industrial level as well as this clean energy generation. That includes using unleaded gasoline, solar energy and alternative fuel vehicles, including plug-in hybrid and hybrid electric vehicles.

Since electric motors consume 60% of all electricity generated, advanced energy efficient electric motor (and electric generator) technology that are cost effective to encourage their application, such as the brushless wound-rotor doubly fed electric machine and energy saving module, can reduce the amount of carbon dioxide ($CO_2$) and sulfur dioxide ($SO_2$) that would otherwise be introduced to the atmosphere, if electricity is generated using fossil fuels. Greasestock is an event held yearly in Yorktown Heights, New York which is one of the largest showcases of environmental technology in the United States.[9] [10] [11] [12] [13]

## Education

Courses aimed at developing graduates with specific skills in environmental systems or environmental technology are becoming more common and fall into three broads classes:

- *Environmental Engineering or Environmental Systems* courses oriented towards a civil engineering approach in which structures and the landscape are constructed to blend with or protect the environment;
- *Environmental chemistry*, *sustainable chemistry* or *environmental chemical engineering* courses oriented towards understanding the effects (good and bad) of chemicals in the environment. Such awards can focus on mining processes, pollutants and commonly also cover biochemical processes;
- *Environmental technology* courses oriented towards producing electronic, electrical or electrotechnology graduates capable of developing devices and artefacts able to monitor, measure, model and control environmental impact, including monitoring and managing energy generation from renewable sources.

## Criticisms

Extreme radical environmentalism, exhibited in publications such as Green Anarchy, criticizes the concept of environmental technology. From this viewpoint, technology is seen as a system rather than a specific physical tool. Technology, accordingly, *requires* the exploitation of the environment through the creation and extraction of resources, and the exploitation of people through labor, specialization and the division of labor. Thus, no “neutral” form of technology; things are always created in a certain context with certain aims and functions. Green technology is rejected as an attempt to reform this exploitative system, merely changing it on the surface to make it seem environmentally friendly, despite continued unsustainable levels of human and natural exploitation.

## References


[1] Recycling”. Retrieved June 15th, 2009. http://earth911.com/recycling/. “Recycle.gif”. Retrieved June 15th, 2009. http://library.uwf.edu/recycle_logo.gif “What is Water Purification”. Retrieved June 16th, 2009, http://www.bionewsonline.com/s/what_is_water_purification.htm “Sewage Treatment”. Retrieved June 17th, 2009 http://www.euwfd.com/html/sewage_treatment.html “Environmental Remedies and water Resource

[2] Kamal Meattle on how to grow fresh air (http://www.ted.com/talks/kamal_meattle_on_how_to_grow_your_own_fresh_air.html) TED (conference)

[3] “Sewage Treatment”. Retrieved June 17th, 2009 http://www.euwfd.com/html/sewage_treatment.html “Environmental remedies and water Resource

[4] Livescience. Retrieved June 27, 2009.10 top emerging environmental technologies. http://www.reference.md/files/D052/mD052918.html

[5] Retrieved June 16th, 2009. http://www-esd.lbl.gov/ERT/index.html “Urban Waste Management”. Retrieved June 16th, 2009. http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTURBANDEVELOPMENT/EXTUSWM

[6] Retrieved Sept 21,2009. NREL official website (http://www.nrel.gov/)

[7] Taesler, R. (1990/91) Climate and Building Energy Management. Energy and Buildings, Vol. 15-16, pp 599 - 608.

[8] United States Patent 6098893 (http://ip.com/patent/US6098893) Comfort control system incorporating weather forecast data and a method for operating such a system (Inventor Stefan Berglund)

[9] Norman, Jim. " Where There’s Never an Oil Shortage (http://www.nytimes.com/2007/05/13/automobiles/13GREASE.html?_r=1&partner=rssnyt&emc=rss&oref=slogin)". *New York Times*. May 13, 2007.

[10] Tillman, Adriane. " Greasestock Festival returns, bigger and better (http://northcountynews.com/news/ncn_news1.asp)". May 14, 2008.

[11] " Greasestock 2008 (http://www.greasestock.org/)". *Greasestock* (http://greasestock.org). Retrieved May 20, 2008.

[12] Max, Josh. " Gas-guzzlers become veggie delights at Greasestock in Yorktown Heights (http://www.nydailynews.com/autos/2008/05/13/2008-05-13_gasguzzlers_become_veggie_delights_at_gr.html)". *Daily News*. May 13, 2008.

[13] " Greasestock 2008: Alternative Fuel, Fun and French Fries (http://www.greasestock.org/images/GreasestockMay08.jpg)". *Natural Awakenings* (http://www.naturalawakeningsmag.com/). May 2008.


## Further reading

- *OECD Studies on Environmental Innovation Invention and Transfer of Environmental Technologies.*. OECD. September 2011. ISBN 9789264115613.

## External links

- Environmental Technologies Action Plan (http://ec.europa.eu/environment/etap/index_en.htm) - European Commission - Wiki Environmental Technologies Action Plan
- BiobasedNews.com: a comprehensive database of environmental technology business news and stories and press releases (http://www.biobasednews.com/)
- EUCETSA (http://www.eucetsa.net/eucetsa) - European Committee of Environmental Technology Supplier Associations (representing over 1.000 companies in the environmental industry)
- Related "*Norway Online*" resources (http://www.norwayonline.no/index.php?cat=23)
- Norway Exports - Publication: Renewable energy & environmental Technology (http://www.mypaper.se/show/findexa/show.asp?pid=345154565064355)
- How Silicon Valley could become the Detroit of electric cars (http://www.mercurynews.com/greenenergy/ci_7392438).
- Consumer Reports GreenerChoices (http://greenerchoices.org/).
- Top 10 emerging environment technologies (http://www.livescience.com/11334-top-10-emerging-environmental-technologies.html). livescience.com.
- Reed, Daniel. 2009. Environmental and Renewable Energy Innovation Potential Among the States: State Rankings. Applied Research Project. Texas State University. http://ecommons.txstate.edu/arp/291/
- E - The Environmental Magazine (http://www.emagazine.com/)
- Texas A&M University-Dallas Urban Living Laboratory project (http://urbanlivinglaboratory.com/)
- TED Talk: Amory Lovins, "On Winnin the Oil Endgame" (http://www.ted.com/talks/amory_lovins_on_winning_the_oil_endgame.html)

- Amory Lovins, NATURAL CAPITALISM (http://www.natcap.org/)
- "Use of Green Energy" (in agriculture) Dr. Roger Beachy, US Embassy in France (http://www.youtube.com/watch?v=DjYmWM-gjBw)
- 7 Modern Wonders of Green Technology: Conceptual and Actual Ecological Designs of the Future (http://weburbanist.com/2008/06/09/modern-wonders-of-green-technology/)
- Going green can be good for business (http://www.courierpress.com/news/2011/may/09/going-green-can-be-good-for-business/)
- IBM Green Technology (http://www-03.ibm.com/systems/greendc/green_technology/)
- Unintended Consequences of Green Technologies (http://berkeley.academia.edu/OzzieZehner/Papers/867475/Unintended_Consequences_of_Green_Technologies/)

# Fisheries science

**Fisheries science** is the academic discipline of managing and understanding fisheries. It is a multidisciplinary science, which draws on the disciplines of oceanography, marine biology, marine conservation, ecology, population dynamics, economics and management to attempt to provide an integrated picture of fisheries. In some cases new disciplines have emerged, as in the case of bioeconomics.


Fisheries scientists sorting a catch of small fish and Norway lobster

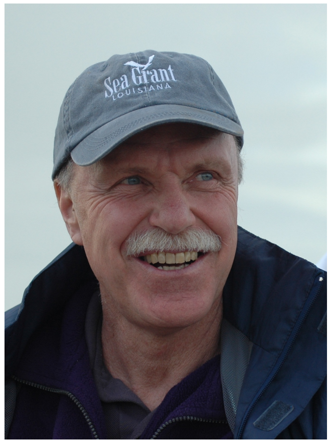
Fisheries science is typically taught in a university setting, and can be the focus of an undergraduate, master's or Ph.D. program. Some universities offer fully integrated programs in fisheries science.

## Notable contributors


Ransom A. Myers

- Spencer F. Baird – founding scientist of the United States Fish Commission
- Fedor I. Baranov - Russian scientist and the father of the *Baranov catch equation*[1] , thereby being one of the founding fathers of fisheries science
- Ludwig von Bertalanffy – Austrian-born biologist and a founder of general systems theory
- Ray Beverton – English fisheries biologist; known for the Beverton–Holt model (with Sidney Holt), credited with being one of the founders of fisheries science
- Villy Christensen – fisheries scientist and ecosystem modeler, known for his work on the development of Ecopath
- John N. Cobb – founder of the first college of fisheries in the United States, the University of Washington College of Fisheries, in 1919
- David Cushing – English born fisheries biologist, who is credited with the development of the match/mismatch hypothesis

Daniel Pauly



Ray Hilborn

- Rainer Froese – Known for his work on the development and coordination of FishBase
- Gotthilf Hempel – German marine biologist and oceanographer, and co-founder of the Alfred Wegener Institute for Polar and Marine Research
- Walther Herwig – Prussian lawyer and promoter of high seas fishing and research
- Ray Hilborn – Canadian-born fisheries biologist, with strong contributions towards fisheries management
- Johan Hjort – Norwegian fisheries biologist, marine zoologist, and oceanographer
- Bruno Hofer – German fishery scientist, credited with being the founder of fish pathology
- Sidney Holt – English fisheries biologist; known for the Beverton–Holt model (with Ray Beverton), credited with being one of the founders of fisheries science
- Uwe Kils – German marine biologist specializing in planktology. Inventor of the ecoSCOPE
- Leo Margolis – Canadian parasitologist and head of the Pacific Biological Station in Nanaimo, British Columbia
- R. J. McKay – Australian-born biologist and a specialist in translocated freshwater fishes
- Ransom A. Myers – Canadian marine biologist and conservationist
- Daniel Pauly – prominent French-born fisheries scientist, known for his work studying human impacts on global fisheries
- Tony J. Pitcher – known for work on the impacts of fishing, management appraisals and the shoaling behavior of fish
- Michael A. Rice – American known for work on molluscan fisheries
- Bill Ricker – Canadian fisheries biologist, known for the Ricker model, credited with being one of the founders of fisheries science
- Ed Ricketts – a colourful American marine biologist and philosopher who introduced ecology to fisheries science.[2]
- Callum Roberts – British marine conservation biologist, known for his work on the role marine reserves play in protecting marine ecosystems
- Harald Rosenthal – German hydrobiologist known for his work in fish farming and ecology
- Carl Safina – author of several writings on marine ecology and the ocean
- Georg Ossian Sars – Norwegian marine biologist credited with the discovery of a number of new species and known for his analysis of cod fisheries
- Tore Schweder – Norwegian statistician whose work includes the assessment of marine resources
- Milner Baily Schaefer – notable for his work on the population dynamics of fisheries
- Ussif Rashid Sumaila – noted for his analysis of the economic aspects of fisheries
- Fred Utter – noted as the founding father of the field of fishery genetics[3]
- Carl Walters – American born biologist known for his work involving fisheries stock assessments, the adaptive management concept, and ecosystem modeling

## Professional societies

- World Council of Fisheries Societies [4]
- American Fisheries Society [5]
- The Fisheries Society of the British Isles [6]
- The Japanese Society of Fisheries Science [7]
- The Australian Society for Fish Biology [8]

## Journals

Some journals about fisheries are

- *Fishery Bulletin* [9]
- *Fisheries Oceanography* [10]
- *Journal of the Fisheries Research Board* [11]
- *Canadian Journal of Fisheries and Aquatic Sciences* [12]
- *Transactions of the American Fisheries Society* [13]
- *Fisheries Management and Ecology* [14]
- *Fish and Fisheries* [15]
- *Journal of Fish Biology* [16]
- *Journal of Northwest Atlantic Fishery Science* [17]
- *Journal of Fisheries and Aquatic Sciences* [18]
- *The Open Fish Science Journal* [19]
- *African Journal of Tropical Hydrobiology and Fisheries* [20]
- *ICES Journal of Marine Science* [21]
- *Reviews in Fish Biology and Fisheries* [22]
- *International journal of fisheries and aquaculture* [23]
- *Reviews in Fisheries Science* [24]
  - *Chinese Fisheries Journal Listings* [25]
  - *General Fisheries Journal Listings* [26]

## Notes

[1] Baranov, F. I. 1918. K voprosu o biologicheskikh osnovaniyakh rylmogo khozyaistva (On the question of the biological basis of fisheries). Nauchnyi Issledovatelski Ikhtiologicheski Institut Izvestia, 1: 81-128. (in Russian)
[2] Ed Ricketts' death, 50 years ago last week, preceded that of Cannery Row by only a few months. (http://www.montereycountyweekly.com/archives/2005/2005-Oct-13/Article.news_feature/2) – Eric Enno Tamm (2005) Monterey County Weekly.
[3] http://celebrating200years.noaa.gov/historymakers/side_hon_mentions.html
[4] http://www.5thwfc2008.com/introduction.html
[5] http://www.fisheries.org/afs/index.html
[6] http://www.fsbi.org.uk/
[7] http://www.miyagi.kopas.co.jp/JSFS/e-main.shtml
[8] http://www.asfb.org.au/
[9] http://fishbull.noaa.gov/fcontent.htm
[10] http://www.blackwellpublishing.com/journal.asp?ref=1054-6006&site=1
[11] http://journalseek.net/cgi-bin/journalseek/journalsearch.cgi?field=issn&query=0015-296X
[12] http://pubs.nrc-cnrc.gc.ca/rp-ps/journalDetail.jsp?jcode=cjfas&lang=eng
[13] http://afs.allenpress.com/perlserv/?request=get-archive
[14] http://www.blackwellpublishing.com/journal.asp?ref=0969-997X&site=1
[15] http://www.blackwellpublishing.com/journal.asp?ref=1467-2960&site=1
[16] http://www.blackwellpublishing.com/journal.asp?ref=0022-1112
[17] http://journal.nafo.int/
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## External links

- Fisheries science (http://www.dmoz.org/Science/Agriculture/Fisheries/) at the Open Directory Project
- The Sea Ahead... learning from the past (http://sites.google.com/a/seaahead.org/the-sea-ahead/Home). A web site of the Peter Wall Institute for Advanced Studies promoting ecosystem-based fisheries science.
- What is fisheries science? (http://www.marine.ie/NR/rdonlyres/A2FEBC5E-6358-4715-96D8-A6F9A3C397F3/0/What_is_fisheries_Science.pdf)

# Forestry


Forestry work in Austria.

**Forestry** is the interdisciplinary profession embracing the science, art, and craft of creating, managing, using, and conserving forests and associated resources in a sustainable manner to meet desired goals, needs, and values for human benefit.[1] Forestry is practiced in plantations and natural stands. The main goal of forestry is to create and implement systems that allow forests to continue a sustainable provision of environmental supplies and services.[2] The challenge of forestry is to create systems that are socially accepted while sustaining the resource and any other resources that might be affected.[3]

Silviculture, a related science, involves the growing and tending of trees and forests. Modern forestry generally embraces a broad range of concerns, including assisting forests to provide timber as raw material for wood products, wildlife habitat, natural water quality management, recreation, landscape and community protection, employment, aesthetically appealing landscapes, biodiversity management, watershed management, erosion control, and preserving forests as 'sinks' for atmospheric carbon dioxide. A practitioner of forestry is known as a forester. The word "forestry" can also refer to a forest itself.

Forest ecosystems have come to be seen as the most important component of the biosphere,[4] and forestry has emerged as a vital field of science, applied art, and technology.

## History


A deciduous beech forest in Slovenia.

In the 5th century monks established a plantation of Stone pine, for use as a source of fuel and food, in the then Byzantine Romagna on the Adriatic coast.[5] This was the beginning of the massive forest mentioned by Dante Alighieri in his 1308 poem Divine Comedy.[5] Formal forestry practices were developed by the Visigoths in the 7th century when, faced with the ever increasing shortage of wood, they instituted a code concerned with the preservation of oak and pine forests.[5] The use and management of many forest resources has a long history in China, dating from the Han Dynasty and taking place under the landowning gentry. It was also later written of by the Ming Dynasty Chinese scholar Xu Guangqi (1562–1633). In Europe, control of the land included hunting rights, and though peasants in many places were permitted to gather firewood and building timber and to graze animals, hunting rights were retained by the members of the nobility. Systematic management of forests for a sustainable yield of timber is said to have begun in the 16th century in both the German states and Japan.[6] Typically, a forest was divided into specific sections and mapped; the harvest of timber was planned with an eye to regeneration.

The practice of establishing tree plantations in the British Isles was promoted by John Evelyn, though it had already acquired some popularity. Louis XIV's minister Jean-Baptiste Colbert's oak forest at Tronçais, planted for the future use of the French Navy, matured as expected in the mid-19th century: "Colbert had thought of everything except the steamship," Fernand Braudel observed.[7] Schools of forestry were established after 1825; most of these schools were in Germany and France. During the nineteenth and early twentieth centuries, forest preservation programs were established in the United States, Europe, and British India. Many foresters were either from continental Europe (like Sir Dietrich Brandis), or educated there (like Gifford Pinchot).

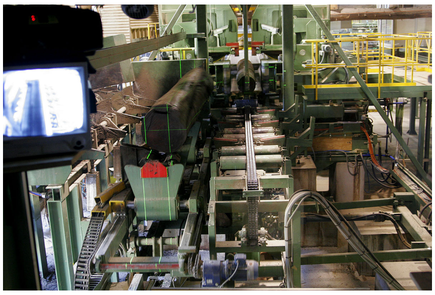
Timber harvesting is a common component of forestry

The enactment and evolution of forestry laws and binding regulations occurred in most Western nations in the 20th century in response to growing conservation concerns and the increasing technological capacity of logging companies.

Tropical forestry is a separate branch of forestry which deals mainly with equatorial forests that yield woods such as teak and mahogany. Sir Dietrich Brandis is considered the father of tropical forestry.

## Today

Today a strong body of research exists regarding the management of forest ecosystems and genetic improvement of tree species and varieties. Forestry also includes the development of better methods for the planting, protecting, thinning, controlled burning, felling, extracting, and processing of timber. One of the applications of modern forestry is reforestation, in which trees are planted and tended in a given area.



A modern sawmill

In many regions the forest industry is of major ecological, economic, and social importance. Third-party certification systems that provide independent verification of sound forest stewardship and sustainable forestry have become commonplace in many areas since the 1990s. These certification systems were developed as a response to criticism of some forestry practices, particularly deforestation in less developed regions along with concerns over resource management in the developed world. Some certification systems are criticised for primarily acting as marketing tools and lacking in their claimed independence.

In topographically severe forested terrain, proper forestry is important for the prevention or minimization of serious soil erosion or even landslides. In areas with a high potential for landslides, forests can stabilize soils and prevent property damage or loss, human injury, or loss of life.

Public perception of forest management has become controversial, with growing public concern over perceived mismanagement of the forest and increasing demands that forest land be managed for uses other than pure timber production, for example, indigenous rights, recreation, watershed management, and preservation of wilderness, waterways and wildlife habitat. Sharp disagreements over the role of forest fires, logging, motorized recreation and others drives debate while the public demand for wood products continues to increase.

## Foresters

Foresters of UACh in the Valdivian forests of San Pablo de Tregua, Chile

Foresters work for the timber industry, government agencies, conservation groups, local authorities, urban parks boards, citizens' associations, and private landowners. The forestry profession includes a wide diversity of jobs, with educational requirements ranging from college bachelor's degrees to PhDs for highly specialized work. Industrial foresters plan forest regeneration starting with careful harvesting. Urban foresters manage trees in urban green spaces. Foresters work in tree nurseries growing seedlings for woodland creation or regeneration projects. Foresters improve tree genetics. Forest engineers develop new building systems. Professional foresters measure and model the growth of forests with tools like geographic information systems. Foresters may combat insect infestation, disease, forest and grassland wildfire, but increasingly allow these natural aspects of forest ecosystems to run their course when the likelihood of epidemics or risk of life or property are low. Increasingly, foresters participate in wildlife conservation planning and watershed protection. Foresters have been mainly concerned with timber management, especially reforestation, maintaining forests at prime conditions, and fire control.[8]

## Forestry plans

Foresters develop and implement forest management plans relying on mapped resource inventories showing an area's topographical features as well as its distribution of trees (by species) and other plant cover. Plans also include landowner objectives, roads, culverts, proximity to human habitation, water features and hydrological conditions, and soils information. Forest management plans typically include recommended silvicultural treatments and a timetable for their implementation.

Forest management plans include recommendations to achieve the landowner's objectives and desired future condition for the property subject to ecological, financial, logistical (e.g. access to resources), and other constraints. On some properties, plans focus on producing quality wood products for processing or sale. Hence, tree species, quantity, and form, all central to the value of harvested products quality and quantity, tend to be important components of silvicultural plans.

Good management plans include consideration of future conditions of the stand after any recommended harvests treatments, including future treatments (particularly in intermediate stand treatments, and plans for natural or artificial regeneration after final harvests.

The objectives of landowners and leaseholder influence plans for harvest and subsequent site treatment. In Britain, plans featuring "good forestry practice" must always consider the needs of other stakeholders such as nearby communities or rural residents living within or adjacent to woodland areas. Foresters consider tree felling and environmental legislation when developing plans. Plans instruct the sustainable harvesting and replacement of trees. They indicate whether road building or other forest engineering operations are required.

Agriculture and forest leaders are also trying to understand how the climate change legislation will affect what they do. The information gathered will provide the data that will determine the role of agriculture and forestry in a new climate change regulatory system.[9]

## Education

Prescribed burning is used by foresters to reduce fuel loads

The first dedicated forestry school was established by Georg Hartig at Dillenburg in Germany in 1787, though forestry had been taught much earlier in central Europe.

In 1877, the first issue of *Šumarski list* (Forestry Review) was published in Croatia by Croatian Forestry Society.[10]

In 1886, the first issue of *Revista Pădurilor* (Forestry Review) was published in Romania.[11]

The first in North America, the Biltmore Forest School was established near Asheville, North Carolina, by Carl A. Schenck on September 1, 1898, on the grounds of George W. Vanderbilt's Biltmore Estate. Another early school was the New York State College of Forestry, established at Cornell University just a few weeks later, in September 1898. Early 19th century North American foresters went to Germany to study forestry. Some early German foresters also emigrated to North America.

In South America the first forestry school was established in Brazil, specifically in Viçosa, Minas Gerais, and later moved to Curitiba, Paraná.[12]

Today, an acceptably trained forester must be educated in general biology, botany, genetics, soil science, climatology, hydrology, economics and forest management. Education in the basics of sociology and political science is often considered an advantage.

In India, forestry education is imparted in the agricultural universities and in Forest Research Institutes (deemed universities). Four year degree programmes are conducted in these universities at the undergraduate level. Masters and Doctorate degrees are also available in these universities.

In the United States, postsecondary forestry education leading to a Bachelor's degree or Master's degree is accredited by the Society of American Foresters.[13]

In Canada the Canadian Institute of Forestry awards silver rings to graduates from accredited university BSc programs, as well as college and technical programs.[14]

The International Union of Forest Research Organizations is the only international organization that coordinates forest science efforts world-wide.[15] Organizations such as the Forest Policy Education Network are dedicated to facilitating international forest politics and exchanging information on the subject.

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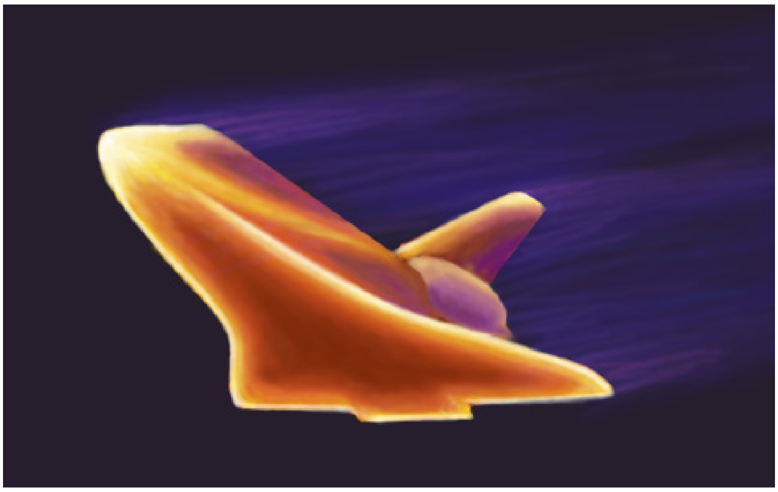
## External links

- Forestry (http://www.dmoz.org/Business/Agriculture_and_Forestry/Forestry/) at the Open Directory Project

# Materials science

**Materials science** is an interdisciplinary field applying the properties of matter to various areas of science and engineering. This scientific field investigates the relationship between the structure of materials at atomic or molecular scales and their macroscopic properties. It incorporates elements of applied physics and chemistry. With significant media attention focused on nanoscience and nanotechnology in recent years, materials science has been propelled to the forefront at many universities. It is also an important part of forensic engineering and failure analysis. Materials science also deals with *fundamental properties* and *characteristics* of materials.



Simulation of the outside of the Space Shuttle as it heats up to over 1500 °C (2730 °F) during re-entry into the Earth's atmosphere

## History

The material of choice of a given era is often a defining point. Phrases such as Stone Age, Bronze Age, and Steel Age are good examples. Originally deriving from the manufacture of ceramics and its putative derivative metallurgy, materials science is one of the oldest forms of engineering and applied science. Modern materials science evolved directly from metallurgy, which itself evolved from mining and (likely) ceramics and the use of fire. A major breakthrough in the understanding of materials occurred in the late 19th century, when the American scientist Josiah Willard Gibbs demonstrated that the thermodynamic properties related to atomic structure in various phases are related to the physical properties of a material. Important elements of modern materials science are a product of the space race: the understanding and engineering of the metallic alloys, and silica and carbon materials, used in the construction of space vehicles enabling the exploration of space. Materials science has driven, and been driven by, the development of revolutionary technologies such as plastics, semiconductors, and biomaterials.

Before the 1960s (and in some cases decades after), many *materials science* departments were named *metallurgy* departments, from a 19th and early 20th century emphasis on metals. The field has since broadened to include every class of materials, including ceramics, polymers, semiconductors, magnetic materials, medical implant materials and biological materials (materiomics).

## Fundamentals

The basis of materials science involves relating the desired properties and relative performance of a material in a certain application to the structure of the atoms and phases in that material through characterization. The major determinants of the structure of a material and thus of its properties are its constituent chemical elements and the way in which it has been processed into its final form. These characteristics, taken together and related through the laws of thermodynamics, govern a material’s microstructure, and thus its properties.

The manufacture of a perfect crystal of a material is currently physically impossible. Instead materials scientists manipulate the defects in crystalline materials such as precipitates, grain boundaries (Hall–Petch relationship), interstitial atoms, vacancies or substitutional atoms, to create materials with the desired properties.

Not all materials have a regular crystal structure. Polymers display varying degrees of crystallinity, and many are completely non-crystalline. Glasses, some ceramics, and many natural materials are amorphous, not possessing any long-range order in their atomic arrangements. The study of polymers combines elements of chemical and statistical thermodynamics to give thermodynamic, as well as mechanical, descriptions of physical properties.

In addition to industrial interest, materials science has gradually developed into a field which provides tests for condensed matter or solid state theories. New physics emerge because of the diverse new material properties which need to be explained.

## Classes of materials

Materials science encompasses various classes of materials, each of which may constitute a separate field. There are several ways to classify materials. For instance by the type of bonding between the atoms. The traditional groups are ceramics, metals and polymers based on atomic structure and chemical composition. New materials has resulted in more classes.[1] One way of classifying materials is:

- Biomaterials
- Ceramics
- Composite materials
- Metals
- Polymers
- Semiconductors

## Materials in industry

Radical materials advances can drive the creation of new products or even new industries, but stable industries also employ materials scientists to make incremental improvements and troubleshoot issues with currently used materials. Industrial applications of materials science include materials design, cost-benefit tradeoffs in industrial production of materials, processing techniques (casting, rolling, welding, ion implantation, crystal growth, thin-film deposition, sintering, glassblowing, etc.), and analytical techniques (characterization techniques such as electron microscopy, x-ray diffraction, calorimetry, nuclear microscopy (HEFIB), Rutherford backscattering, neutron diffraction, small-angle X-ray scattering (SAXS), etc.).

Besides material characterization, the material scientist/engineer also deals with the extraction of materials and their conversion into useful forms. Thus ingot casting, foundry techniques, blast furnace extraction, and electrolytic extraction are all part of the required knowledge of a metallurgist/engineer. Often the presence, absence or variation of minute quantities of secondary elements and compounds in a bulk material will have a great impact on the final properties of the materials produced, for instance, steels are classified based on 1/10 and 1/100 weight percentages of the carbon and other alloying elements they contain. Thus, the extraction and purification techniques employed in the extraction of iron in the blast furnace will have an impact of the quality of steel that may be produced.

The overlap between physics and materials science has led to the offshoot field of *materials physics*, which is concerned with the physical properties of materials. The approach is generally more macroscopic and applied than in condensed matter physics. See important publications in materials physics for more details on this field of study.

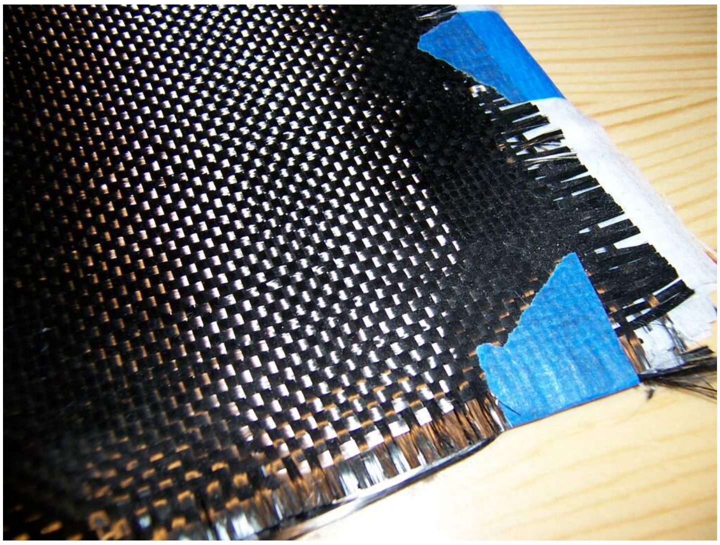
## Ceramics and glasses

$Si_3N_4$ ceramic bearing parts

Another application of the material sciences is the structures of glass and ceramics, typically associated with the most brittle materials. Bonding in ceramics and glasses are using covalent and ionic-covalent types with $SiO_2$ (silica or sand) as a fundamental building block. Ceramics are as soft as clay and as hard as stone and concrete. Usually, they are crystalline in form. Most glasses contain a metal oxide fused with silica. At high temperatures used to prepare glass, the material is a viscous liquid. The structure of glass forms into an amorphous state upon cooling. Windowpanes and eyeglasses are important examples. Fibers of glass are also available. Diamond and carbon in its graphite form are considered to be ceramics.

Engineering ceramics are known for their stiffness, high temperature, and stability under compression and electrical stress. Alumina, silica carbide, and tungsten carbide are made from a fine powder of their constituents in a process of sintering with a binder. Hot pressing provides higher density material. Chemical vapor deposition can place a film of a ceramic on another material. Cermets are ceramic particles containing some metals. The wear resistance of tools is derived from cemented carbides with the metal phase of cobalt and nickel typically added to modify properties.

## Composite materials



A cloth of woven carbon fiber filaments is commonly used for reinforcement in composite materials.

Another application of material science in industry is the making of composite materials. Composite materials are structured materials composed of two or more macroscopic phases. Applications range from structural elements such as steel-reinforced concrete, to the thermally insulative tiles which play a key and integral role in NASA's Space Shuttle thermal protection system which is used to protect the surface of the shuttle from the heat of re-entry into the Earth's atmosphere. One example is reinforced Carbon-Carbon (RCC), The light gray material which withstands re-entry temperatures up to 1510 °C (2750 °F) and protects the Space Shuttle's wing leading edges and nose cap. RCC is a laminated composite material made from graphite rayon cloth and impregnated with a phenolic resin. After curing at high temperature in an autoclave, the laminate is pyrolized to convert the resin to carbon, impregnated with furfural alcohol in a vacuum chamber, and cured/pyrolized to convert the furfural alcohol to carbon. In order to provide oxidation resistance for reuse capability, the outer layers of the RCC are converted to silicon carbide.

Other examples can be seen in the "plastic" casings of television sets, cell-phones and so on. These plastic casings are usually a composite material made up of a thermoplastic matrix such as acrylonitrile-butadiene-styrene (ABS) in which calcium carbonate chalk, talc, glass fibers or carbon fibers have been added for added strength, bulk, or electrostatic dispersion. These additions may be referred to as reinforcing fibers, or dispersants, depending on their purpose.

## Polymers

Polymers are also an important part of materials science. Polymers are the raw materials (the resins) used to make what we commonly call plastics. Plastics are really the final product, created after one or more polymers or additives have been added to a resin during processing, which is then shaped into a final form. Polymers which have been around, and which are in current widespread use, include polyethylene, polypropylene, PVC, polystyrene, nylons, polyesters, acrylics, polyurethanes, and polycarbonates. Plastics are generally classified as "commodity", "specialty" and "engineering" plastics.

Household items made of various kinds of plastic.

PVC (polyvinyl-chloride) is widely used, inexpensive, and annual production quantities are large. It lends itself to an incredible array of applications, from artificial leather to electrical insulation and cabling, packaging and containers. Its fabrication and processing are simple and well-established. The versatility of PVC is due to the wide range of plasticisers and other additives that it accepts. The term "additives" in polymer science refers to the chemicals and compounds added to the polymer base to modify its material properties.

Polycarbonate would be normally considered an engineering plastic (other examples include PEEK, ABS). Engineering plastics are valued for their superior strengths and other special material properties. They are usually not used for disposable applications, unlike commodity plastics.

Specialty plastics are materials with unique characteristics, such as ultra-high strength, electrical conductivity, electro-fluorescence, high thermal stability, etc.

The dividing lines between the various types of plastics is not based on material but rather on their properties and applications. For instance, polyethylene (PE) is a cheap, low friction polymer commonly used to make disposable shopping bags and trash bags, and is considered a commodity plastic, whereas medium-density polyethylene (MDPE) is used for underground gas and water pipes, and another variety called Ultra-high Molecular Weight Polyethylene UHMWPE is an engineering plastic which is used extensively as the glide rails for industrial equipment and the low-friction socket in implanted hip joints.

### Metal alloys

The study of metal alloys is a significant part of materials science. Of all the metallic alloys in use today, the alloys of iron (steel, stainless steel, cast iron, tool steel, alloy steels) make up the largest proportion both by quantity and commercial value. Iron alloyed with various proportions of carbon gives low, mid and high carbon steels. An iron carbon alloy is only considered steel if the carbon level is between 0.01% and 2.00%. For the steels, the hardness and tensile strength of the steel is related to the amount of carbon present, with increasing carbon levels also leading to lower ductility and toughness. Heat treatment processes such as quenching and tempering can significantly change these properties however. Cast Iron is defined as an iron–carbon alloy with more than 2.00% but less than 6.67% carbon. Stainless steel is defined as a regular steel alloy with greater than 10% by weight alloying content of Chromium. Nickel and Molybdenum are typically also found in stainless steels.

Other significant metallic alloys are those of aluminium, titanium, copper and magnesium. Copper alloys have been known for a long time (since the Bronze Age), while the alloys of the other three metals have been relatively recently developed. Due to the chemical reactivity of these metals, the electrolytic extraction processes required were only developed relatively recently. The alloys of aluminium, titanium and magnesium are also known and valued for their high strength-to-weight ratios and, in the case of magnesium, their ability to provide electromagnetic shielding. These materials are ideal for situations where high strength-to-weight ratios are more important than bulk cost, such as in the aerospace industry and certain automotive engineering applications.

## Overview

- Biomaterials – materials that are derived from and/or used with biological systems.
- Ceramography – the study of the microstructures of high-temperature materials and refractories, including structural ceramics such as RCC, polycrystalline silicon carbide and transformation toughened ceramics
- Materials Characterization – such as diffraction with x-rays, electrons, or neutrons, and various forms of spectroscopy and chemical analysis such as Raman spectroscopy, energy-dispersive spectroscopy (EDS), chromatography, thermal analysis, electron microscope analysis, etc., in order to understand and define the properties of materials. See also List of surface analysis methods
- Crystallography – the study of how atoms in a solid fill space, the defects associated with crystal structures such as grain boundaries and dislocations, and the characterization of these structures and their relation to physical properties.
- Electronic and magnetic materials – materials such as semiconductors used to create integrated circuits, storage media, sensors, and other devices.
- Forensic engineering – the study of how products fail, and the vital role of the materials of construction
- Forensic materials engineering – the study of material failure, and the light it sheds on how engineers specify materials in their product
- Glass Science – any non-crystalline material including inorganic glasses, vitreous metals and non-oxide glasses.
- Microtechnology – study of materials and processes and their interaction, allowing microfabrication of structures of micrometric dimensions, such as MicroElectroMechanical Systems (MEMS).
- Nanotechnology – rigorously, the study of materials where the effects of quantum confinement, the Gibbs–Thomson effect, or any other effect only present at the nanoscale is the defining property of the material; but more commonly, it is the creation and study of materials whose defining structural properties are anywhere from less than a nanometer to one hundred nanometers in scale, such as molecularly engineered materials.
- Metallurgy – the study of metals and their alloys, including their extraction, microstructure and processing.
- Surface science/Catalysis – interactions and structures between solid-gas solid-liquid or solid-solid interfaces.

- Textile Reinforced Materials – materials in the form of ceramic or concrete are reinforced with a primarily woven or non-woven textile structure to impose high strength with comparatively more flexibility to withstand vibrations and sudden jerks.

Some practitioners consider rheology a sub-field of materials science, because it can cover any material that flows. However, modern rheology typically deals with non-Newtonian fluid dynamics, so it is often considered a sub-field of continuum mechanics. See also granular material.

- Tribology – the study of the wear of materials due to friction and other factors.

### Primary topics

- Thermodynamics, statistical mechanics, and physical chemistry, for phase equilibrium conditions, phase diagrams of materials systems (multi-phase, multi-component, reacting and non-reacting systems)
- Phase transformation kinetics, for the kinetics of phase transformations (with particular emphasis on solid-solid phase transitions)
- Transport phenomena for the transport of heat, mass, and momentum in materials processing.
- Crystallography, quantum chemistry or quantum physics, for the structure (symmetry and defects) and bonding in materials (e.g., ionic, metallic, covalent, and van der Waals bonding)
- Mechanical behavior of materials, to understand the mechanical properties of materials, defects and their propagation, and their behavior under static, dynamic, and cyclic loads
- Electronic properties of materials, and solid-state physics, for the understanding of the electronic, thermal, magnetic, and optical properties of materials
- Diffraction and wave mechanics, for the science behind characterization systems, e.g., transmission electron microscopy (TEM)
- Polymer properties, synthesis, and characterization, for a specialized understanding of how polymers behave, how they are made, and how they are characterized; exciting applications of polymers include liquid crystal displays (LCDs, the displays found in most cell phones, cameras, and iPods), novel photovoltaic devices based on semiconductor polymers (which, unlike the traditional silicon solar panels, are flexible and cheap to manufacture, albeit with lower efficiency), and membranes for room-temperature fuel cells (as proton exchange membranes) and filtration systems in the environmental and biomedical fields
- Biomaterials, physiology, biomechanics, biochemistry, for a specialized understanding of how materials integrate into biological systems, e.g., through materiomics
- Semiconductor materials and semiconductor devices, for a specialized understanding of the advanced processes used in industry (e.g. crystal growth techniques, thin-film deposition, ion implantation, photolithography), their properties, and their integration in electronic devices
- Alloying, corrosion, and thermal or mechanical processing, for a specialized treatment of metallurgical materials—with applications ranging from aerospace and industrial equipment to the civil industries

## Professional organizations

- Materials Research Society, MRS [2]
- European Materials Research Society, EMRS [3]
- ASM International [4]
- The Minerals, Metals, & Materials Society, TMS [5]
- Materials Australia [6]
- American Ceramic Society, ACerS [7]
- NACE International [8]
- The American Institute of Mining, Metallurgical, and Petroleum Engineers, AIME [9]
- Society for the Advancement of Material and Process Engineering, SAMPE [10]

- The Institute of Materials, Minerals and Mining, $IOM^3$ [11]
- Alpha Sigma Mu, AΣM [12]
- Central European Institute of Technology, CEITEC [13]
- Association for Iron and Steel Technology, AIST [14]
- Federation of European Materials Societies, FEMS [15]

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[3] http://www.emrs-strasbourg.com/
[4] http://asmcommunity.asminternational.org/portal/site/www/
[5] http://www.tms.org/TMSHome.aspx
[6] http://www.materialsaustralia.com.au/
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[8] http://www.nace.org/
[9] http://www.aimehq.org/
[10] http://www.sampe.org/
[11] http://www.iom3.org/
[12] http://www.alphasigmamu.org/
[13] http://www.ceitec.eu/
[14] http://www.aist.org/
[15] http://www.fems.org/
[16] http://www.materialmoments.org/top100.html


## External links

- Nanoscale Interdisciplinary Research Team (http://nirt.pa.msu.edu/)
- CMR – Centre for Materials Research (http://cmr.curtin.edu.au/)
- Materials Science and Engineering (https://inlportal.inl.gov/portal/server.pt?open=514&objID=1650&parentname=CommunityPage&parentid=7&mode=2&in_hi_userid=200&cached=true) – Idaho National Laboratory
- Dissemination of IT for the Promotion of Materials Science (DoITPoMS) (http://www.doitpoms.ac.uk/tlplib/index.php)
- EURELNET Technology Transfer Department at the University of Bordeaux (https://www.eurelnet.org/)
- MATTER (Materials e-Learning Resources) at the University of Liverpool (http://www.matter.org.uk/)
- CORE-Materials Open Educational Resources for Materials Science & Engineering (http://core.materials.ac.uk/)
- Materials Research [[CEIT (http://www.ceit.es/index.php?option=com_content&view=article&id=25&Itemid=28&lang=en)] Research Institute]
- Manufacturing engineering and mechanical properties of plastic parts (http://www3.fi.mdp.edu.ar/ingpolimeros/en/) – INTEMA (Research Institute), Universidad Nacional de Mar del Plata – CONICET

# Microtechnology

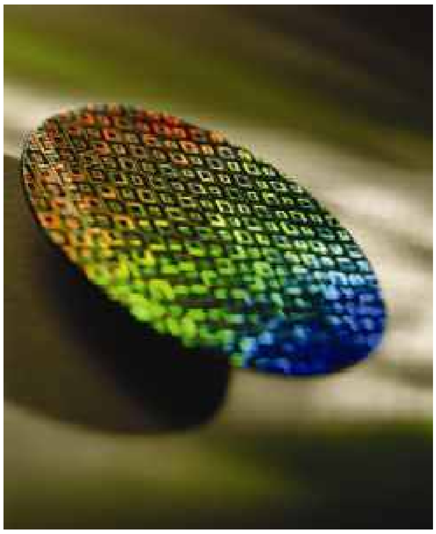
**Microtechnology** is technology with features near one micrometre (one millionth of a metre, or $10^{-6}$ metre, or 1μm).

In the 1960s, scientists learned that by arraying large numbers of microscopic transistors on a single chip, microelectronic circuits could be built that dramatically improved performance, functionality, and reliability, all while reducing cost and increasing volume. This development led to the Information Revolution.

More recently, scientists have learned that not only electrical devices, but also mechanical devices, may be miniaturized and batch-fabricated, promising the same benefits to the mechanical world as integrated circuit technology has given to the electrical world. While electronics now provide the 'brains' for today's advanced systems and products, micromechanical devices can provide the sensors and actuators — the eyes and ears, hands and feet — which interface to the outside world.

Today, micromechanical devices are the key components in a wide range of products such as automobile airbags, ink-jet printers, blood pressure monitors, and projection display systems. It seems clear that in the not-too-distant future these devices will be as pervasive as electronics.

## Micro electromechanical systems



An etched silicon wafer

The term MEMS, for Micro Electro Mechanical Systems, was coined in the 1980s to describe new, sophisticated mechanical systems on a chip, such as micro electric motors, resonators, gears, and so on. Today, the term MEMS in practice is used to refer to any microscopic device with a mechanical function, which can be fabricated in a batch process (for example, an array of microscopic gears fabricated on a microchip would be considered a MEMS device but a tiny laser-machined stent or watch component would not). In Europe, the term MST for Micro System Technology is preferred, and in Japan MEMS are simply referred to as "micromachines". The distinctions in these terms are relatively minor and are often used interchangeably.

Though MEMS processes are generally classified into a number of categories – such as surface machining, bulk machining, LIGA, and EFAB – there are indeed thousands of different MEMS processes. Some produce fairly simple geometries, while others offer more complex 3-D geometries and more versatility. A company making accelerometers for airbags would need a completely different design and process to produce an accelerometer for inertial navigation. Changing from an accelerometer to another inertial device such as a gyroscope requires an even greater change in design and process, and most likely a completely different fabrication facility and engineering team.

MEMS technology has generated a tremendous amount of excitement, due to the vast range of important applications where MEMS can offer previously unattainable performance and reliability standards. In an age where everything must be smaller, faster, and cheaper, MEMS offers a compelling solution. MEMS have already had a profound impact on certain applications such as automotive sensors and inkjet printers. The emerging MEMS industry is already a multi-billion dollar market. It is expected to grow rapidly and become one of the major industries of the 21st century. Cahners In-Stat Group has projected sales of MEMS to reach $12B by 2005. The European NEXUS group projects even larger revenues, using a more inclusive definition of MEMS.

Microtechnology is often constructed using photolithography. Lightwaves are focused through a mask onto a surface. They solidify a chemical film. The soft, unexposed parts of the film are washed away. Then acid etches away the material not protected.

Microtechnology's most famous success is the integrated circuit. It has also been used to construct micromachinery.

## Items constructed at the microscopic level

The following items have been constructed on a scale of 1 micrometre using photolithography:

- Electronics:
  - wires
  - resistors
  - transistors
  - thermionic valves
  - diodes
  - sensors
  - capacitors
- Machinery:
  - electric motors
  - gears
  - levers
  - bearings
  - hinges
- Fluidics:
  - valves
  - Channels
  - pumps
  - turbines

## External links

- C-MAC MicroTechnology [1]
- Institute for Micromachine and Microfabrication Research at Simon Fraser University [2]

## References

[1] http://www.cmac.com/index.php
[2] http://www.sfu.ca/immr/

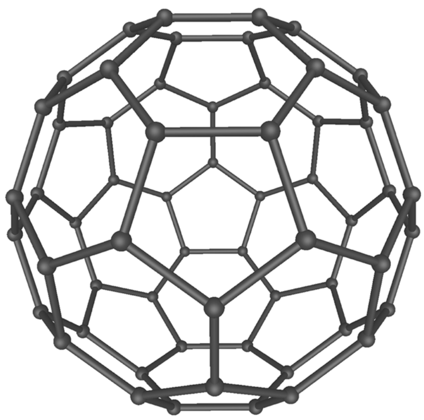
# Nanotechnology

**Nanotechnology** (sometimes shortened to "**nanotech**") is the study of manipulating matter on an atomic and molecular scale. Generally, nanotechnology deals with developing materials, devices, or other structures possessing at least one dimension sized from 1 to 100 nanometres. Quantum mechanical effects are important at this quantum-realm scale.

Nanotechnology is very diverse, ranging from extensions of conventional device physics to completely new approaches based upon molecular self-assembly, from developing new materials with dimensions on the nanoscale to investigating whether we can directly control matter on the atomic scale. Nanotechnology entails the application of fields of science as diverse as surface science, organic chemistry, molecular biology, semiconductor physics, microfabrication, etc.

There is much debate on the future implications of nanotechnology. Nanotechnology may be able to create many new materials and devices with a vast range of applications, such as in medicine, electronics, biomaterials and energy production. On the other hand, nanotechnology raises many of the same issues as any new technology, including concerns about the toxicity and environmental impact of nanomaterials,[1] and their potential effects on global economics, as well as speculation about various doomsday scenarios. These concerns have led to a debate among advocacy groups and governments on whether special regulation of nanotechnology is warranted.

## Origins



Buckminsterfullerene $C_{60}$, also known as the buckyball, is a representative member of the carbon structures known as fullerenes. Members of the fullerene family are a major subject of research falling under the nanotechnology umbrella.

Although nanotechnology is a relatively recent development in scientific research, the development of its central concepts happened over a longer period of time. The emergence of nanotechnology in the 1980s was caused by the convergence of experimental advances such as the invention of the scanning tunneling microscope in 1981 and the discovery of fullerenes in 1985, with the elucidation and popularization of a conceptual framework for the goals of nanotechnology beginning with the 1986 publication of the book *Engines of Creation*.

The scanning tunneling microscope, an instrument for imaging surfaces at the atomic level, was developed in 1981 by Gerd Binnig and Heinrich Rohrer at IBM Zurich Research Laboratory, for which they received the Nobel Prize in Physics in 1986.[2] [3] Fullerenes were discovered in 1985 by Harry Kroto, Richard Smalley, and Robert Curl, who together won the 1996 Nobel Prize in Chemistry.[4] [5]

Around the same time, K. Eric Drexler developed and popularized the concept of nanotechnology and founded the field of molecular nanotechnology. In 1979, Drexler encountered Richard Feynman's 1959 talk "There's Plenty of Room at the Bottom". The term "nanotechnology", originally coined by Norio Taniguchi in 1974, was unknowingly appropriated by Drexler in his 1986 book *Engines of Creation: The Coming Era of Nanotechnology*, which proposed the idea of a nanoscale "assembler" which would be able to build a copy of itself and of other items of arbitrary complexity. He also first published the term "grey goo" to describe what might happen if a hypothetical self-replicating molecular nanotechnology went out of control. Drexler's vision of nanotechnology is often called "Molecular Nanotechnology" (MNT) or "molecular manufacturing," and Drexler at one point proposed the term "zettatech" which never became popular.

In the early 2000s, the field was subject to growing public awareness and controversy, with prominent debates about both its potential implications, exemplified by the Royal Society's report on nanotechnology,[6] as well as the feasibility of the applications envisioned by advocates of molecular nanotechnology, which culminated in the public debate between Eric Drexler and Richard Smalley in 2001 and 2003.[7] Governments moved to promote and fund research into nanotechnology with programs such as the National Nanotechnology Initiative.

The early 2000s also saw the beginnings of commercial applications of nanotechnology, although these were limited to bulk applications of nanomaterials, such as the Silver Nano platform for using silver nanoparticles as an antibacterial agent, nanoparticle-based transparent sunscreens, and carbon nanotubes for stain-resistant textiles.[8] [9]

## Fundamental concepts

Nanotechnology is the engineering of functional systems at the molecular scale. This covers both current work and concepts that are more advanced. In its original sense, nanotechnology refers to the projected ability to construct items from the bottom up, using techniques and tools being developed today to make complete, high performance products.

One nanometer (nm) is one billionth, or $10^{-9}$, of a meter. By comparison, typical carbon-carbon bond lengths, or the spacing between these atoms in a molecule, are in the range 0.12–0.15 nm, and a DNA double-helix has a diameter around 2 nm. On the other hand, the smallest cellular life-forms, the bacteria of the genus Mycoplasma, are around 200 nm in length. By convention, nanotechnology is taken as the scale range 1 to 100 nm following the definition used by the National Nanotechnology Initiative in the US. The lower limit is set by the size of atoms (hydrogen has the smallest atoms, which are approximately a quarter of a nm diameter) since nanotechnology must build its devices from atoms and molecules. The upper limit is more or less arbitrary but is around the size that phenomena not observed in larger structures start to become apparent and can be made use of in the nano device.[10] These new phenomena make nanotechnology distinct from devices which are merely miniaturised versions of an equivalent macroscopic device; such devices are on a larger scale and come under the description of microtechnology.[11]

To put that scale in another context, the comparative size of a nanometer to a meter is the same as that of a marble to the size of the earth.[12] Or another way of putting it: a nanometer is the amount an average man's beard grows in the time it takes him to raise the razor to his face.[12]

Two main approaches are used in nanotechnology. In the "bottom-up" approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the "top-down" approach, nano-objects are constructed from larger entities without atomic-level control.[13]

Areas of physics such as nanoelectronics, nanomechanics, nanophotonics and nanoionics have evolved during the last few decades to provide a basic scientific foundation of nanotechnology.

## Larger to smaller: a materials perspective

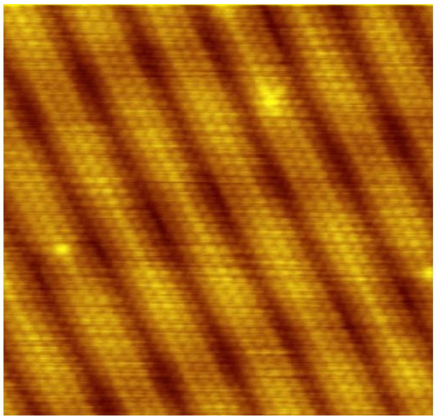


Image of reconstruction on a clean Gold(100) surface, as visualized using scanning tunneling microscopy. The positions of the individual atoms composing the surface are visible.

A number of physical phenomena become pronounced as the size of the system decreases. These include statistical mechanical effects, as well as quantum mechanical effects, for example the “quantum size effect” where the electronic properties of solids are altered with great reductions in particle size. This effect does not come into play by going from macro to micro dimensions. However, quantum effects become dominant when the nanometer size range is reached, typically at distances of 100 nanometers or less, the so called quantum realm. Additionally, a number of physical (mechanical, electrical, optical, etc.) properties change when compared to macroscopic systems. One example is the increase in surface area to volume ratio altering mechanical, thermal and catalytic properties of materials. Diffusion and reactions at nanoscale, nanostructures materials and nanodevices with fast ion transport are generally referred to nanoionics. *Mechanical* properties of nanosystems are of interest in the nanomechanics research. The catalytic activity of nanomaterials also opens potential risks in their interaction with biomaterials.

Materials reduced to the nanoscale can show different properties compared to what they exhibit on a macroscale, enabling unique applications. For instance, opaque substances become transparent (copper); stable materials turn combustible (aluminum); insoluble materials become soluble (gold). A material such as gold, which is chemically inert at normal scales, can serve as a potent chemical catalyst at nanoscales. Much of the fascination with nanotechnology stems from these quantum and surface phenomena that matter exhibits at the nanoscale.[14]

## Simple to complex: a molecular perspective

Modern synthetic chemistry has reached the point where it is possible to prepare small molecules to almost any structure. These methods are used today to manufacture a wide variety of useful chemicals such as pharmaceuticals or commercial polymers. This ability raises the question of extending this kind of control to the next-larger level, seeking methods to assemble these single molecules into supramolecular assemblies consisting of many molecules arranged in a well defined manner.

These approaches utilize the concepts of molecular self-assembly and/or supramolecular chemistry to automatically arrange themselves into some useful conformation through a bottom-up approach. The concept of molecular recognition is especially important: molecules can be designed so that a specific configuration or arrangement is favored due to non-covalent intermolecular forces. The Watson–Crick basepairing rules are a direct result of this, as is the specificity of an enzyme being targeted to a single substrate, or the specific folding of the protein itself. Thus, two or more components can be designed to be complementary and mutually attractive so that they make a more complex and useful whole.

Such bottom-up approaches should be capable of producing devices in parallel and be much cheaper than top-down methods, but could potentially be overwhelmed as the size and complexity of the desired assembly increases. Most useful structures require complex and thermodynamically unlikely arrangements of atoms. Nevertheless, there are many examples of self-assembly based on molecular recognition in biology, most notably Watson–Crick basepairing and enzyme-substrate interactions. The challenge for nanotechnology is whether these principles can be used to engineer new constructs in addition to natural ones.

## Molecular nanotechnology: a long-term view

Molecular nanotechnology, sometimes called molecular manufacturing, describes engineered nanosystems (nanoscale machines) operating on the molecular scale. Molecular nanotechnology is especially associated with the molecular assembler, a machine that can produce a desired structure or device atom-by-atom using the principles of mechanosynthesis. Manufacturing in the context of productive nanosystems is not related to, and should be clearly distinguished from, the conventional technologies used to manufacture nanomaterials such as carbon nanotubes and nanoparticles.

When the term "nanotechnology" was independently coined and popularized by Eric Drexler (who at the time was unaware of an earlier usage by Norio Taniguchi) it referred to a future manufacturing technology based on molecular machine systems. The premise was that molecular scale biological analogies of traditional machine components demonstrated molecular machines were possible: by the countless examples found in biology, it is known that sophisticated, stochastically optimised biological machines can be produced.

It is hoped that developments in nanotechnology will make possible their construction by some other means, perhaps using biomimetic principles. However, Drexler and other researchers[15] have proposed that advanced nanotechnology, although perhaps initially implemented by biomimetic means, ultimately could be based on mechanical engineering principles, namely, a manufacturing technology based on the mechanical functionality of these components (such as gears, bearings, motors, and structural members) that would enable programmable, positional assembly to atomic specification.[16] The physics and engineering performance of exemplar designs were analyzed in Drexler's book *Nanosystems*.

In general it is very difficult to assemble devices on the atomic scale, as all one has to position atoms on other atoms of comparable size and stickiness. Another view, put forth by Carlo Montemagno,[17] is that future nanosystems will be hybrids of silicon technology and biological molecular machines. Yet another view, put forward by the late Richard Smalley, is that mechanosynthesis is impossible due to the difficulties in mechanically manipulating individual molecules.

This led to an exchange of letters in the ACS publication Chemical & Engineering News in 2003.[18] Though biology clearly demonstrates that molecular machine systems are possible, non-biological molecular machines are today only in their infancy. Leaders in research on non-biological molecular machines are Dr. Alex Zettl and his colleagues at Lawrence Berkeley Laboratories and UC Berkeley. They have constructed at least three distinct molecular devices whose motion is controlled from the desktop with changing voltage: a nanotube nanomotor, a molecular actuator,[19] and a nanoelectromechanical relaxation oscillator.[20] See nanotube nanomotor for more examples.

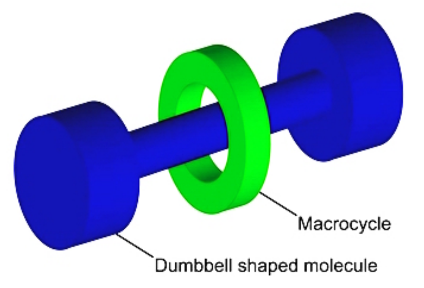
An experiment indicating that positional molecular assembly is possible was performed by Ho and Lee at Cornell University in 1999. They used a scanning tunneling microscope to move an individual carbon monoxide molecule (CO) to an individual iron atom (Fe) sitting on a flat silver crystal, and chemically bound the CO to the Fe by applying a voltage.

## Current research

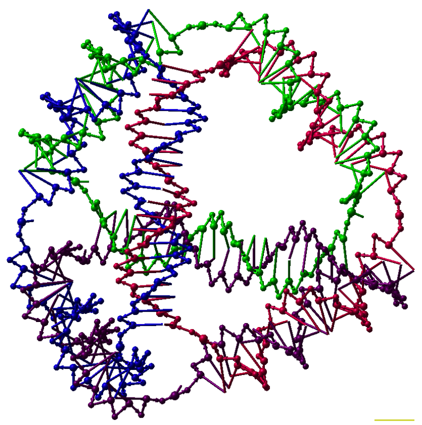
### Nanomaterials

The nanomaterials field includes subfields which develop or study materials having unique properties arising from their nanoscale dimensions.[23]

- Interface and colloid science has given rise to many materials which may be useful in nanotechnology, such as carbon nanotubes and other fullerenes, and various nanoparticles and nanorods. Nanomaterials with fast ion transport are related also to nanoionics and nanoelectronics.
- Nanoscale materials can also be used for bulk applications; most present commercial applications of nanotechnology are of this flavor.
- Progress has been made in using these materials for medical applications; see Nanomedicine.
- Nanoscale materials are sometimes used in solar cells which combats the cost of traditional Silicon solar cells
- Development of applications incorporating semiconductor nanoparticles to be used in the next generation of products, such as display technology, lighting, solar cells and biological imaging; see quantum dots.



Graphical representation of a rotaxane, useful as a molecular switch.


This DNA tetrahedron[21] is an artificially designed nanostructure of the type made in the field of DNA nanotechnology. Each edge of the tetrahedron is a 20 base pair DNA double helix, and each vertex is a three-arm junction.

### Bottom-up approaches

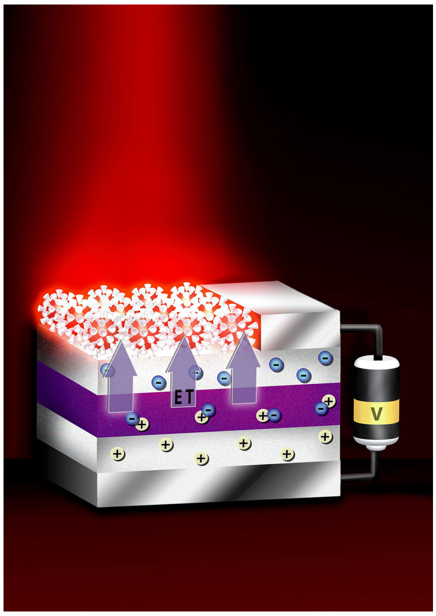
These seek to arrange smaller components into more complex assemblies.

- DNA nanotechnology utilizes the specificity of Watson–Crick basepairing to construct well-defined structures out of DNA and other nucleic acids.
- Approaches from the field of "classical" chemical synthesis (inorganic and organic synthesis) also aim at designing molecules with well-defined shape (e.g. bis-peptides[24] ).
- More generally, molecular self-assembly seeks to use concepts of supramolecular chemistry, and molecular recognition in particular, to cause single-molecule components to automatically arrange themselves into some useful conformation.
- Atomic force microscope tips can be used as a nanoscale "write head" to deposit a chemical upon a surface in a desired pattern in a process called dip pen nanolithography. This technique fits into the larger subfield of nanolithography.

### Top-down approaches

These seek to create smaller devices by using larger ones to direct their assembly.

- Many technologies that descended from conventional solid-state silicon methods for fabricating microprocessors are now capable of creating features smaller than 100 nm, falling under the definition of nanotechnology. Giant magnetoresistance-based hard drives already on the market fit this description,[25] as do atomic layer deposition (ALD) techniques. Peter Grünberg and Albert Fert received the Nobel Prize in Physics in 2007 for their discovery of Giant magnetoresistance and contributions to the field of spintronics.[26]
- Solid-state techniques can also be used to create devices known as nanoelectromechanical systems or NEMS, which are related to microelectromechanical systems or MEMS.
- Focused ion beams can directly remove material, or even deposit material when suitable pre-cursor gasses are applied at the same time. For example, this technique is used routinely to create sub-100 nm sections of material for analysis in Transmission electron microscopy.



This device transfers energy from nano-thin layers of quantum wells to nanocrystals above them, causing the nanocrystals to emit visible light.[22]

- Atomic force microscope tips can be used as a nanoscale "write head" to deposit a resist, which is then followed by an etching process to remove material in a top-down method.

### Functional approaches

These seek to develop components of a desired functionality without regard to how they might be assembled.

- Molecular scale electronics seeks to develop molecules with useful electronic properties. These could then be used as single-molecule components in a nanoelectronic device.[27] For an example see rotaxane.
- Synthetic chemical methods can also be used to create synthetic molecular motors, such as in a so-called nanocar.

### Biomimetic approaches

- Bionics or biomimicry seeks to apply biological methods and systems found in nature, to the study and design of engineering systems and modern technology. Biomineralization is one example of the systems studied.
- Bionanotechnology is the use of biomolecules for applications in nanotechnology, including use of viruses.[28] Nanocellulose is a potential bulk-scale application.

### Speculative

These subfields seek to anticipate what inventions nanotechnology might yield, or attempt to propose an agenda along which inquiry might progress. These often take a big-picture view of nanotechnology, with more emphasis on its societal implications than the details of how such inventions could actually be created.

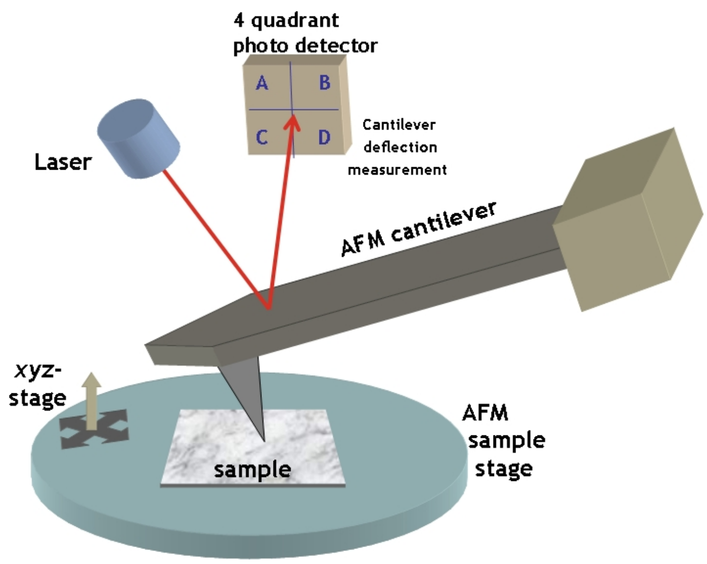
- Molecular nanotechnology is a proposed approach which involves manipulating single molecules in finely controlled, deterministic ways. This is more theoretical than the other subfields and is beyond current capabilities.
- Nanorobotics centers on self-sufficient machines of some functionality operating at the nanoscale. There are hopes for applying nanorobots in medicine,[29] [30] [31] but it may not be easy to do such a thing because of several drawbacks of such devices.[32] Nevertheless, progress on innovative materials and methodologies has been demonstrated with some patents granted about new nanomanufacturing devices for future commercial

applications, which also progressively helps in the development towards nanorobots with the use of embedded nanobioelectronics concepts.[33] [34]

- Productive nanosystems are "systems of nanosystems" which will be complex nanosystems that produce atomically precise parts for other nanosystems, not necessarily using novel nanoscale-emergent properties, but well-understood fundamentals of manufacturing. Because of the discrete (i.e. atomic) nature of matter and the possibility of exponential growth, this stage is seen as the basis of another industrial revolution. Mihail Roco, one of the architects of the USA's National Nanotechnology Initiative, has proposed four states of nanotechnology that seem to parallel the technical progress of the Industrial Revolution, progressing from passive nanostructures to active nanodevices to complex nanomachines and ultimately to productive nanosystems.[35]
- Programmable matter seeks to design materials whose properties can be easily, reversibly and externally controlled though a fusion of information science and materials science.
- Due to the popularity and media exposure of the term nanotechnology, the words picotechnology and femtotechnology have been coined in analogy to it, although these are only used rarely and informally.

## Tools and techniques

There are several important modern developments. The atomic force microscope (AFM) and the Scanning Tunneling Microscope (STM) are two early versions of scanning probes that launched nanotechnology. There are other types of scanning probe microscopy, all flowing from the ideas of the scanning confocal microscope developed by Marvin Minsky in 1961 and the scanning acoustic microscope (SAM) developed by Calvin Quate and coworkers in the 1970s, that made it possible to see structures at the nanoscale.




Typical AFM setup. A microfabricated cantilever with a sharp tip is deflected by features on a sample surface, much like in a phonograph but on a much smaller scale. A laser beam reflects off the backside of the cantilever into a set of photodetectors, allowing the deflection to be measured and assembled into an image of the surface.

The tip of a scanning probe can also be used to manipulate nanostructures (a process called positional assembly). Feature-oriented scanning methodology suggested by Rostislav Lapshin appears to be a promising way to implement these nanomanipulations in automatic mode.[36] [37] However, this is still a slow process because of low scanning velocity of the microscope.

Various techniques of nanolithography such as optical lithography, X-ray lithography dip pen nanolithography, electron beam lithography or nanoimprint lithography were also developed. Lithography is a top-down fabrication technique where a bulk material is reduced in size to nanoscale pattern.

Another group of nanotechnological techniques include those used for fabrication of nanotubes and nanowires, those used in semiconductor fabrication such as deep ultraviolet lithography, electron beam lithography, focused ion beam machining, nanoimprint lithography, atomic layer deposition, and molecular vapor deposition, and further including molecular self-assembly techniques such as those employing di-block copolymers. However, all of these techniques preceded the nanotech era, and are extensions in the development of scientific advancements rather than techniques which were devised with the sole purpose of creating nanotechnology and which were results of nanotechnology research.

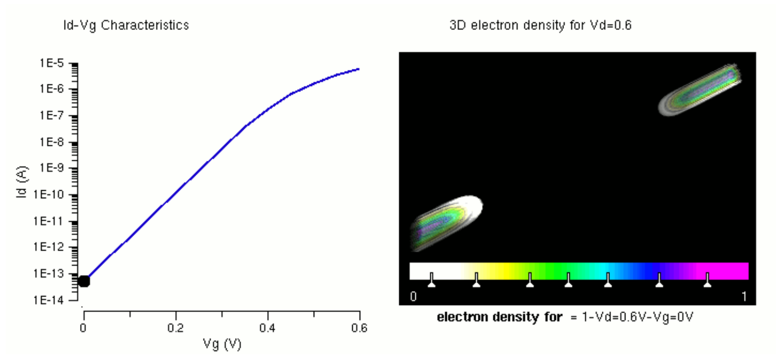
The top-down approach anticipates nanodevices that must be built piece by piece in stages, much as manufactured items are made. Scanning probe microscopy is an important technique both for characterization and synthesis of nanomaterials. Atomic force microscopes and scanning tunneling microscopes can be used to look at surfaces and to move atoms around. By designing different tips for these microscopes, they can be used for carving out structures on surfaces and to help guide self-assembling structures. By using, for example, feature-oriented scanning approach, atoms or molecules can be moved around on a surface with scanning probe microscopy techniques.[36] [37] At present, it is expensive and time-consuming for mass production but very suitable for laboratory experimentation.

In contrast, bottom-up techniques build or grow larger structures atom by atom or molecule by molecule. These techniques include chemical synthesis, self-assembly and positional assembly. Dual polarisation interferometry is one tool suitable for characterisation of self assembled thin films. Another variation of the bottom-up approach is molecular beam epitaxy or MBE. Researchers at Bell Telephone Laboratories like John R. Arthur. Alfred Y. Cho, and Art C. Gossard developed and implemented MBE as a research tool in the late 1960s and 1970s. Samples made by MBE were key to the discovery of the fractional quantum Hall effect for which the 1998 Nobel Prize in Physics was awarded. MBE allows scientists to lay down atomically precise layers of atoms and, in the process, build up complex structures. Important for research on semiconductors, MBE is also widely used to make samples and devices for the newly emerging field of spintronics.

However, new therapeutic products, based on responsive nanomaterials, such as the ultradeformable, stress-sensitive Transfersome vesicles, are under development and already approved for human use in some countries.

## Applications

As of August 21, 2008, the Project on Emerging Nanotechnologies estimates that over 800 manufacturer-identified nanotech products are publicly available, with new ones hitting the market at a pace of 3–4 per week.[9] The project lists all of the products in a publicly accessible online database. Most applications are limited to the use of "first generation" passive nanomaterials which includes titanium dioxide in sunscreen, cosmetics, surface coatings,[38] and some food products; Carbon allotropes used to produce gecko tape; silver in food packaging, clothing, disinfectants and household appliances; zinc oxide in sunscreens and cosmetics, surface coatings, paints and outdoor furniture varnishes; and cerium oxide as a fuel catalyst.[8]




One of the major applications of nanotechnology is in the area of nanoelectronics with MOSFET's being made of small nanowires ~10 nm in length. Here is a simulation of such a nanowire.

The National Science Foundation (a major distributor for nanotechnology research in the United States) funded researcher David Berube to study the field of nanotechnology. His findings are published in the monograph Nano-Hype: The Truth Behind the Nanotechnology Buzz. This study concludes that much of what is sold as “nanotechnology” is in fact a recasting of straightforward materials science, which is leading to a “nanotech industry built solely on selling nanotubes, nanowires, and the like” which will “end up with a few suppliers selling low margin products in huge volumes." Further applications which require actual manipulation or arrangement of nanoscale components await further research. Though technologies branded with the term 'nano' are sometimes little related to and fall far short of the most ambitious and transformative technological goals of the sort in molecular manufacturing proposals, the term still connotes such ideas. According to Berube, there may be a danger that a "nano bubble" will form, or is forming already, from the use of the term by scientists and entrepreneurs to garner funding, regardless of interest in the transformative possibilities of more ambitious and far-sighted work.[39]

## Nanoproducts

**Nanoproduct**s are considered to be consumer goods that have been enhanced by nanotechnology in some form.

The consumer world is seeing more products being released that have been enhanced with nanotechnology. Experts claim that the most immediate impact of nanotechnology is with everyday consumer products. There are numerous amount of products that have been enhanced with nanotechnology. Tennis balls last longer, golf balls fly straighter, even bowling balls become more endurable and have a harder surface to them. Trousers and socks have been infused with nanotechnology so that they will last longer and keep people cool in the summer. Arcade-size video games of yesteryear have been replaced with games like *Madden NFL 2005*, *Grand Theft Auto*, and *Halo 2* for the PlayStation, Xbox, and Nintendo Game Cube thanks to nanotechnology.[40]

Nano-scale manufacturing techniques have revolutionized consumer electronics and are responsible for such products as BlackBerries, flash drives, digital cameras, and MP3 players. Bandages are being infused with silver nanoparticles to heal cuts faster.[40]

Cars are being manufactured with nanomaterials so they may need fewer metals and less fuel to operate in the future.[41] Video game consoles and personal computers may become cheaper, faster, and contain more memory thanks to nanotechnology.[42] Nanotechnology may have the ability to make existing medical applications cheaper and easier to use in places like the general practitioner's office and at home.[43]

## Implications

Because of the far-ranging claims that have been made about potential applications of nanotechnology, a number of serious concerns have been raised about what effects these will have on our society if realized, and what action if any is appropriate to mitigate these risks.

There are possible dangers that arise with the development of nanotechnology. The Center for Responsible Nanotechnology suggests that new developments could result, among other things, in untraceable weapons of mass destruction, networked cameras for use by the government, and weapons developments fast enough to destabilize arms races ("Nanotechnology Basics").

Public deliberations on risk perception in the US and UK carried out by the Center for Nanotechnology in Society at UCSB found that participants were more positive about nanotechnologies for energy than health applications, with health applications raising moral and ethical dilemmas such as cost and availability.[44]

One area of concern is the effect that industrial-scale manufacturing and use of nanomaterials would have on human health and the environment, as suggested by nanotoxicology research. Groups such as the Center for Responsible Nanotechnology have advocated that nanotechnology should be specially regulated by governments for these reasons. Others counter that overregulation would stifle scientific research and the development of innovations which could greatly benefit mankind.

Other experts, including director of the Woodrow Wilson Center's Project on Emerging Nanotechnologies David Rejeski, have testified[45] that successful commercialization depends on adequate oversight, risk research strategy, and public engagement. Berkeley, California is currently the only city in the United States to regulate nanotechnology;[46] Cambridge, Massachusetts in 2008 considered enacting a similar law,[47] but ultimately rejected this.[48]

## Health and environmental concerns

Some of the recently developed nanoparticle products may have unintended consequences. Researchers have discovered that silver nanoparticles used in socks only to reduce foot odor are being released in the wash with possible negative consequences.[49] Silver nanoparticles, which are bacteriostatic, may then destroy beneficial bacteria which are important for breaking down organic matter in waste treatment plants or farms.[50]

A study at the University of Rochester found that when rats breathed in nanoparticles, the particles settled in the brain and lungs, which led to significant increases in biomarkers for inflammation and stress response.[51] A study in China indicated that nanoparticles induce skin aging through oxidative stress in hairless mice.[52] [53]

A two-year study at UCLA's School of Public Health found lab mice consuming nano-titanium dioxide showed DNA and chromosome damage to a degree "linked to all the big killers of man, namely cancer, heart disease, neurological disease and aging".[54]

A major study published more recently in Nature Nanotechnology suggests some forms of carbon nanotubes – a poster child for the “nanotechnology revolution” – could be as harmful as asbestos if inhaled in sufficient quantities. Anthony Seaton of the Institute of Occupational Medicine in Edinburgh, Scotland, who contributed to the article on carbon nanotubes said "We know that some of them probably have the potential to cause mesothelioma. So those sorts of materials need to be handled very carefully."[55] In the absence of specific nano-regulation forthcoming from governments, Paull and Lyons (2008) have called for an exclusion of engineered nanoparticles from organic food.[56] A newspaper article reports that workers in a paint factory developed serious lung disease and nanoparticles were found in their lungs.[57]

## Regulation

Calls for tighter regulation of nanotechnology have occurred alongside a growing debate related to the human health and safety risks associated with nanotechnology.[58] Furthermore, there is significant debate about who is responsible for the regulation of nanotechnology. While some non-nanotechnology specific regulatory agencies currently cover some products and processes (to varying degrees) – by “bolting on” nanotechnology to existing regulations – there are clear gaps in these regimes.[59] In "Nanotechnology Oversight: An Agenda for the Next Administration,"[60] former EPA deputy administrator J. Clarence (Terry) Davies lays out a clear regulatory roadmap for the next presidential administration and describes the immediate and longer term steps necessary to deal with the current shortcomings of nanotechnology oversight.

Stakeholders concerned by the lack of a regulatory framework to assess and control risks associated with the release of nanoparticles and nanotubes have drawn parallels with bovine spongiform encephalopathy (‘mad cow’s disease), thalidomide, genetically modified food,[61] nuclear energy, reproductive technologies, biotechnology, and asbestosis. Dr. Andrew Maynard, chief science advisor to the Woodrow Wilson Center’s Project on Emerging Nanotechnologies, concludes (among others) that there is insufficient funding for human health and safety research, and as a result there is currently limited understanding of the human health and safety risks associated with nanotechnology.[62] As a result, some academics have called for stricter application of the precautionary principle, with delayed marketing approval, enhanced labelling and additional safety data development requirements in relation to certain forms of nanotechnology.[63]

The Royal Society report[6] identified a risk of nanoparticles or nanotubes being released during disposal, destruction and recycling, and recommended that “manufacturers of products that fall under extended producer responsibility regimes such as end-of-life regulations publish procedures outlining how these materials will be managed to minimize possible human and environmental exposure” (p.xiii). Reflecting the challenges for ensuring responsible life cycle regulation, the Institute for Food and Agricultural Standards [64] has proposed standards for nanotechnology research and development should be integrated across consumer, worker and environmental standards. They also propose that NGOs and other citizen groups play a meaningful role in the development of these standards.

The Center for Nanotechnology in Society at UCSB has found that people respond differently to nanotechnologies based upon application - with participants in public deliberations more positive about nanotechnologies for energy than health applications - suggesting that any public calls for nano regulations may differ by technology sector.[44]

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## External links

- Nanotechnology (http://www.dmoz.org/Science/Technology/Nanotechnology//) at the Open Directory Project
- What is Nanotechnology? (http://www.vega.org.uk/video/programme/3) (A Vega/BBC/OU Video Discussion).
- Course on *Introduction to Nanotechnology* (http://nanohub.org/resources/6583)
- Nanex Project (http://nanex-project.eu/index.php/home)
- SAFENANO (http://www.safenano.org/) A nanotechnology initiative of the Institute of Occupational Medicine

# Nuclear technology

A residential smoke detector is the most familiar piece of nuclear technology for some people

**Nuclear technology** is technology that involves the reactions of atomic nuclei. Among the notable nuclear technologies are nuclear power, nuclear medicine, and nuclear weapons. It has found applications from smoke detectors to nuclear reactors, and from gun sights to nuclear weapons.

## History and scientific background

### Discovery

The vast majority of common, natural phenomena on Earth only involve gravity and electromagnetism, and not nuclear reactions. This is because atomic nuclei are generally kept apart because they contain positive electrical charges and therefore repel each other.

In 1896, Henri Becquerel was investigating phosphorescence in uranium salts when he discovered a new phenomenon which came to be called radioactivity.[1] He, Pierre Curie and Marie Curie began investigating the phenomenon. In the process, they isolated the element radium, which is highly radioactive. They discovered that radioactive materials produce intense, penetrating rays of three distinct sorts, which they labeled alpha, beta, and gamma after the Greek letters. Some of these kinds of radiation could pass through ordinary matter, and all of them could be harmful in large amounts. All the early researchers received various radiation burns, much like sunburn, and thought little of it.

The new phenomenon of radioactivity was seized upon by the manufacturers of quack medicine (as had the discoveries of electricity and magnetism, earlier), and a number of patent medicines and treatments involving radioactivity were put forward. Gradually it was realized that the radiation produced by radioactive decay was ionizing radiation, and that even quantities too small to burn posed a severe long-term hazard. Many of the scientists working on radioactivity died of cancer as a result of their exposure. Radioactive patent medicines mostly disappeared, but other applications of radioactive materials persisted, such as the use of radium salts to produce glowing dials on meters.

As the atom came to be better understood, the nature of radioactivity became clearer. Some larger atomic nuclei are unstable, and so decay (release matter or energy) after a random interval. The three forms of radiation that Becquerel and the Curies discovered are also more fully understood. Alpha decay is when a nucleus releases an alpha particle, which is two protons and two neutrons, equivalent to a helium nucleus. Beta decay is the release of a beta particle, a high-energy electron. Gamma decay releases gamma rays, which unlike alpha and beta radiation are not matter but electromagnetic radiation of very high frequency, and therefore energy. This type of radiation is the most dangerous, and most difficult to block. All three types of radiation occur naturally in certain elements.

It has also become clear that the ultimate source of most terrestrial energy is nuclear, either through radiation from the Sun caused by stellar thermonuclear reactions or by radioactive decay of uranium within the Earth, the principal source of geothermal energy.

## Fission

In natural nuclear radiation, the byproducts are very small compared to the nuclei from which they originate. Nuclear fission is the process of splitting a nucleus into roughly equal parts, and releasing energy and neutrons in the process. If these neutrons are captured by another unstable nucleus, they can fission as well, leading to a chain reaction. The average number of neutrons released per nucleus that go on to fission another nucleus is referred to as *k*. Values of *k* larger than 1 mean that the fission reaction is releasing more neutrons than it absorbs, and therefore is referred to as a self-sustaining chain reaction. A mass of fissile material large enough (and in a suitable configuration) to induce a self-sustaining chain reaction is called a critical mass.

When a neutron is captured by a suitable nucleus, fission may occur immediately, or the nucleus may persist in an unstable state for a short time. If there are enough immediate decays to carry on the chain reaction, the mass is said to be prompt critical, and the energy release will grow rapidly and uncontrollably, usually leading to an explosion.

When discovered on the eve of World War II, this insight led multiple countries to begin programs investigating the possibility of constructing an atomic bomb — a weapon which utilized fission reactions to generate far more energy than could be created with chemical explosives. The Manhattan Project, run by the United States with the help of the United Kingdom and Canada, developed multiple fission weapons which were used against Japan in 1945. During the project, the first fission reactors were developed as well, though they were primarily for weapons manufacture and did not generate electricity.

However, if the mass is critical only when the delayed neutrons are included, then the reaction can be controlled, for example by the introduction or removal of neutron absorbers. This is what allows nuclear reactors to be built. Fast neutrons are not easily captured by nuclei; they must be slowed (slow neutrons), generally by collision with the nuclei of a neutron moderator, before they can be easily captured. Today, this type of fission is commonly used to generate electricity.

## Fusion

If nuclei are forced to collide, they can undergo nuclear fusion. This process may release or absorb energy. When the resulting nucleus is lighter than that of iron, energy is normally released; when the nucleus is heavier than that of iron, energy is generally absorbed. This process of fusion occurs in stars, which derive their energy from hydrogen and helium. They form, through stellar nucleosynthesis, the light elements (lithium to calcium) as well as some of the heavy elements (beyond iron and nickel, via the S-process). The remaining abundance of heavy elements, from nickel to uranium and beyond, is due to supernova nucleosynthesis, the R-process.

Of course, these natural processes of astrophysics are not examples of nuclear "technology". Because of the very strong repulsion of nuclei, fusion is difficult to achieve in a controlled fashion. Hydrogen bombs obtain their enormous destructive power from fusion, but their energy cannot be controlled. Controlled fusion is achieved in particle accelerators; this is how many synthetic elements are produced. A fusor can also produce controlled fusion and is a useful neutron source. However, both of these devices operate at a net energy loss. Controlled, viable fusion power has proven elusive, despite the occasional hoax. Technical and theoretical difficulties have hindered the development of working civilian fusion technology, though research continues to this day around the world.

Nuclear fusion was initially pursued only in theoretical stages during World War II, when scientists on the Manhattan Project (led by Edward Teller) investigated it as a method to build a bomb. The project abandoned fusion after concluding that it would require a fission reaction to detonate. It took until 1952 for the first full hydrogen bomb to be detonated, so-called because it used reactions between deuterium and tritium. Fusion reactions are much more energetic per unit mass of fuel than fission reactions, but starting the fusion chain reaction is much more difficult.

## Nuclear weapons

A nuclear weapon is an explosive device that derives its destructive force from nuclear reactions, either fission or a combination of fission and fusion. Both reactions release vast quantities of energy from relatively small amounts of matter. Even small nuclear devices can devastate a city by blast, fire and radiation. Nuclear weapons are considered weapons of mass destruction, and their use and control has been a major aspect of international policy since their debut.

The design of a nuclear weapon is more complicated than it might seem. Such a weapon must hold one or more subcritical fissile masses stable for deployment, then induce criticality (create a critical mass) for detonation. It also is quite difficult to ensure that such a chain reaction consumes a significant fraction of the fuel before the device flies apart. The procurement of a nuclear fuel is also more difficult than it might seem, as no naturally occurring substance is sufficiently unstable for this process to occur.

One isotope of uranium, namely uranium-235, is naturally occurring and sufficiently unstable, but it is always found mixed with the more stable isotope uranium-238. The latter accounts for more than 99% of the weight of natural uranium. Therefore some method of isotope separation based on the weight of three neutrons must be performed to enrich (isolate) uranium-235.

Alternatively, the element plutonium possesses an isotope that is sufficiently unstable for this process to be usable. Plutonium does not occur naturally, so it must be manufactured in a nuclear reactor.

Ultimately, the Manhattan Project manufactured nuclear weapons based on each of these elements. They detonated the first nuclear weapon in a test code-named "Trinity", near Alamogordo, New Mexico, on July 16, 1945. The test was conducted to ensure that the implosion method of detonation would work, which it did. A uranium bomb, Little Boy, was dropped on the Japanese city Hiroshima on August 6, 1945, followed three days later by the plutonium-based Fat Man on Nagasaki. In the wake of unprecedented devastation and casualties from a single weapon, the Japanese government soon surrendered, ending World War II.

Since these bombings, no nuclear weapons have been deployed offensively. Nevertheless, they prompted an arms race to develop increasingly destructive bombs to provide a nuclear deterrent. Just over four years later, on August 29, 1949, the Soviet Union detonated its first fission weapon. The United Kingdom followed on October 2, 1952; France, on February 13, 1960; and China component to a nuclear weapon. Approximately half of the deaths from Hiroshima and Nagasaki died two to five years afterward from radiation exposure.[2] [3] A radiological weapons is a type of nuclear weapon designed to distribute hazardous nuclear material in enemy areas. Such a weapon would not have the explosive capability of a fission or fusion bomb, but would kill many people and contaminate a large area. A radiological weapon has never been deployed. While considered useless by a conventional military, such a weapon raises concerns over nuclear terrorism.

There have been over 2,000 nuclear tests conducted since 1945. In 1963, all nuclear and many non-nuclear states signed the Limited Test Ban Treaty, pledging to refrain from testing nuclear weapons in the atmosphere, underwater, or in outer space. The treaty permitted underground nuclear testing. France continued atmospheric testing until 1974, while China continued up until 1980. The last underground test by the United States was in 1992, the Soviet Union in 1990, the United Kingdom in 1991, and both France and China continued testing until 1996. After signing the Comprehensive Test Ban Treaty in 1996 (which had as of 2011 not entered into force), all of these states have pledged to discontinue all nuclear testing. Non-signatories India and Pakistan last tested nuclear weapons in 1998.

Nuclear weapons are the most destructive weapons known - the archetypal weapons of mass destruction. Throughout the Cold War, the opposing powers had huge nuclear arsenals, sufficient to kill hundreds of millions of people. Generations of people grew up under the shadow of nuclear devastation, portrayed in films such as *Dr. Strangelove* and *The Atomic Cafe*.

However, the tremendous energy release in the detonation of a nuclear weapon also suggested the possibility of a new energy source.

# Civilian uses

## Nuclear power

Further information: Nuclear power and Nuclear reactor technology

Nuclear power is a type of nuclear technology involving the controlled use of nuclear fission to release energy for work including propulsion, heat, and the generation of electricity. Nuclear energy is produced by a controlled nuclear chain reaction which creates heat—and which is used to boil water, produce steam, and drive a steam turbine. The turbine is used to generate electricity and/or to do mechanical work.

Currently nuclear power provides approximately 15.7% of the world's electricity (in 2004) and is used to propel aircraft carriers, icebreakers and submarines (so far economics and fears in some ports have prevented the use of nuclear power in transport ships).[4] All nuclear power plants use fission. Despite years of effort and the occasional hoax (i.e. cold fusion), no man-made fusion reaction has produced more energy than it consumed and been a viable source of electricity.

## Medical applications

The medical applications of nuclear technology are divided into diagnostics and radiation treatment.

Imaging - medical and dental x-ray imagers use of Cobalt-60 or other x-ray sources. Technetium-99m is used, attached to organic molecules, as radioactive tracer in the human body, before being excreted by the kidneys. Positron emitting nucleotides are used for high resolution, short time span imaging in applications known as Positron emission tomography.

Radiation therapy is an effective treatment for cancer.

## Industrial applications

**Oil and Gas Exploration**- Nuclear well logging is used to help predict the commercial viability of new or existing wells. The technology involves the use of a neutron or gamma-ray source and a radiation detector which are lowered into boreholes to determine the properties of the surrounding rock such as porosity and lithography.[5]

**Road Construction** - Nuclear moisture/density gauges are used to determine the density of soils, asphalt, and concrete. Typically a Cesium-137 source is used.

### Commercial applications

An ionization smoke detector includes a tiny mass of radioactive americium-241, which is a source of alpha radiation. Tritium is used with phosphor in rifle sights to increase nighttime firing accuracy. Luminescent exit signs use the same technology.[6]

### Food processing and agriculture

Food irradiation[7] is the process of exposing food to ionizing radiation in order to destroy microorganisms, bacteria, viruses, or insects that might be present in the food. The radiation sources used include radioisotope gamma ray sources, X-ray generators and electron accelerators. Further applications include sprout inhibition, delay of ripening, increase of juice yield, and improvement of re-hydration. Irradiation is a more general term of deliberate exposure of materials to radiation to achieve a technical goal (in this context 'ionizing radiation' is implied). As such it is also used on non-food items, such as medical hardware, plastics, tubes for gas-pipelines, hoses for floor-heating, shrink-foils for food packaging, automobile parts, wires and cables (isolation), tires, and even gemstones. Compared to the amount of food irradiated, the volume of those every-day applications is huge but not noticed by the consumer.

The Radura logo, used to show a food has been treated with ionizing radiation.

The genuine effect of processing food by ionizing radiation relates to damages to the DNA, the basic genetic information for life. Microorganisms can no longer proliferate and continue their malignant or pathogen activities. Spoilage causing micro-organisms cannot continue their activities. Insects do not survive or become incapable of procreation. Plants cannot continue the natural ripening or aging process. All these effects are beneficial to the consumer and the food industry, likewise.[7]

The amount of energy imparted for effective food irradiation is low compared to cooking the same; even at a typical dose of 10 kGy most food, which is (with regard to warming) physically equivalent to water, would warm by only about 2.5 °C (4.5 °F).

The specialty of processing food by ionizing radiation is the fact, that the energy density per atomic transition is very high, it can cleave molecules and induce ionization (hence the name) which cannot be achieved by mere heating. This is the reason for new beneficial effects, however at the same time, for new concerns. The treatment of solid food by ionizing radiation can provide an effect similar to heat pasteurization of liquids, such as milk. However, the use of the term, cold pasteurization, to describe irradiated foods is controversial, because pasteurization and irradiation are fundamentally different processes, although the intended end results can in some cases be similar.

Food irradiation is currently permitted by over 40 countries and volumes are estimated to exceed 500000 metric tons ( long tons; short tons) annually world wide.[8] [9] [10]

Food irradiation is essentially a non-nuclear technology; it relies on the use of ionizing radiation which may be generated by accelerators for electrons and conversion into bremsstrahlung, but which may use also gamma-rays from nuclear decay. There is a worldwide industry for processing by ionizing radiation, the majority by number and by processing power using accelerators. Food irradiation is only a niche application compared to medical supplies, plastic materials, raw materials, gemstones, cables and wires, etc.

## Accidents

Nuclear accidents, because of the powerful forces involved, are often very dangerous. Historically, the first incidents involved fatal radiation exposure. Marie Curie died from aplastic anemia which resulted from her high levels of exposure. Two scientists, an American and Canadian respectively, Harry Daghlian and Louis Slotin, died after mishandling the same plutonium mass. Unlike convention weapons, the intense light, heat, and explosive force is not the only deadly component to a nuclear weapon. Approximately half of the deaths from Hiroshima and Nagasaki died two to five years afterward from radiation exposure.[2] [3]

Civilian nuclear and radiological accidents primarily involve nuclear power plants. Most common are nuclear leaks that expose workers to hazardous material. A nuclear meltdown refers to the more serious hazard of releasing nuclear material into the surrounding environment. The most significant meltdowns occurred at Three Mile Island in Pennsylvania and Chernobyl in the Soviet Ukraine. The earthquake and tsunami on March 11, 2011 caused serious damage to three nuclear reactors and a spent fuel storage pond at the Fukushima Daiichi nuclear power plant in Japan. Military reactors that experienced similar accidents were Windscale in the United Kingdom and SL-1 in the United States.

Military accidents usually involve the loss or unexpected detonation of nuclear weapons. The Castle Bravo test in 1954 produced a larger yield than expected, which contaminated nearby islands, a Japanese fishing boat (with one fatality), and raised concerns about contaminated fish in Japan. In the 1950s through 1970s, several nuclear bombs were lost from submarines and aircraft, some of which have never been recovered. The last twenty years have seen a marked decline in such accidents.

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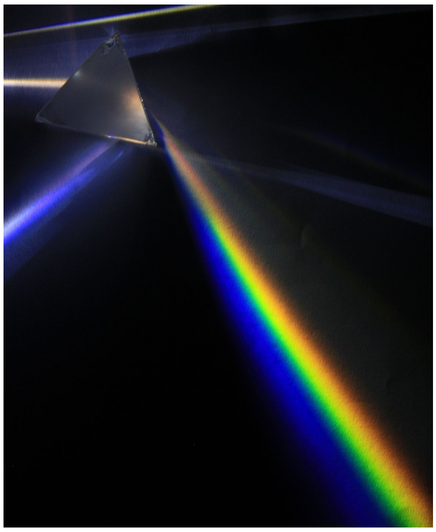
## External links

- Nuclear Energy Institute – Beneficial Uses of Radiation (http://www.nei.org/howitworks)
- Nuclear Technology (http://www.ans.org/pubs/journals/nt/)
- National Isotope Development Center (http://isotopes.gov/) – U.S. Government source of isotopes for basic and applied nuclear science and nuclear technology - production, research, development, distribution, and information

# Optics


Optics includes study of dispersion of light.

**Optics** is the branch of physics which involves the behavior and properties of light, including its interactions with matter and the construction of instruments that use or detect it.[1] Optics usually describes the behavior of visible, ultraviolet, and infrared light. Because light is an electromagnetic wave, other forms of electromagnetic radiation such as X-rays, microwaves, and radio waves exhibit similar properties.[1]

Most optical phenomena can be accounted for using the classical electromagnetic description of light. Complete electromagnetic descriptions of light are, however, often difficult to apply in practice. Practical optics is usually done using simplified models. The most common of these, geometric optics, treats light as a collection of rays that travel in straight lines and bend when they pass through or reflect from surfaces. Physical optics is a more comprehensive model of light, which includes wave effects such as diffraction and interference that cannot be accounted for in geometric optics. Historically, the ray-based model of light was developed first, followed by the wave model of light. Progress in electromagnetic theory in the 19th century led to the discovery that light waves were in fact electromagnetic radiation.

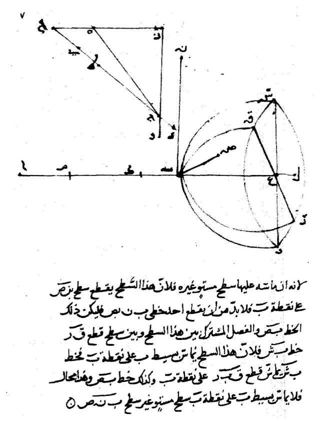
Some phenomena depend on the fact that light has both wave-like and particle-like properties. Explanation of these effects requires quantum mechanics. When considering light's particle-like properties, the light is modeled as a collection of particles called "photons". Quantum optics deals with the application of quantum mechanics to optical systems.

Optical science is relevant to and studied in many related disciplines including astronomy, various engineering fields, photography, and medicine (particularly ophthalmology and optometry). Practical applications of optics are found in a variety of technologies and everyday objects, including mirrors, lenses, telescopes, microscopes, lasers, and fiber optics.

## History

Optics began with the development of lenses by the ancient Egyptians and Mesopotamians. The earliest known lenses were made from polished crystal, often quartz, and have been dated as early as 700 BC for Assyrian lenses such as the Layard/Nimrud lens.[2] The ancient Romans and Greeks filled glass spheres with water to make lenses. These practical developments were followed by the development of theories of light and vision by ancient Greek and Indian philosophers, and the development of geometrical optics in the Greco-Roman world. The word *optics* comes from the ancient Greek word *ὀπτική*, meaning *appearance* or *look*.[3] Plato first articulated emission theory, the idea that visual perception is accomplished by rays emitted by the eyes. He also commented on the parity reversal of mirrors in *Timaeus*.[4] Some hundred years later, Euclid wrote a treatise entitled *Optics* wherein he described the mathematical rules of perspective and describes the effects of refraction qualitatively.[5] Ptolemy, in his treatise *Optics*, summarizes much of Euclid and goes on to describe a way to measure the angle of refraction, though he failed to notice the empirical relationship between it and the angle of incidence.[6]

During the Middle Ages, Greek ideas about optics were resurrected and extended by writers in the Muslim world. One of the earliest of these was Al-Kindi (c. 801–73). In 984, the Persian mathematician Ibn Sahl wrote the treatise "On burning mirrors and lenses", correctly describing a law of refraction equivalent to Snell's law.[7] He used this law to compute optimum shapes for lenses and curved mirrors. In the early 11th century, Alhazen (Ibn al-Haytham) wrote his *Book of Optics*, which documented the then-current understanding of vision.[8] [9] [10]



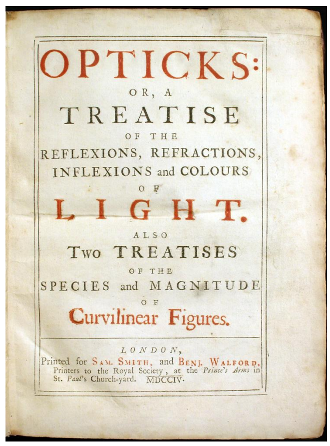
Reproduction of a page of Ibn Sahl's manuscript showing his knowledge of the law of refraction, now known as Snell's law

In the 13th century, Roger Bacon used parts of glass spheres as magnifying glasses, and discovered that light reflects from objects rather than being released from them. In Italy, around 1284, Salvino D'Armate invented the first wearable eyeglasses.[11]

The earliest known telescopes were refracting telescopes developed within the Netherlands eyeglass industry[12] [13] in 1608 with contemporaneous or after the fact claims of invention citing three individuals: Hans Lippershey and Zacharias Janssen, who were spectacle makers in Middelburg, and Jacob Metius of Alkmaar.[14] In Italy, Galileo greatly improved upon these designs the following year. In 1668, Isaac Newton constructed the first practical reflecting telescope, which bears his name, the Newtonian reflector.[15]

The first microscope was made around 1595, also in Middelburg.[16] Three different eyeglass makers have been given credit for the invention: Lippershey, Janssen, and his father, Hans. The coining of the name "microscope" has been credited to Giovanni Faber, who gave that name to Galileo's compound microscope in 1625.[17]

Optical theory progressed in the mid-17th century with treatises written by philosopher René Descartes, which explained a variety of optical phenomena including reflection and refraction by assuming that light was emitted by objects which produced it.[18] This differed substantively from the ancient Greek emission theory. In the late 1660s and early 1670s, Newton expanded Descartes' ideas into a corpuscle theory of light, famously showing that white light, instead of being a unique color, was really a composite of different colors that can be separated into a spectrum with a prism. In 1690, Christian Huygens proposed a wave theory for light based on suggestions that had been made by Robert Hooke in 1664. Hooke himself publicly criticized Newton's theories of light and the feud between the two lasted until Hooke's death. In 1704, Newton published *Opticks* and, at the time, partly because of his success in other areas of physics, he was generally considered to be the victor in the debate over the nature of light.[18]




Cover of the first edition of Newton's *Opticks*

Newtonian optics was generally accepted until the early 19th century when Thomas Young and Augustin-Jean Fresnel conducted experiments on the interference of light that firmly established light's wave nature. Young's famous double slit experiment showed that light followed the law of superposition, which is a wave-like property not predicted by Newton's corpuscle theory. This work led to a theory of diffraction for light and opened an entire area of study in physical optics.[19] Wave optics was successfully unified with electromagnetic theory by James Clerk Maxwell in the 1860s.[20]

The next development in optical theory came in 1899 when Max Planck correctly modeled blackbody radiation by assuming that the exchange of energy between light and matter only occurred in discrete amounts he called *quanta*.[21] In 1905, Albert Einstein published the theory of the photoelectric effect that firmly established the quantization of light itself.[22] [23] In 1913, Niels Bohr showed that atoms could only emit discrete amounts of energy, thus explaining the discrete lines seen in emission and absorption spectra.[24] The understanding of the interaction between light and matter, which followed from these developments, not only formed the basis of quantum optics but also was crucial for the development of quantum mechanics as a whole. The ultimate culmination was the theory of quantum electrodynamics, which explains all optics and electromagnetic processes in general as being the result of the exchange of real and virtual photons.[25]

Quantum optics gained practical importance with the invention of the maser in 1953 and the laser in 1960.[26] Following the work of Paul Dirac in quantum field theory, George Sudarshan, Roy J. Glauber, and Leonard Mandel applied quantum theory to the electromagnetic field in the 1950s and 1960s to gain a more detailed understanding of photodetection and the statistics of light.

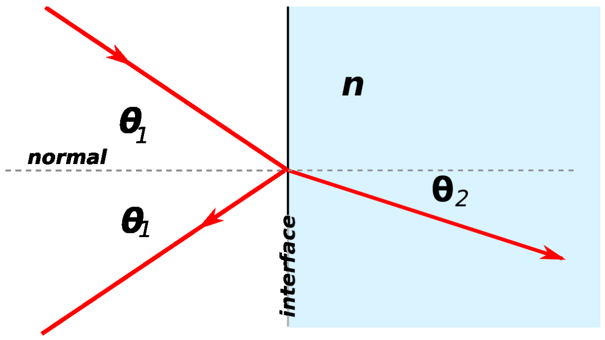
## Classical optics

Classical optics is divided into two main branches: geometrical optics and physical optics. In geometrical, or ray optics, light is considered to travel in straight lines, and in physical, or wave optics, light is considered to be an electromagnetic wave.

Geometrical optics can be viewed as an approximation of physical optics which can be applied when the wavelength of the light used is much smaller than the size of the optical elements or system being modelled.

### Geometrical optics

*Geometrical optics*, or *ray optics*, describes the propagation of light in terms of "rays" which travel in straight lines, and whose paths are governed by the laws of reflection and refraction at interfaces between different media.[27] These laws were discovered empirically as far back as 984AD [28] and have been used in the design of optical components and instruments from then until the present day. They can be summarised as follows:



Geometry of reflection and refraction of light rays

When a ray of light hits the boundary between two transparent materials, it is divided into a reflected and a refracted ray.

The law of reflection says that the reflected ray lies in the plane of incidence, and the angle of reflection equals the angle of incidence.

The law of refraction says that the refracted ray lies in the plane of incidence, and the sine of the angle of refraction divided by the sine of the angle of incidence is a constant.

$$\frac{\sin\theta_1}{\sin\theta_2} = n$$

where $n$ is a constant for any two materials and a given colour of light. It is known as the refractive index.

The laws of reflection and refraction can be derived from Fermat's principle which states that *the path taken between two points by a ray of light is the path that can be traversed in the least time.*[29]

### Approximations

Geometrical optics is often simplified by making the paraxial approximation, or "small angle approximation." The mathematical behavior then becomes linear, allowing optical components and systems to be described by simple matrices. This leads to the techniques of Gaussian optics and *paraxial ray tracing*, which are used to find basic properties of optical systems, such as approximate image and object positions and magnifications.[30]

### Reflections

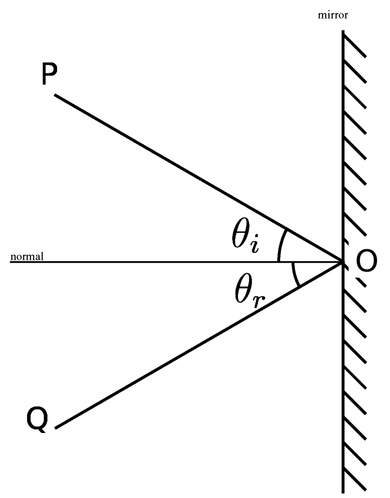


Diagram of specular reflection

Reflections can be divided into two types: specular reflection and diffuse reflection. Specular reflection describes the gloss of surfaces such as mirrors, which reflect light in a simple, predictable way. This allows for production of reflected images that can be associated with an actual (real) or extrapolated (virtual) location in space. Diffuse reflection describes opaque, non limpid materials, such as paper or rock. The reflections from these surfaces can only be described statistically, with the exact distribution of the reflected light depending on the microscopic structure of the material. Many diffuse reflectors are described or can be approximated by Lambert's cosine law, which describes surfaces that have equal luminance when viewed from any angle. Glossy surfaces can give both specular and diffuse reflection.

In specular reflection, the direction of the reflected ray is determined by the angle the incident ray makes with the surface normal, a line perpendicular to the surface at the point where the ray hits. The incident and reflected rays and the normal lie in a single plane, and the angle between the reflected ray and the surface normal is the same as that between the incident ray and the normal.[31] This is known as the Law of Reflection.

For flat mirrors, the law of reflection implies that images of objects are upright and the same distance behind the mirror as the objects are in front of the mirror. The image size is the same as the object size. The law also implies that mirror images are parity inverted, which we perceive as a left-right inversion. Images formed from reflection in two (or any even number of) mirrors are not parity inverted. Corner reflectors[31] retroreflect light, producing reflected rays that travel back in the direction from which the incident rays came.

Mirrors with curved surfaces can be modeled by ray-tracing and using the law of reflection at each point on the surface. For mirrors with parabolic surfaces, parallel rays incident on the mirror produce reflected rays that converge at a common focus. Other curved surfaces may also focus light, but with aberrations due to the diverging shape causing the focus to be smeared out in space. In particular, spherical mirrors exhibit spherical aberration. Curved mirrors can form images with magnification greater than or less than one, and the magnification can be negative, indicating that the image is inverted. An upright image formed by reflection in a mirror is always virtual, while an inverted image is real and can be projected onto a screen.[31]

### Refractions

Refraction occurs when light travels through an area of space that has a changing index of refraction; this principle allows for lenses and the focusing of light. The simplest case of refraction occurs when there is an interface between a uniform medium with index of refraction $n_1$ and another medium with index of refraction $n_2$. In such situations, Snell's Law describes the resulting deflection of the light ray:

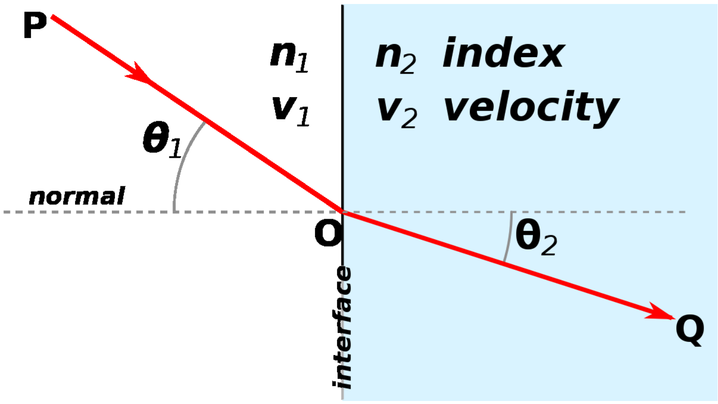



Illustration of Snell's Law for the case $n_1 < n_2$, such as air/water interface

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where $\theta_1$ and $\theta_2$ are the angles between the normal (to the interface) and the incident and refracted waves, respectively. This phenomenon is also associated with a changing speed of light as seen from the definition of index of refraction provided above which implies:

$$v_1 \sin\theta_2 = v_2 \sin\theta_1$$

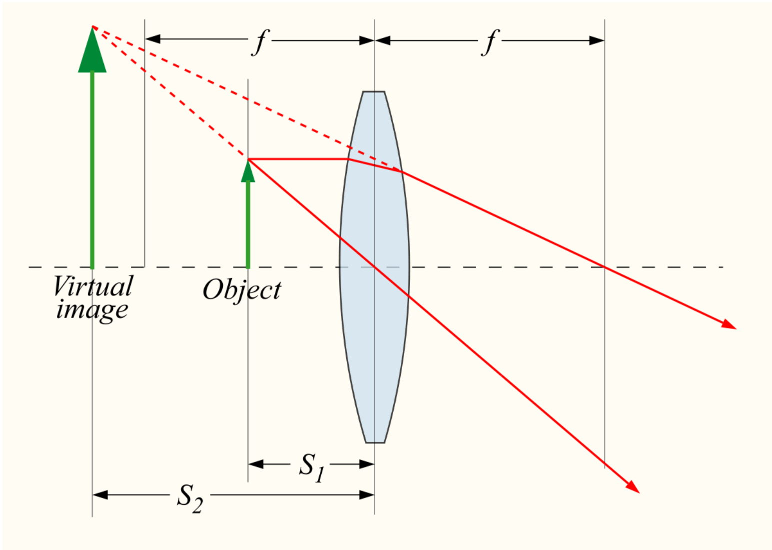
where $v_1$ and $v_2$ are the wave velocities through the respective media.[31]

Various consequences of Snell's Law include the fact that for light rays traveling from a material with a high index of refraction to a material with a low index of refraction, it is possible for the interaction with the interface to result in zero transmission. This phenomenon is called total internal reflection and allows for fiber optics technology. As light signals travel down a fiber optic cable, it undergoes total internal reflection allowing for essentially no light lost over the length of the cable. It is also possible to produce polarized light rays using a combination of reflection and refraction: When a refracted ray and the reflected ray form a right angle, the reflected ray has the property of "plane polarization". The angle of incidence required for such a scenario is known as Brewster's angle.[31]

Snell's Law can be used to predict the deflection of light rays as they pass through "linear media" as long as the indexes of refraction and the geometry of the media are known. For example, the propagation of light through a prism results in the light ray being deflected depending on the shape and orientation of the prism. Additionally, since different frequencies of light have slightly different indexes of refraction in most materials, refraction can be used to produce dispersion spectra that appear as rainbows. The discovery of this phenomenon when passing light through a prism is famously attributed to Isaac Newton.[31]

Some media have an index of refraction which varies gradually with position and, thus, light rays curve through the medium rather than travel in straight lines. This effect is what is responsible for mirages seen on hot days where the changing index of refraction of the air causes the light rays to bend creating the appearance of specular reflections in the distance (as if on the surface of a pool of water). Material that has a varying index of refraction is called a gradient-index (GRIN) material and has many useful properties used in modern optical scanning technologies including photocopiers and scanners. The phenomenon is studied in the field of gradient-index optics.[32]

A device which produces converging or diverging light rays due to refraction is known as a lens. Thin lenses produce focal points on either side that can be modeled using the lensmaker's equation.[33] In general, two types of lenses exist: convex lenses, which cause parallel light rays to converge, and concave lenses, which cause parallel light rays to diverge. The detailed prediction of how images are produced by these lenses can be made using ray-tracing similar to curved mirrors. Similarly to curved mirrors, thin lenses follow a simple equation that determines the location of the images given a particular focal length ( $f$ ) and object distance ( $S_1$ ):

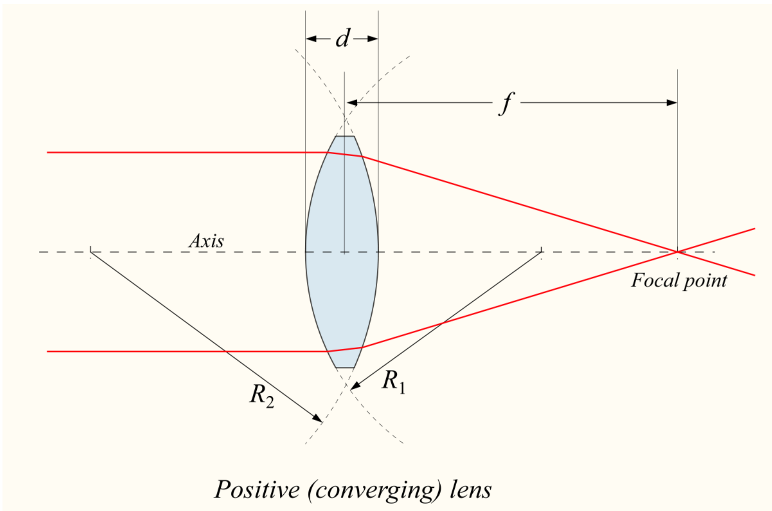


A ray tracing diagram for a converging lens.

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

where $S_2$ is the distance associated with the image and is considered by convention to be negative if on the same side of the lens as the object and positive if on the opposite side of the lens.[33] The focal length f is considered negative for concave lenses.

Incoming parallel rays are focused by a convex lens into an inverted real image one focal length from the lens, on the far side of the lens. Rays from an object at finite distance are focused further from the lens than the focal distance; the closer the object is to the lens, the further the image is from the lens. With concave lenses, incoming parallel rays diverge after going through the lens, in such a way that they seem to have originated at an upright virtual image one focal length from the lens, on the same side of the lens that the parallel rays are approaching on. Rays from an object at finite distance are associated with a virtual image that is closer to the lens than the focal length, and on the same side of the lens as the object. The closer the object is to the lens, the closer the virtual image is to the lens.

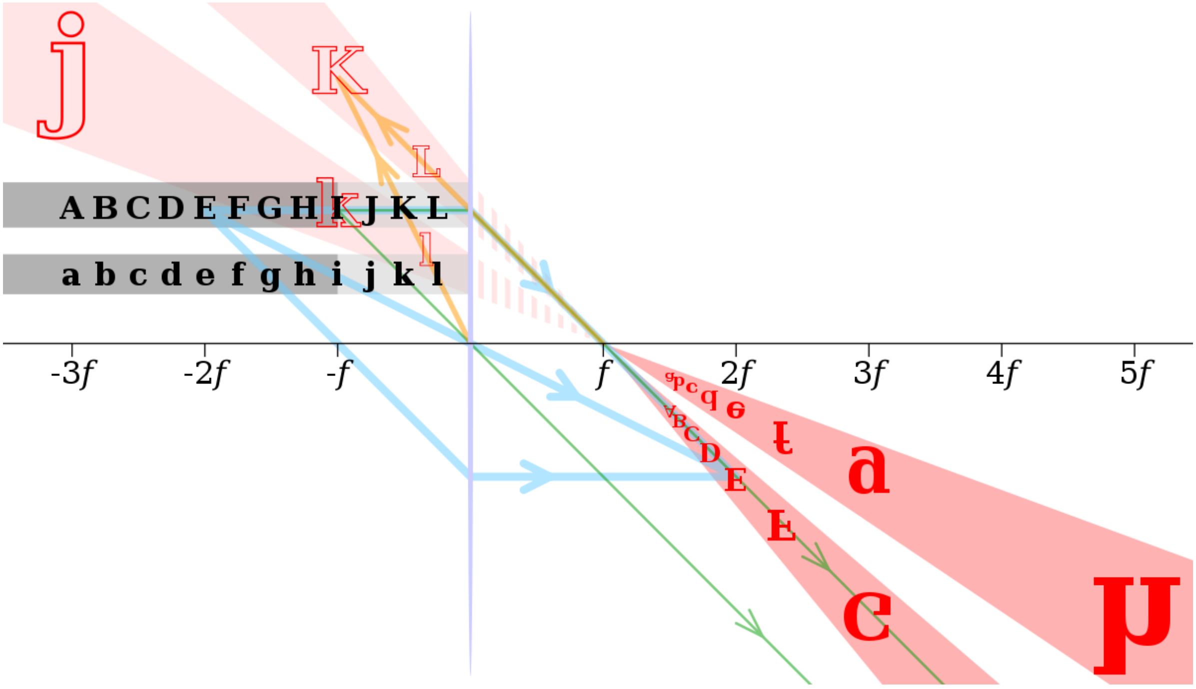



Likewise, the magnification of a lens is given by

$$M = -\frac{S_2}{S_1} = \frac{f}{f - S_1}$$

where the negative sign is given, by convention, to indicate an upright object for positive values and an inverted object for negative values. Similar to mirrors, upright images produced by single lenses are virtual while inverted images are real.[31]

Lenses suffer from aberrations that distort images and focal points. These are due to both to geometrical imperfections and due to the changing index of refraction for different wavelengths of light (chromatic aberration).[31]




Images of black letters in a thin convex lens of focal length *f* are shown in red. Selected rays are shown for letters **E**, **I** and **K** in blue, green and orange, respectively. Note that **E** (at 2*f*) has an equal-size, real and inverted image; **I** (at *f*) has its image at infinity; and **K** (at *f*/2) has a double-size, virtual and upright image.

## Physical optics

In physical optics, light is considered to propagate as a wave. This model predicts phenomena such as interference and diffraction which are not explained by geometric optics. The speed of light waves is approximately $3.10^{8}$ m/s. The wavelength of visible light waves varies between 400-700nm but light waves are usually considered to also include infrared waves (0.7-300μm) and ultraviolet waves (10-400nm).

The wave model can be used to make predictions about how an optical system will behave without requiring an explanation of what is "waving" in what medium. Until the middle of the 19th century, most physicists believed in an "ethereal" medium in which the light disturbance propagated.[34] The existence of electromagnetic waves was predicted in 1865 by Maxwell's equations. These waves propagate at the speed of light and have varying electric and magnetic fields which are orthogonal to one another, and also to the direction of propagation of the waves.[35] Light waves are now generally treated as electromagnetic waves except when quantum mechanical effects have to be considered.

### Modelling and design of optical systems using physical optics

Many simplifed approximations are available for analysing and designing optical systems. Most of these use a single scalar quantity to represent the electric field of the light wave, rather than using a vector model with orthogonal electric and magnetic vectors.[36] The Huygens–Fresnel equation is one such model. This was derived empirically by Fresnel in 1815, based on Huygen's hypothesis that each point on a wavefront generates a secondary spherical wavefront, which Fresnel combined with the principle of superposition of waves. The Kirchoff diffraction equation, which is derived using Maxwell's equations, puts the Huygens-Fresnel equation on a firmer physical foundation.

Examples of the application of Huygens–Fresnel principle can be found in the sections on diffraction and Fraunhofer diffraction.

More rigorous models, involving the modelling of both electric and magnetic fields of the light wave, are required when dealing with the detailed interaction of light with materials where the interaction depends on their electric and magnetic properties. For instance, the behaviour of a light wave interacting with a metal surface is quite different from what happens when it interacts with a di-electric material. A vector model must also be used to model polarized light.

Numerical modeling techniques such as the Finite element method, the Boundary element method and the Transmission-line matrix method can be used to model the propagation of light in systems which cannot be solved analytically. Such models are computationally demanding and are normally only used to solve small-scale problems that require accuracy beyond that which can be achieved with analytical solutions.[37]

All of the results from geometrical optics can be recovered using the techniques of Fourier optics which apply many of the same mathematical and analytical techniques used in acoustic engineering and signal processing.

Gaussian beam propagation is a simple paraxial physical optics model for the propagation of coherent radiation such as laser beams. This technique partially accounts for diffraction, allowing accurate calculations of the rate at which a laser beam expands with distance, and the minimum size to which the beam can be focused. Gaussian beam propagation thus bridges the gap between geometric and physical optics.[38]

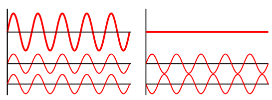
### Superposition and interference

In the absence of nonlinear effects, the superposition principle can be used to predict the shape of interacting waveforms through the simple addition of the disturbances.[39] This interaction of waves to produce a resulting pattern is generally termed "interference" and can result in a variety of outcomes. If two waves of the same wavelength and frequency are *in phase*, both the wave crests and wave troughs align. This results in constructive interference and an increase in the amplitude of the wave, which for light is associated with a brightening of the waveform in that location. Alternatively, if the two waves of the same wavelength and frequency are out of phase, then the wave crests will align with wave troughs and vice-versa. This results in destructive interference and a decrease in the amplitude of the wave, which for light is associated with a dimming of the waveform at that location. See below for an illustration of this effect.[39]

**combined waveform**

**wave 1**

**wave 2**



**Two waves in phase** **Two waves 180° out of phase**

Since the Huygens–Fresnel principle states that every point of a wavefront is associated with the production of a new disturbance, it is possible for a wavefront to interfere with itself constructively or destructively at different locations producing bright and dark fringes in regular and predictable patterns.[39] Interferometry is the science of measuring these patterns, usually as a means of making precise determinations of distances or angular resolutions.[40] The Michelson interferometer was a famous instrument which used interference effects to accurately measure the speed of light.[41]

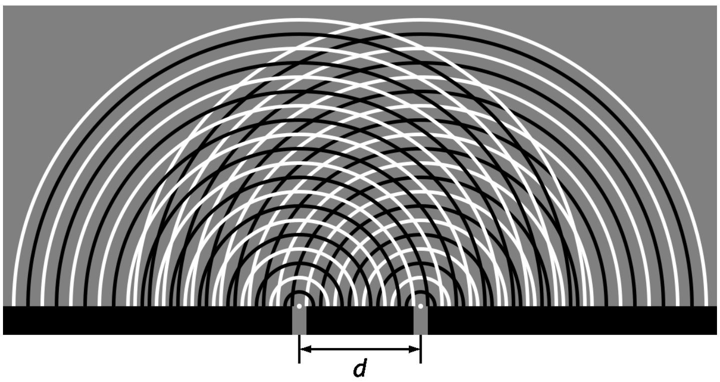

When oil or fuel is spilled, colorful patterns are formed by thin-film interference.

The appearance of thin films and coatings is directly affected by interference effects. Antireflective coatings use destructive interference to reduce the reflectivity of the surfaces they coat, and can be used to minimize glare and unwanted reflections. The simplest case is a single layer with thickness one-fourth the wavelength of incident light. The reflected wave from the top of the film and the reflected wave from the film/material interface are then exactly 180° out of phase, causing destructive interference. The waves are only exactly out of phase for one wavelength, which would typically be chosen to be near the center of the visible spectrum, around 550 nm. More complex designs using multiple layers can achieve low reflectivity over a broad band, or extremely low reflectivity at a single wavelength.

Constructive interference in thin films can create strong reflection of light in a range of wavelengths, which can be narrow or broad depending on the design of the coating. These films are used to make dielectric mirrors, interference filters, heat reflectors, and filters for color separation in color television cameras. This interference effect is also what causes the colorful rainbow patterns seen in oil slicks.[39]

#### Diffraction and optical resolution

Diffraction is the process by which light interference is most commonly observed. The effect was first described in 1665 by Francesco Maria Grimaldi, who also coined the term from the Latin *diffringere*, 'to break into pieces'.[42] [43] Later that century, Robert Hooke and Isaac Newton also described phenomena now known to be diffraction in Newton's rings[44] while James Gregory recorded his observations of diffraction patterns from bird feathers.[45]



Diffraction on two slits separated by distance $d$ . The bright fringes occur along lines where black lines intersect with black lines and white lines intersect with white lines. These fringes are separated by angle $\theta$ and are numbered as order $n$ .

The first physical optics model of diffraction that relied on the Huygens–Fresnel principle was developed in 1803 by Thomas Young in his interference experiments with the interference patterns of two closely spaced slits. Young showed that his results could only be explained if the two slits acted as two unique sources of waves rather than corpuscles.[46] In 1815 and 1818, Augustin-Jean Fresnel firmly established the mathematics of how wave interference can account for diffraction.[33]

The simplest physical models of diffraction use equations that describe the angular separation of light and dark fringes due to light of a particular wavelength ( $\lambda$ ). In general, the equation takes the form

$$m\lambda = d\sin\theta$$

where $d$ is the separation between two wavefront sources (in the case of Young's experiments, it was two slits), $\theta$ is the angular separation between the central fringe and the $m$ th order fringe, where the central maximum is $m = 0$.[47]

This equation is modified slightly to take into account a variety of situations such as diffraction through a single gap, diffraction through multiple slits, or diffraction through a diffraction grating that contains a large number of slits at equal spacing.[47] More complicated models of diffraction require working with the mathematics of Fresnel or Fraunhofer diffraction.[48]

X-ray diffraction makes use of the fact that atoms in a crystal have regular spacing at distances that are on the order of one angstrom. To see diffraction patterns, x-rays with similar wavelengths to that spacing are passed through the crystal. Since crystals are three-dimensional objects rather than two-dimensional gratings, the associated diffraction pattern varies in two directions according to Bragg reflection, with the associated bright spots occurring in unique patterns and $d$ being twice the spacing between atoms.[47]

Diffraction effects limit the ability for an optical detector to optically resolve separate light sources. In general, light that is passing through an aperture will experience diffraction and the best images that can be created (as described in diffraction-limited optics) appear as a central spot with surrounding bright rings, separated by dark nulls; this pattern is known as an Airy pattern, and the central bright lobe as an Airy disk.[33] The size of such a disk is given by

$$\sin\theta = 1.22\frac{\lambda}{D}$$

where $\theta$ is the angular resolution, $\lambda$ is the wavelength of the light, and $D$ is the diameter of the lens aperture. If the angular separation of the two points is significantly less than the Airy disk angular radius, then the two points cannot be resolved in the image, but if their angular separation is much greater than this, distinct images of the two points are formed and they can therefore be resolved. Rayleigh defined the somewhat arbitrary "Rayleigh criterion" that two points whose angular separation is equal to the Airy disk radius (measured to first null, that is, to the first place where no light is seen) can be considered to be resolved. It can be seen that the greater the diameter of the lens or its aperture, the finer the resolution.[47] Interferometry, with its ability to mimic extremely large baseline apertures, allows for the greatest angular resolution possible.[40]

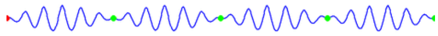
For astronomical imaging, the atmosphere prevents optimal resolution from being achieved in the visible spectrum due to the atmospheric scattering and dispersion which cause stars to twinkle. Astronomers refer to this effect as the quality of astronomical seeing. Techniques known as adaptive optics have been utilized to eliminate the atmospheric disruption of images and achieve results that approach the diffraction limit.[49]

### Dispersion and scattering

Refractive processes take place in the physical optics limit, where the wavelength of light is similar to other distances, as a kind of scattering. The simplest type of scattering is Thomson scattering which occurs when electromagnetic waves are deflected by single particles. In the limit of Thompson scattering, in which the wavelike nature of light is evident, light is dispersed independent of the frequency, in contrast to Compton scattering which is frequency-dependent and strictly a quantum mechanical process, involving the nature of light as particles. In a statistical sense, elastic scattering of light by numerous particles much smaller than the wavelength of the light is a process known as Rayleigh scattering while the similar process for scattering by particles that are similar or larger in wavelength is known as Mie scattering with the Tyndall effect being a commonly observed result. A small proportion of light scattering from atoms or molecules may undergo Raman scattering, wherein the frequency changes due to excitation of the atoms and molecules. Brillouin scattering occurs when the frequency of light changes due to local changes with time and movements of a dense material.[50]

Dispersion occurs when different frequencies of light have different phase velocities, due either to material properties (*material dispersion*) or to the geometry of an optical waveguide (*waveguide dispersion*). The most familiar form of dispersion is a decrease in index of refraction with increasing wavelength, which is seen in most transparent materials. This is called "normal dispersion". It occurs in all dielectric materials, in wavelength ranges where the material does not absorb light.[51] In wavelength ranges where a medium has significant absorption, the index of refraction can increase with wavelength. This is called "anomalous dispersion".[31] [51]

The separation of colors by a prism is an example of normal dispersion. At the surfaces of the prism, Snell's law predicts that light incident at an angle θ to the normal will be refracted at an angle arcsin(sin (θ) / $n$) . Thus, blue light, with its higher refractive index, is bent more strongly than red light, resulting in the well-known rainbow pattern.[31]



Dispersion: two sinusoids propagating at different speeds make a moving interference pattern. The red dot moves with the phase velocity, and the green dots propagate with the group velocity. In this case, the phase velocity is twice the group velocity. The red dot overtakes two green dots, when moving from the left to the right of the figure. In effect, the individual waves (which travel with the phase velocity) escape from the wave packet (which travels with the group velocity).

Material dispersion is often characterized by the Abbe number, which gives a simple measure of dispersion based on the index of refraction at three specific wavelengths. Waveguide dispersion is dependent on the propagation constant.[33] Both kinds of dispersion cause changes in the group characteristics of the wave, the features of the wave packet that change with the same frequency as the amplitude of the electromagnetic wave. "Group velocity dispersion" manifests as a spreading-out of the signal "envelope" of the radiation and can be quantified with a group dispersion delay parameter:

$$D = \frac{1}{v_g^2}\frac{dv_g}{d\lambda}$$

where $v_g$ is the group velocity.[52] For a uniform medium, the group velocity is

$$v_g = c\left(n - \lambda\frac{dn}{d\lambda}\right)^{-1}$$

where $n$ is the index of refraction and $c$ is the speed of light in a vacuum.[53] This gives a simpler form for the dispersion delay parameter:

$$D = -\frac{\lambda}{c}\,\frac{d^2 n}{d\lambda^2}.$$

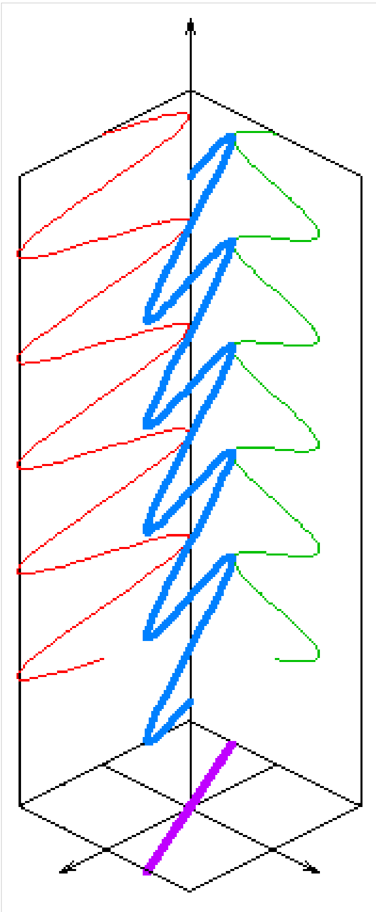
If $D$ is less than zero, the medium is said to have *positive dispersion* or normal dispersion. If $D$ is greater than zero, the medium has *negative dispersion*. If a light pulse is propagated through a normally dispersive medium, the result is the higher frequency components slow down more than the lower frequency components. The pulse therefore becomes *positively chirped*, or *up-chirped*, increasing in frequency with time. This causes the spectrum coming out of a prism to appear with red light the least refracted and blue/violet light the most refracted. Conversely, if a pulse travels through an anomalously (negatively) dispersive medium, high frequency components travel faster than the lower ones, and the pulse becomes *negatively chirped*, or *down-chirped*, decreasing in frequency with time.[54]

The result of group velocity dispersion, whether negative or positive, is ultimately temporal spreading of the pulse. This makes dispersion management extremely important in optical communications systems based on optical fibers, since if dispersion is too high, a group of pulses representing information will each spread in time and merge together, making it impossible to extract the signal.[52]

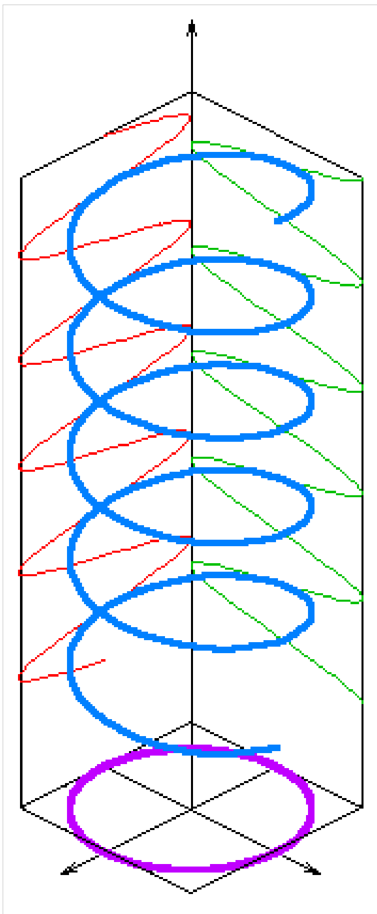
### Polarization

Polarization is a general property of waves that describes the orientation of their oscillations. For transverse waves such as many electromagnetic waves, it describes the orientation of the oscillations in the plane perpendicular to the wave's direction of travel. The oscillations may be oriented in a single direction (linear polarization), or the oscillation direction may rotate as the wave travels (circular or elliptical polarization). Circularly polarized waves can rotate rightward or leftward in the direction of travel, and which of those two rotations is present in a wave is called the wave's chirality.[55]

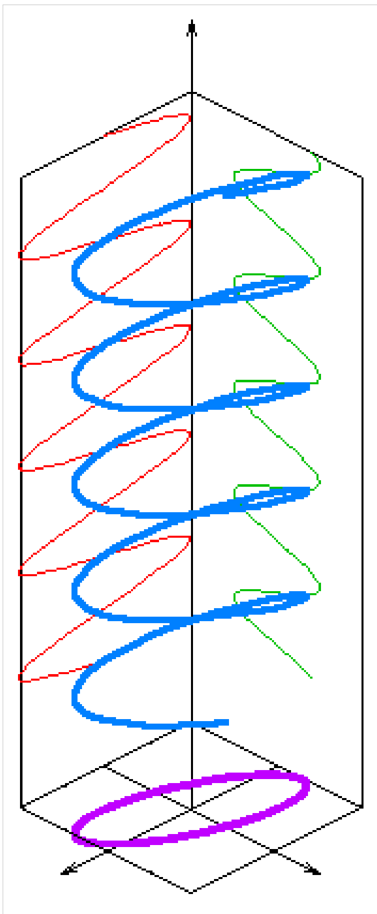
The typical way to consider polarization is to keep track of the orientation of the electric field vector as the electromagnetic wave propagates. The electric field vector of a plane wave may be arbitrarily divided into two perpendicular components labeled *x* and *y* (with **z** indicating the direction of travel). The shape traced out in the x-y plane by the electric field vector is a Lissajous figure that describes the *polarization state*.[33] The following figures show some examples of the evolution of the electric field vector (blue), with time (the vertical axes), at a particular point in space, along with its *x* and *y* components (red/left and green/right), and the path traced by the vector in the plane (purple): The same evolution would occur when looking at the electric field at a particular time while evolving the point in space, along the direction opposite to propagation.



*Linear*



*Circular*



*Elliptical polarization*

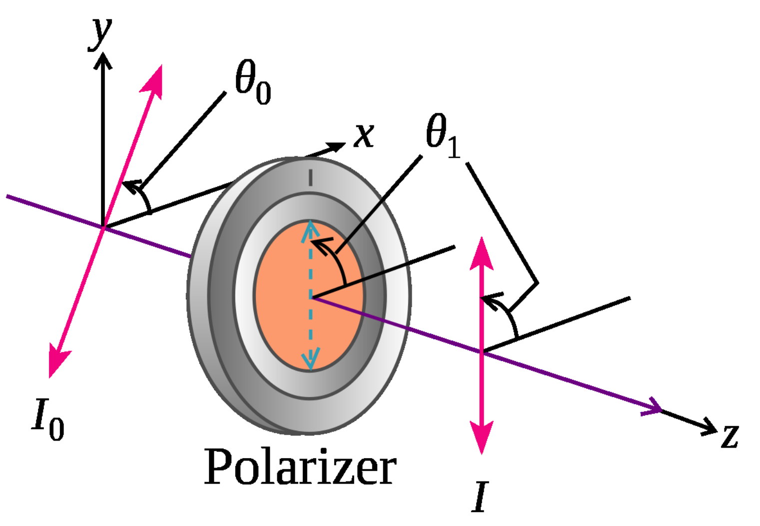
In the leftmost figure above, the x and y components of the light wave are in phase. In this case, the ratio of their strengths is constant, so the direction of the electric vector (the vector sum of these two components) is constant. Since the tip of the vector traces out a single line in the plane, this special case is called linear polarization. The direction of this line depends on the relative amplitudes of the two components.[55]

In the middle figure, the two orthogonal components have the same amplitudes and are 90° out of phase. In this case, one component is zero when the other component is at maximum or minimum amplitude. There are two possible phase relationships that satisfy this requirement: the $x$ component can be 90° ahead of the $y$ component or it can be 90° behind the $y$ component. In this special case, the electric vector traces out a circle in the plane, so this polarization is called circular polarization. The rotation direction in the circle depends on which of the two phase relationships exists and corresponds to *right-hand circular polarization* and *left-hand circular polarization*.[33]

In all other cases, where the two components either do not have the same amplitudes and/or their phase difference is neither zero nor a multiple of 90°, the polarization is called elliptical polarization because the electric vector traces out an ellipse in the plane (the *polarization ellipse*). This is shown in the above figure on the right. Detailed mathematics of polarization is done using Jones calculus and is characterized by the Stokes parameters.[33]

Media that have different indexes of refraction for different polarization modes are called *birefringent*.[55] Well known manifestations of this effect appear in optical wave plates/retarders (linear modes) and in Faraday rotation/optical rotation (circular modes).[33] If the path length in the birefringent medium is sufficient, plane waves will exit the material with a significantly different propagation direction, due to refraction. For example, this is the case with macroscopic crystals of calcite, which present the viewer with two offset, orthogonally polarized images of whatever is viewed through them. It was this effect that provided the first discovery of polarization, by Erasmus Bartholinus in 1669. In addition, the phase shift, and thus the change in polarization state, is usually frequency dependent, which, in combination with dichroism, often gives rise to bright colors and rainbow-like effects. In mineralogy, such properties, known as pleochroism, are frequently exploited for the purpose of identifying minerals using polarization microscopes. Additionally, many plastics that are not normally birefringent will become so when subject to mechanical stress, a phenomenon which is the basis of photoelasticity.[55] Non-birefringent methods, to rotate the linear polarization of light beams, include the use of prismatic polarization rotators which utilize total internal reflection in a prism set designed for efficient colinear transmission.[56]

Media that reduce the amplitude of certain polarization modes are called *dichroic*. with devices that block nearly all of the radiation in one mode known as *polarizing filters* or simply "polarizers". Malus' law, which is named after Etienne-Louis Malus, says that when a perfect polarizer is placed in a linear polarized beam of light, the intensity, $I$, of the light that passes through is given by




A polarizer changing the orientation of linearly polarized light.
In this picture, $\theta_1 - \theta_0 = \theta_i$.

$$I = I_0 \cos^2 \theta_i \quad ,$$

where

$I_0$ is the initial intensity,

and $\theta_i$ is the angle between the light's initial polarization direction and the axis of the polarizer.[55]

A beam of unpolarized light can be thought of as containing a uniform mixture of linear polarizations at all possible angles. Since the average value of $\cos^2 \theta$ is 1/2, the transmission coefficient becomes

$$\frac{I}{I_0} = \frac{1}{2}$$

In practice, some light is lost in the polarizer and the actual transmission of unpolarized light will be somewhat lower than this, around 38% for Polaroid-type polarizers but considerably higher (>49.9%) for some birefringent prism types.[33]

In addition to birefringence and dichroism in extended media, polarization effects can also occur at the (reflective) interface between two materials of different refractive index. These effects are treated by the Fresnel equations. Part of the wave is transmitted and part is reflected, with the ratio depending on angle of incidence and the angle of refraction. In this way, physical optics recovers Brewster's angle.[33]


The effects of a polarizing filter on the sky in a photograph. Left picture is taken without polarizer. For the right picture, filter was adjusted to eliminate certain polarizations of the scattered blue light from the sky.

Most sources of electromagnetic radiation contain a large number of atoms or molecules that emit light. The orientation of the electric fields produced by these emitters may not be correlated, in which case the light is said to be *unpolarized*. If there is partial correlation between the emitters, the light is *partially polarized*. If the polarization is consistent across the spectrum of the source, partially polarized light can be described as a superposition of a completely unpolarized component, and a completely polarized one. One may then describe the light in terms of the degree of polarization, and the parameters of the polarization ellipse.[33]

Light reflected by shiny transparent materials is partly or fully polarized, except when the light is normal (perpendicular) to the surface. It was this effect that allowed the mathematician Etienne Louis Malus to make the measurements that allowed for his development of the first mathematical models for polarized light. Polarization occurs when light is scattered in the atmosphere. The scattered light produces the brightness and color in clear skies. This partial polarization of scattered light can be taken advantage of using polarizing filters to darken the sky in photographs. Optical polarization is principally of importance in chemistry due to circular dichroism and optical rotation ("*circular birefringence*") exhibited by optically active (chiral) molecules.[33]

## Modern optics

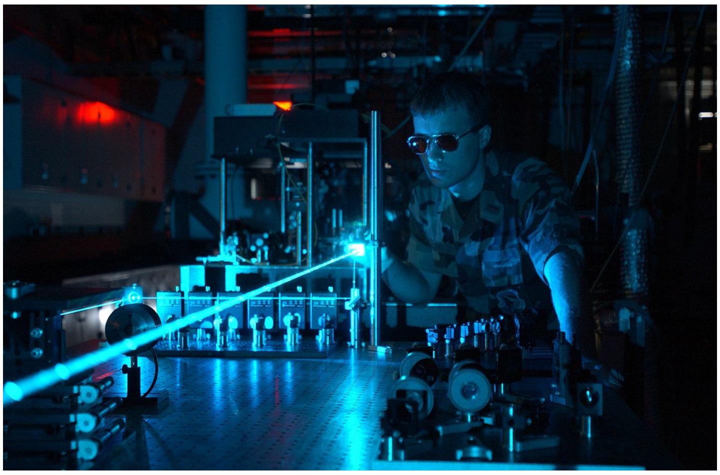
*Modern optics* encompasses the areas of optical science and engineering that became popular in the 20th century. These areas of optical science typically relate to the electromagnetic or quantum properties of light but do include other topics. A major subfield of modern optics, quantum optics, deals with specifically quantum mechanical properties of light. Quantum optics is not just theoretical; some modern devices, such as lasers, have principles of operation that depend on quantum mechanics. Light detectors, such as photomultipliers and channeltrons, respond to individual photons. Electronic image sensors, such as CCDs, exhibit shot noise corresponding to the statistics of individual photon events. Light-emitting diodes and photovoltaic cells, too, cannot be understood without quantum mechanics. In the study of these devices, quantum optics often overlaps with quantum electronics.[57]

Specialty areas of optics research include the study of how light interacts with specific materials as in crystal optics and metamaterials. Other research focuses on the phenomenology of electromagnetic waves as in singular optics, non-imaging optics, non-linear optics, statistical optics, and radiometry. Additionally, computer engineers have taken an interest in integrated optics, machine vision, and photonic computing as possible components of the "next generation" of computers.[58]

Today, the pure science of optics is called optical science or optical physics to distinguish it from applied optical sciences, which are referred to as optical engineering. Prominent subfields of optical engineering include illumination engineering, photonics, and optoelectronics with practical applications like lens design, fabrication and testing of optical components, and image processing. Some of these fields overlap, with nebulous boundaries between the subjects terms that mean slightly different things in different parts of the world and in different areas of industry.[59] A professional community of researchers in nonlinear optics has developed in the last several decades due to advances in laser technology.[60]

## Lasers

A laser is a device that emits light (electromagnetic radiation) through a process called *stimulated emission*. The term *laser* is an acronym for *Light Amplification by Stimulated Emission of Radiation*.[61] Laser light is usually spatially coherent, which means that the light either is emitted in a narrow, low-divergence beam, or can be converted into one with the help of optical components such as lenses. Because the microwave equivalent of the laser, the *maser*, was developed first, devices that emit microwave and radio frequencies are usually called *masers*.[62]



Experiments such as this one with high-power lasers are part of the modern optics research.

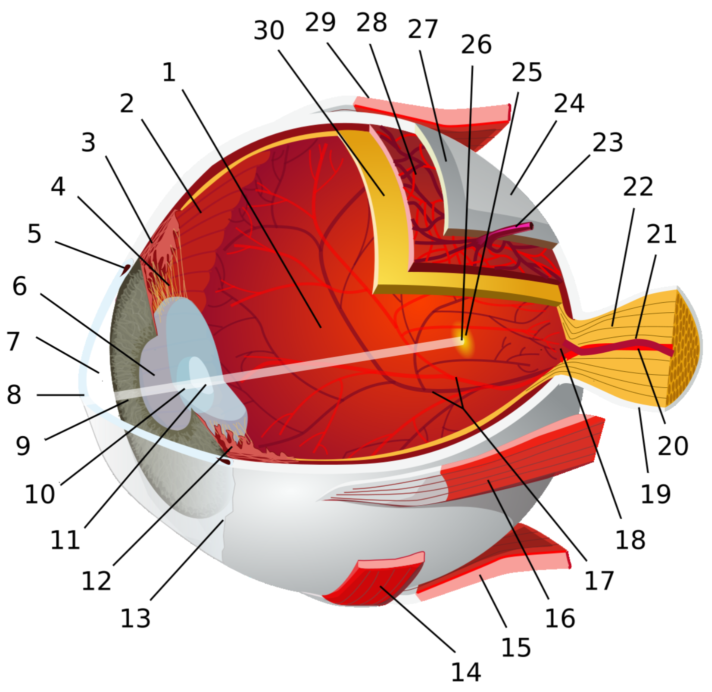
The first working laser was demonstrated on 16 May 1960 by Theodore Maiman at Hughes Research Laboratories.[63] When first invented, they were called "a solution looking for a problem".[64] Since then, lasers have become a multi-billion dollar industry, finding utility in thousands of highly varied applications. The first application of lasers visible in the daily lives of the general population was the supermarket barcode scanner, introduced in 1974.[65] The laserdisc player, introduced in 1978, was the first successful consumer product to include a laser, but the compact disc player was the first laser-equipped device to become truly common in consumers' homes, beginning in 1982.[66] These optical storage devices use a semiconductor laser less than a millimeter wide to scan the surface of the disc for data retrieval. Fiber-optic communication relies on lasers to transmit large amounts of information at the speed of light. Other common applications of lasers include laser printers and laser pointers. Lasers are used in medicine in areas such as bloodless surgery, laser eye surgery, and laser capture microdissection and in military applications such as missile defense systems, electro-optical countermeasures (EOCM), and LIDAR. Lasers are also used in holograms, bubblegrams, laser light shows, and laser hair removal.[67]

# Applications

Optics is part of everyday life. The ubiquity of visual systems in biology indicate the central role optics plays as the science of one of the five senses. Many people benefit from eyeglasses or contact lenses, and optics are integral to the functioning of many consumer goods including cameras. Rainbows and mirages are examples of optical phenomena. Optical communication provides the backbone for both the Internet and modern telephony.

## Human eye

The human eye functions by focusing light onto an array of photoreceptor cells called the retina, which covers the back of the eye. The focusing is accomplished by a series of transparent media. Light entering the eye passes first through the cornea, which provides much of the eye's optical power. The light then continues through the fluid just behind the cornea—the anterior chamber, then passes through the pupil. The light then passes through the lens, which focuses the light further and allows adjustment of focus. The light then passes through the main body of fluid in the eye—the vitreous humor, and reaches the retina. The cells in the retina cover the back of the eye, except for where the optic nerve exits; this results in a blind spot.




Model of a human eye. Features mentioned in this article are 3. ciliary muscle, 6. pupil, 8. cornea, 10. lens cortex, 22. optic nerve, 26. fovea, 30. retina

There are two types of photoreceptor cells, rods and cones, which are sensitive to different aspects of light.[68] Rod cells are sensitive to the intensity of light over a wide frequency range, thus are responsible for black-and-white vision. Rod cells are not present on the fovea, the area of the retina responsible for central vision, and are not as responsive as cone cells to spatial and temporal changes in light. There are, however, twenty times more rod cells than cone cells in the retina because the rod cells are present across a wider area. Because of their wider distribution, rods are responsible for peripheral vision.[69]

In contrast, cone cells are less sensitive to the overall intensity of light, but come in three varieties that are sensitive to different frequency-ranges and thus are used in the perception of color and photopic vision. Cone cells are highly concentrated in the fovea and have a high visual acuity meaning that they are better at spatial resolution than rod cells. Since cone cells are not as sensitive to dim light as rod cells, most night vision is limited to rod cells. Likewise, since cone cells are in the fovea, central vision (including the vision needed to do most reading, fine detail work such as sewing, or careful examination of objects) is done by cone cells.[69]

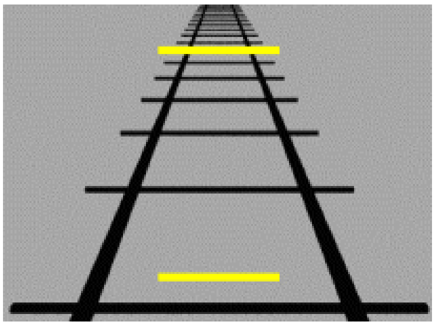
Ciliary muscles around the lens allow the eye's focus to be adjusted. This process is known as accommodation. The near point and far point define the nearest and farthest distances from the eye at which an object can be brought into sharp focus. For a person with normal vision, the far point is located at infinity. The near point's location depends on how much the muscles can increase the curvature of the lens, and how inflexible the lens has become with age. Optometrists, ophthalmologists, and opticians usually consider an appropriate near point to be closer than normal reading distance—approximately 25 cm.[68]

Defects in vision can be explained using optical principles. As people age, the lens becomes less flexible and the near point recedes from the eye, a condition known as presbyopia. Similarly, people suffering from hyperopia cannot decrease the focal length of their lens enough to allow for nearby objects to be imaged on their retina. Conversely, people who cannot increase the focal length of their lens enough to allow for distant objects to be imaged on the retina suffer from myopia and have a far point that is considerably closer than infinity. A condition known as astigmatism results when the cornea is not spherical but instead is more curved in one direction. This causes horizontally extended objects to be focused on different parts of the retina than vertically extended objects, and results in distorted images.[68]

All of these conditions can be corrected using corrective lenses. For presbyopia and hyperopia, a converging lens provides the extra curvature necessary to bring the near point closer to the eye while for myopia a diverging lens provides the curvature necessary to send the far point to infinity. Astigmatism is corrected with a cylindrical surface lens that curves more strongly in one direction than in another, compensating for the non-uniformity of the cornea.[70]

The optical power of corrective lenses is measured in diopters, a value equal to the reciprocal of the focal length measured in meters; with a positive focal length corresponding to a converging lens and a negative focal length corresponding to a diverging lens. For lenses that correct for astigmatism as well, three numbers are given: one for the spherical power, one for the cylindrical power, and one for the angle of orientation of the astigmatism.[70]

### Visual effects



The Ponzo Illusion relies on the fact that parallel lines appear to converge as they approach infinity.

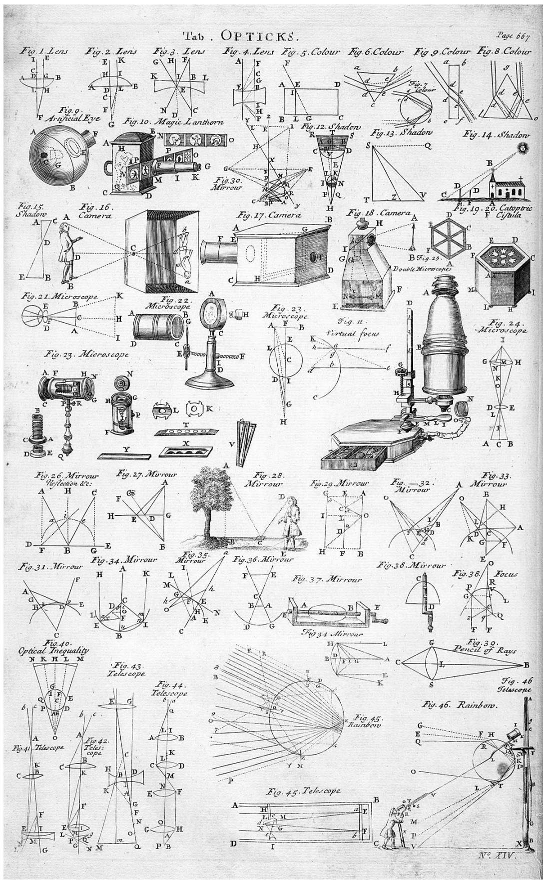
Optical illusions (also called visual illusions) are characterized by visually perceived images that differ from objective reality. The information gathered by the eye is processed in the brain to give a percept that differs from the object being imaged. Optical illusions can be the result of a variety of phenomena including physical effects that create images that are different from the objects that make them, the physiological effects on the eyes and brain of excessive stimulation (e.g. brightness, tilt, color, movement), and cognitive illusions where the eye and brain make unconscious inferences.[71]

Cognitive illusions include some which result from the unconscious misapplication of certain optical principles. For example, the Ames room, Hering, Müller-Lyer, Orbison, Ponzo, Sander, and Wundt illusions all rely on the suggestion of the appearance of distance by using converging and diverging lines, in the same way that parallel light rays (or indeed any set of parallel lines) appear to converge at a vanishing point at infinity in two-dimensionally rendered images with artistic perspective.[72] This suggestion is also responsible for the famous moon illusion where the moon, despite having essentially the same angular size, appears much larger near the horizon than it does at zenith.[73] This illusion so confounded Ptolemy that he incorrectly attributed it to atmospheric refraction when he described it in his treatise, *Optics*.[6]

Another type of optical illusion exploits broken patterns to trick the mind into perceiving symmetries or asymmetries that are not present. Examples include the café wall, Ehrenstein, Fraser spiral, Poggendorff, and Zöllner illusions. Related, but not strictly illusions, are patterns that occur due to the superimposition of periodic structures. For example transparent tissues with a grid structure produce shapes known as moiré patterns, while the superimposition of periodic transparent patterns comprising parallel opaque lines or curves produces line moiré patterns.[74]

### Optical instruments

Single lenses have a variety of applications including photographic lenses, corrective lenses, and magnifying glasses while single mirrors are used in parabolic reflectors and rear-view mirrors. Combining a number of mirrors, prisms, and lenses produces compound optical instruments which have practical uses. For example, a periscope is simply two plane mirrors aligned to allow for viewing around obstructions. The most famous compound optical instruments in science are the microscope and the telescope which were both invented by the Dutch in the late 16th century.[75]



Illustrations of various optical instruments from the 1728 *Cyclopaedia*

Microscopes were first developed with just two lenses: an objective lens and an eyepiece. The objective lens is essentially a magnifying glass and was designed with a very small focal length while the eyepiece generally has a longer focal length. This has the effect of producing magnified images of close objects. Generally, an additional source of illumination is used since magnified images are dimmer due to the conservation of energy and the spreading of light rays over a larger surface area. Modern microscopes, known as *compound microscopes* have many lenses in them (typically four) to optimize the functionality and enhance image stability.[75] A slightly different variety of microscope, the comparison microscope, looks at side-by-side images to produce a stereoscopic binocular view that appears three dimensional when used by humans.[76]

The first telescopes, called *refracting telescopes* were also developed with a single objective and eyepiece lens. In contrast to the microscope, the objective lens of the telescope was designed with a large focal length to avoid optical aberrations. The objective focuses an image of a distant object at its focal point which is adjusted to be at the focal point of an eyepiece of a much smaller focal length. The main goal of a telescope is not necessarily magnification, but rather collection of light which is determined by the physical size of the objective lens. Thus, telescopes are normally indicated by the diameters of their objectives rather than by the magnification which can be changed by switching eyepieces. Because the magnification of a telescope is equal to the focal length of the objective divided by the focal length of the eyepiece, smaller focal-length eyepieces cause greater magnification.[75]

Since crafting large lenses is much more difficult than crafting large mirrors, most modern telescopes are *reflecting telescopes*, that is, telescopes that use a primary mirror rather than an objective lens. The same general optical considerations apply to reflecting telescopes that applied to refracting telescopes, namely, the larger the primary mirror, the more light collected, and the magnification is still equal to the focal length of the primary mirror divided by the focal length of the eyepiece. Professional telescopes generally do not have eyepieces and instead place an instrument (often a charge-coupled device) at the focal point instead.[75]

## Photography

The optics of photography involves both lenses and the medium in which the electromagnetic radiation is recorded, whether it be a plate, film, or charge-coupled device. Photographers must consider the reciprocity of the camera and the shot which is summarized by the relation

$$\text{Exposure} \propto \text{ApertureArea} \times \text{ExposureTime} \times \text{SceneLuminance}$$[77]

In other words, the smaller the aperture (giving greater depth of focus), the less light coming in, so the length of time has to be increased (leading to possible blurriness if motion occurs). An example of the use of the law of reciprocity is the Sunny 16 rule which gives a rough estimate for the settings needed to estimate the proper exposure in daylight.[78]

Photograph taken with aperture *f*/32

Photograph taken with aperture *f*/5

A camera's aperture is measured by a unitless number called the f-number or f-stop, *f*/#, often notated as $N$, and given by

$$f/\# = N = \frac{f}{D}$$

where $f$ is the focal length, and $D$ is the diameter of the entrance pupil. By convention, "*f*/#" is treated as a single symbol, and specific values of *f*/# are written by replacing the number sign with the value. The two ways to increase the f-stop are to either decrease the diameter of the entrance pupil or change to a longer focal length (in the case of a zoom lens, this can be done by simply adjusting the lens). Higher f-numbers also have a larger depth of field due to the lens approaching the limit of a pinhole camera which is able to focus all images perfectly, regardless of distance, but requires very long exposure times.[79]

The field of view that the lens will provide changes with the focal length of the lens. There are three basic classifications based on the relationship to the diagonal size of the film or sensor size of the camera to the focal length of the lens:[80]

- Normal lens: angle of view of about 50° (called *normal* because this angle considered roughly equivalent to human vision[80] ) and a focal length approximately equal to the diagonal of the film or sensor.[81]
- Wide-angle lens: angle of view wider than 60° and focal length shorter than a normal lens.[82]
- Long focus lens: angle of view narrow than a normal lens. This is any lens with a focal length longer than the diagonal measure of the film or sensor.[83] The most common type of long focus lens is the telephoto lens, a

design that uses a special *telephoto group* to be physically shorter than its focal length.[84]

Modern zoom lenses may have some or all of these attributes.

The absolute value for the exposure time required depends on how sensitive to light the medium being used is (measured by the film speed, or, for digital media, by the quantum efficiency).[85] Early photography used media that had very low light sensitivity, and so exposure times had to be long even for very bright shots. As technology has improved, so has the sensitivity through film cameras and digital cameras.[86]

Other results from physical and geometrical optics apply to camera optics. For example, the maximum resolution capability of a particular camera set-up is determined by the diffraction limit associated with the pupil size and given, roughly, by the Rayleigh criterion.[87]

## Atmospheric optics

A colorful sky is often due to scattering of light off particulates and pollution, as in this photograph of a sunset during the October 2007 California wildfires.

The unique optical properties of the atmosphere cause a wide range of spectacular optical phenomena. The blue color of the sky is a direct result of Rayleigh scattering which redirects higher frequency (blue) sunlight back into the field of view of the observer. Because blue light is scattered more easily than red light, the sun takes on a reddish hue when it is observed through a thick atmosphere, as during a sunrise or sunset. Additional particulate matter in the sky can scatter different colors at different angles creating colorful glowing skies at dusk and dawn. Scattering off of ice crystals and other particles in the atmosphere are responsible for halos, afterglows, coronas, rays of sunlight, and sun dogs. The variation in these kinds of phenomena is due to different particle sizes and geometries.[88]

Mirages are optical phenomena in which light rays are bent due to thermal variations in the refraction index of air, producing displaced or heavily distorted images of distant objects. Other dramatic optical phenomena associated with this include the Novaya Zemlya effect where the sun appears to rise earlier than predicted with a distorted shape. A spectacular form of refraction occurs with a temperature inversion called the Fata Morgana where objects on the horizon or even beyond the horizon, such as islands, cliffs, ships or icebergs, appear elongated and elevated, like "fairy tale castles".[89]

Rainbows are the result of a combination of internal reflection and dispersive refraction of light in raindrops. A single reflection off the backs of an array of raindrops produces a rainbow with an angular size on the sky that ranges from 40° to 42° with red on the outside. Double rainbows are produced by two internal reflections with angular size of 50.5° to 54° with violet on the outside. Because rainbows are seen with the sun 180° away from the center of the rainbow, rainbows are more prominent the closer the sun is to the horizon.[55]

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[14] galileo.rice.edu **The Galileo Project > Science > The Telescope** by Al Van Helden *"The Hague discussed the patent applications first of Hans Lipperhey of Middelburg, and then of Jacob Metius of Alkmaar... another citizen of Middelburg, Sacharias Janssen had a telescope at about the same time but was at the Frankfurt Fair where he tried to sell it"* (http://galileo.rice.edu/sci/instruments/telescope.html)

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# External links

Relevant discussions

- Optics (http://www.bbc.co.uk/programmes/b00774t5) on In Our Time at the BBC. ( listen now (http://www.bbc.co.uk/iplayer/console/b00774t5/In_Our_Time_Optics))

Textbooks and tutorials

- Optics (http://www.lightandmatter.com/area1book5.html) – an open-source optics textbook
- Optics2001 (http://www.optics2001.com) – Optics library and community
- Fundamental Optics (http://www.cvimellesgriot.com/products/Documents/TechnicalGuide/fundamental-Optics.pdf) – CVI Melles Griot Technical Guide
- Physics of Light and Optics (http://optics.byu.edu/textbook.aspx) – Brigham Young University Undergraduate Book

Wikibooks modules

- Physics Study Guide/Optics
- Optics

Further reading

- Optics and photonics: Physics enhancing our lives (http://www.iop.org/publications/iop/2009/page_38205.html) by Institute of Physics publications (http://www.iop.org/publications/iop/index.html)

Societies

- SPIE – link (http://www.spie.org)
- Optical Society of America – link (http://www.osa.org)
- European Optical Society – link (http://www.myeos.org)
- European Photonics Industry Consortium – link (http://www.epic-assoc.com)
- Optical Society of India – link (http://www.osiindia.org)
- Dutch Photonics Society – link (http://www.photonicscluster-nl.org)

# Applied psychology

The basic premise of **applied psychology** is the use of psychological principles and theories to overcome problems in other areas, such as mental health, business management, education, health, product design, ergonomics, and law. Applied psychology includes the areas of clinical psychology, industrial and organizational psychology, occupational health psychology, human factors, forensic psychology, engineering psychology, as well as many other areas such as school psychology, sports psychology and community psychology. In addition, a number of specialized areas in the general field of psychology have applied branches (e.g., applied social psychology, applied cognitive psychology).

One founder of applied psychology was Hugo Münsterberg. He came to America from Germany, and, like many aspiring psychologists during the late 19th century, originally studied philosophy. Münsterberg had many interests in the field of psychology such as purposive psychology, social psychology and forensic psychology. In 1907 he wrote several magazine articles concerning legal aspects of testimony, confessions and courtroom procedures, which eventually developed into his book, *On the Witness Stand*. The following year the Division of Applied Psychology was adjoined to the Harvard Psychological Laboratory. Within 9 years he had contributed eight books in English, applying psychology to education, industrial efficiency, business and teaching. Eventually Hugo Münsterberg and his contributions would define him as the creator of applied psychology. In 1920, the International Association of Applied Psychology (IAAP) was founded, as the first international scholarly society within the field of psychology.

## Clinical psychology

Clinical psychology includes the study and application of psychology for the purpose of understanding, preventing, and relieving psychologically-based distress or dysfunction and to promote subjective well-being and personal development.[1] Central to its practice are psychological assessment and psychotherapy, although clinical psychologists may also engage in research, teaching, consultation, forensic testimony, and program development and administration.[2] Some clinical psychologists may focus on the clinical management of patients with brain injury—this area is known as clinical neuropsychology. In many countries clinical psychology is a regulated mental health profession.

The work performed by clinical psychologists tends to be done inside various therapy models, all of which involve a formal relationship between professional and client—usually an individual, couple, family, or small group—that employs a set of procedures intended to form a therapeutic alliance, explore the nature of psychological problems, and encourage new ways of thinking, feeling, or behaving. The four major perspectives are psychodynamic, cognitive behavioral, existential-humanistic, and systems or family therapy. There has been a growing movement to integrate these various therapeutic approaches, especially with an increased understanding of issues regarding ethnicity, gender, spirituality, and sexual-orientation. With the advent of more robust research findings regarding psychotherapy, there is growing evidence that most of the major therapies are about of equal effectiveness, with the key common element being a strong therapeutic alliance.[3] [4] Because of this, more training programs and psychologists are now adopting an eclectic therapeutic orientation.

Clinical psychologists do not usually prescribe medication, although there is a growing number of psychologists who do have prescribing privileges, in the field of medical psychology.[5] In general, however, when medication is warranted many psychologists will work in cooperation with psychiatrists so that clients get all their therapeutic needs met.[2] Clinical psychologists may also work as part of a team with other professionals, such as social workers and nutritionists.

## Educational psychology

Educational psychology is devoted to the study of how humans learn in educational settings, especially schools, and the effectiveness of educational interventions (e.g., phonics versus whole language instruction in early reading attainment). Another domain of educational psychology is the psychology of teaching. In some colleges, educational psychology courses are called "the psychology of learning and teaching". Educational psychology derives a great deal from basic-science disciplines within psychology including cognitive science and behaviorially-oriented research on learning.

## Forensic psychology and legal psychology

Forensic psychology and legal psychology are the area concerned with the application of psychological methods and principles to legal questions and issues. Most typically, forensic psychology involves a clinical analysis of a particular individual and an assessment of some specific psycho-legal question. Legal psychology refers to any application of psychological principles, methods or understanding to legal questions or issues. In addition to the applied practices, legal psychology also includes academic or empirical research on topics involving the relationship of law to human mental processes and behavior.

## Health psychology

Health psychology concerns itself with understanding how biology, behavior, and social context influence health and illness.[6] Health psychologists generally work alongside other medical professionals in clinical settings, although many also teach and conduct research. Although its early beginnings can be traced to the kindred field of clinical psychology, four different approaches to health psychology have been defined: clinical, public health, community and critical health psychology.[7] Health psychologists also aim to change health behaviors for the dual purpose of helping people stay healthy and helping patients adhere to disease treatment regimens. Cognitive behavioral therapy and behavior modification are techniques often used for this purpose.

## Human factors

Human factors is the study of how cognitive and psychological processes affect our interaction with tools and objects in the environment. The goal of research in human factors is to understand the limitations and biases of human mental processes and behavior.

## Industrial and organizational psychology

Industrial and organizational psychology focuses to varying degrees on the psychology of the workforce, customer, and consumer, including issues such as the psychology of recruitment, selecting employees from an applicant pool which overall includes training, performance appraisal, job satisfaction, work behavior, stress at work and management.

Career counseling is another aspect of counseling closely related to industrial/organizational psychology. Counselors in this field assist clients in a variety of settings ranging from schools to vocational to organization sites, to name a few. One of the main goals of the profession is to help clients realize their talents and dreams in response to a career and help them create successful job skills to then apply to their career search. Many times career counselors act as consultants to companies, other times they work as a team in academic and career counseling capacities, and other times they work for a social service agency specifically working with people who need assistance in the job search process.

Generally a Master's degree is needed to get into the field. As there are not many career counseling Master's programs, many enter the field with a degree in mental health counseling or community counseling.

Since jobs are such defining experiences for people, having the ability to gain helpful insight, tips, and encouragement from career counselors is a definite benefit. The career counseling field can only increase in popularity as people on average change jobs every ten years, instead of 30 years ago where many people stayed with the same company the majority of their working career.

## Occupational health psychology

Occupational health psychology (OHP) is a relatively new discipline that emerged out of the confluence of health psychology, industrial and organizational psychology, and occupational health.[8] OHP has its own doctoral programs, journals, and professional organizations. The field is concerned with identifying psychosocial characteristics of workplaces that give rise to health-related problems in people who work. These problems can involve physical health (e.g., cardiovascular disease[9] ) or mental health (e.g., depression[10] ). Examples of psychosocial characteristics of workplaces that OHP has investigated include amount of decision latitude[11] a worker can exercise and the supportiveness of supervisors.[12] OHP is also concerned with the development and implementation of interventions that can prevent or ameliorate work-related health problems.[13] In addition, OHP research has important implications for the economic success of organizations.[14] Other research areas of concern to OHP include workplace incivility[15] and violence,[16] work-home carryover,[17] unemployment[18] and downsizing,[19] and workplace safety[20] and accident prevention.[21] Two important OHP journals are the *Journal of Occupational Health Psychology* and *Work & Stress*. Two important organizations closely associated with OHP are the Society for Occupational Health Psychology and the European Academy of Occupational Health Psychology.

## School psychology

School psychology is a field that applies principles of clinical psychology and educational psychology to the diagnosis and treatment of students' behavioral and learning problems. School psychologists are educated in child and adolescent development, learning theories, psychological and psychoeducational assessment, personality theories, therapeutic interventions, special education, psychology, consultation, child and adolescent psychopathology, and the ethical, legal and administrative codes of their profession.

According to Division 16 (Division of School Psychology) of the American Psychological Association (APA), school psychologists operate according to a scientific framework. They work to promote effectiveness and efficiency in the field. School psychologists conduct psychological assessments, provide brief interventions, and develop or help develop prevention programs. Additionally, they evaluate services with special focus on developmental processes of children within the school system, and other systems, such as families. School psychologists consult with teachers, parents, and school personnel about learning, behavioral, social, and emotional problems. They may teach lessons on parenting skills (like school counselors), learning strategies, and other skills related to school mental health. In addition, they explain test results to parents and students. They provide individual, group, and in some cases family counseling (State Board of Education 2003; National Clearinghouse for Professions in Special Education, n.d.). School psychologists are actively involved in district and school crisis intervention teams. They also supervise graduate students in school psychology. School psychologists in many districts provide professional development to teachers and other school personnel on topics such as positive behavior intervention plans and achievement tests.

School psychologists are influential within the school system and are frequently consulted to solve problems. Practitioners should be able to provide consultation and collaborate with other members of the educational community and confidently make decisions based on empirical research.

## Sport psychology (related to exercise psychology)

Sport psychology is a specialization within psychology that seeks to understand psychological/mental factors that affect performance in sports, physical activity and exercise and apply these to enhance individual and team performance. It deals with increasing performance by managing emotions and minimizing the psychological effects of injury and poor performance. Some of the most important skills taught are goal setting, relaxation, visualization, self-talk awareness and control, concentration, using rituals, attribution training, and periodization. The principles and theories may be applied to any human movement or performance tasks (e.g., playing a musical instrument, acting in a play, public speaking, motor skills). Usually, experts recommend that students be trained in both kinesiology (i.e., sport and exercise sciences, physical education) and counseling.

## Additional areas

- Community psychology
- Counseling psychology
- Ecological psychology
- Environmental psychology
- Neuropsychology
- Media psychology
- Military psychology
- Operational psychology
- Outline of psychology
- Traffic psychology

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# Zoology


Conrad Gesner (1516–1565). His *Historiae animalium* is considered the beginning of modern zoology.

**Zoology** (pronounced English pronunciation: /zoʊˈɒlədʒi/, though the nonstandard pronunciation English pronunciation: /zuːˈɒlədʒi/[1] is also common, occasionally also spelled *zoölogy*), is the branch of biology that relates to the animal kingdom, including the structure, embryology, evolution, classification, habits, and distribution of all animals, both living and extinct. The term is derived from Ancient Greek ζῷον (zōon, “animal”) + λόγος (logos, “knowledge”).

## History

*Main articles: History of zoology (through 1859), History of zoology (since 1859)*

### Ancient history to Darwin

The history of zoology traces the study of the animal kingdom from ancient to modern times. Although the concept of *zoology* as a single coherent field arose much later, the zoological sciences emerged from natural history reaching back to the works of Aristotle and Galen in the ancient Greco-Roman world. This ancient work was further developed in the Middle Ages by Muslim physicians and scholars such as Albertus Magnus.[2] [3] [4] During the Renaissance and early modern period, zoological thought was revolutionized in Europe by a renewed interest in empiricism and the discovery of many novel organisms. Prominent in this movement were Vesalius and William Harvey, who used experimentation and careful observation in physiology, and naturalists such as Carl Linnaeus and Buffon who began to classify the diversity of life and the fossil record, as well as the development and behavior of organisms. Microscopy revealed the previously unknown world of microorganisms, laying the groundwork for cell theory.[5] The growing importance of natural theology, partly a response to the rise of mechanical philosophy, encouraged the growth of natural history (although it entrenched the argument from design).

Over the 18th and 19th centuries, zoology became an increasingly professional scientific discipline. Explorer-naturalists such as Alexander von Humboldt investigated the interaction between organisms and their environment, and the ways this relationship depends on geography, laying the foundations for biogeography, ecology and ethology. Naturalists began to reject essentialism and consider the importance of extinction and the mutability of species. Cell theory provided a new perspective on the fundamental basis of life.[6]

### Since Darwin

These developments, as well as the results from embryology and paleontology, were synthesized in Charles Darwin's theory of evolution by natural selection. In 1859, Darwin placed the theory of organic evolution on a new footing, by his discovery of a process by which organic evolution can occur, and provided observational evidence that it had done so.[7]

Darwin gave new direction to morphology and physiology, by uniting them in a common biological theory: the theory of organic evolution. The result was a reconstruction of the classification of animals upon a genealogical basis, fresh investigation of the development of animals, and early attempts to determine their genetic relationships. The end of the 19th century saw the fall of spontaneous generation and the rise of the germ theory of disease, though the mechanism of inheritance remained a mystery. In the early 20th century, the rediscovery of Mendel's work led to the rapid development of genetics by Thomas Hunt Morgan and his students, and by the 1930s the combination of population genetics and natural selection in the "neo-Darwinian synthesis".[8]

# Research

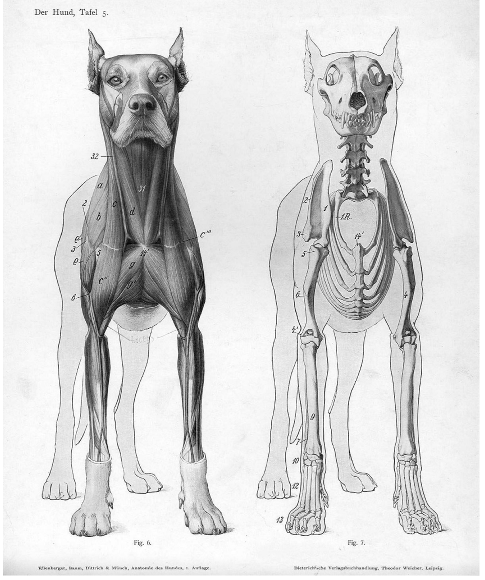
## Structural

Cell biology studies the structural and physiological properties of cells, including their behaviors, interactions, and environment. This is done on both the microscopic and molecular levels, for single-celled organisms such as bacteria as well as the specialized cells in multicellular organisms such as humans. Understanding the structure and function of cells is fundamental to all of the biological sciences. The similarities and differences between cell types are particularly relevant to molecular biology.

Anatomy considers the forms of macroscopic structures such as organs and organ systems.[9]

## Physiological

Physiology studies the mechanical, physical, and biochemical processes of living organisms by attempting to understand how all of the structures function as a whole. The theme of "structure to function" is central to biology. Physiological studies have traditionally been divided into plant physiology and animal physiology, but some principles of physiology are universal, no matter what particular organism is being studied. For example, what is learned about the physiology of yeast cells can also apply to human cells. The field of animal physiology extends the tools and methods of human physiology to non-human species. Physiology studies how for example nervous, immune, endocrine, respiratory, and circulatory systems, function and interact.



Animal anatomical engraving from *Handbuch der Anatomie der Tiere für Künstler*.

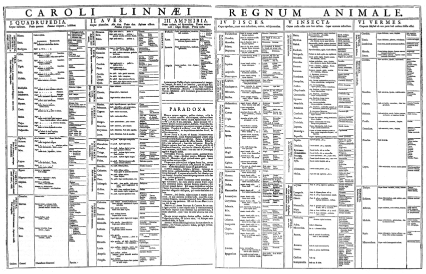
## Evolutionary

Evolutionary research is concerned with the origin and descent of species, as well as their change over time, and includes scientists from many taxonomically oriented disciplines. For example, it generally involves scientists who have special training in particular organisms such as mammalogy, ornithology, or herpetology, but use those organisms as systems to answer general questions about evolution.

Evolutionary biology is partly based on paleontology, which uses the fossil record to answer questions about the mode and tempo of evolution,[10] and partly on the developments in areas such as population genetics[11] and evolutionary theory. In the 1980s, developmental biology re-entered evolutionary biology from its initial exclusion from the modern synthesis through the study of evolutionary developmental biology.[12] Related fields often considered part of evolutionary biology are phylogenetics, systematics, and taxonomy.

## Systematics

Scientific classification in zoology, is a method by which zoologists group and categorize organisms by biological type, such as genus or species. Biological classification is a form of scientific taxonomy. Modern biological classification has its root in the work of Carolus Linnaeus, who grouped species according to shared physical characteristics. These groupings have since been revised to improve consistency with the Darwinian principle of common descent. Molecular phylogenetics, which uses DNA sequences as data, has driven many recent revisions and is likely to continue to do so. Biological classification belongs to the science of zoological systematics.




Linnaeus's table of the Animal Kingdom from the first edition of *Systema Naturae* (1735).

Many scientists now consider the five-kingdom system outdated. Modern alternative classification systems generally begin with the three-domain system: Archaea (originally Archaebacteria); Bacteria (originally Eubacteria); Eukaryota (including protists, fungi, plants, and animals)[13] These domains reflect whether the cells have nuclei or not, as well as differences in the chemical composition of the cell exteriors.[13]

Further, each kingdom is broken down recursively until each species is separately classified. The order is: Domain; Kingdom; Phylum; Class; Order; Family; Genus; Species. The scientific name of an organism is generated from its genus and species. For example, humans are listed as *Homo sapiens*. *Homo* is the genus, and *sapiens* the species. When writing the scientific name of an organism, it is proper to capitalize the first letter in the genus and put all of the species in lowercase. Additionally, the entire term may be italicized or underlined.[14] [15]

The dominant classification system is called the Linnaean taxonomy. It includes ranks and binomial nomenclature. The classification, taxonomy, and nomenclature of zoological organisms is administered by the International Code of Zoological Nomenclature, and International Code of Nomenclature of Bacteria for animals and bacteria, respectively. The classification of viruses, viroids, prions, and all other sub-viral agents that demonstrate biological characteristics is conducted by the International Code of Virus classification and nomenclature.[16] [17] [18] [19] However, several other viral classification systems do exist.

A merging draft, BioCode, was published in 1997 in an attempt to standardize nomenclature in these areas, but has yet to be formally adopted.[20] The BioCode draft has received little attention since 1997; its originally planned implementation date of January 1, 2000, has passed unnoticed. However, a 2004 paper concerning the cyanobacteria does advocate a future adoption of a BioCode and interim steps consisting of reducing the differences between the codes.[21] The International Code of Virus Classification and Nomenclature (ICVCN) remains outside the BioCode.

### Ethology

Ethology studies animal behavior (particularly that of social animals such as primates and canids), and is sometimes considered a separate branch of study. Ethologists have been particularly concerned with the evolution of behavior and the understanding of behavior in terms of the theory of natural selection. In one sense, the first modern ethologist was Charles Darwin, whose book, *The Expression of the Emotions in Man and Animals,* influenced many ethologists to come.[22]

Kelp Gull chicks peck at red spot on mother's beak to stimulate regurgitating reflex.

Biogeography studies the spatial distribution of organisms on the Earth,[23] focusing on topics like plate tectonics, climate change, dispersal and migration, and cladistics.

## Branches of zoology

Although the study of animal life is ancient, its scientific incarnation is relatively modern. This mirrors the transition from natural history to biology at the start of the nineteenth century. Since Hunter and Cuvier, comparative anatomical study has been associated with morphography shapins the modern areas of zoological investigation: anatomy, physiology, histology, embryology, teratology and ethology. Modern zoology first arose in German and British universities. In Britain, Thomas Henry Huxley was a prominent figure. His ideas were centered on the morphology of animals. Many consider him the greatest comparative anatomist of the latter half of the nineteenth century. Similar to Hunter, his courses were composed of lectures and laboratory practical classes in contrast the previous format of lectures only. This system became widely spread.

Gradually zoology expanded beyond Huxley's comparative anatomy to include the following sub-disciplines:

- Zoography, also known as *descriptive zoology*, describes animals and their habitats.
- Comparative anatomy studies the structure of animals.
- Animal physiology
- Behavioral ecology
- Ethology is the study of animal behavior.
- The various taxonomically oriented disciplines such as mammalogy, herpetology, ornithology and entomology identify and classify species and study the structures and mechanisms specific to those groups.

Related fields:

- Evolutionary biology: Development of both animals and plants is considered in the articles on evolution, population genetics, heredity, variation, Mendelism, reproduction.
- Molecular Biology studies the common genetic and developmental mechanisms of animals and plants
- Palaeontology
- Systematics, cladistics, phylogenetics, phylogeography, biogeography and taxonomy classify and group species via common descent and regional associations.

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B., A.K.Karthikeyan, Abby1028, Abcfox, Abhishekchavan79, Abrech, Adambro, Admiral Roo, Aerielle 7@yahoo.com, Ahoerstemeier, Aillema, Alan Liefting, Aldie, AlexiusHoratius, Alf Boggis, Allen3, Allstarecho, Almasimagorwa, Almonit, Altenmann, Ancheta Wis, Anna Lincoln, Anonymous anonymous, Anoop t, AnthonyQBachler, Antilived, Ap, Archanamiya, Archivist, ArcticREPtilia, ArglebargleIV, Arpit.withu, Arunr.in, Asaurabh, Atlant, Atreusk, Aulis Eskola, Austin Maxwell, B1u SkR33N, BD2412, Bandasuppan, Barticus88, Bduke, Beatnik8983, BenB4, BetoVinci, Betterusername, Bibijee, Bidabadi, BillC, Biscay, BjarteSorensen, Black Stripe, Blanchardb, Bobo192, Bomac, Bongwarrior, Bookofjude, BostonMA, Brad2006, Branddobbe, Brandon.irwin, Breno, Brianga, Bryan Derksen, Bulan, Bzlcs, Bücherwürmlein, Cal 1234, Can't sleep, clown will eat me, CanisRufus, Capmo, Capricorn42, Carl086, CaseKid, Casull, Catgut, Cbdorsett, Cbennyi, Cburnett, Cedars, Chaser, Chebbs, Cinnagingercat, Clipjoint, Closedmouth, Commander, Conversion script, Corti, Coty0816, Craig Lyd, Crazynas, Creativesoul8, CrniBombarder!!!, Crusadeonilliteracy, CuteHappyBrute, Cwmccabe, CyrilB, DASonnenfeld, DHN, DV8 2XL, Dalyman, DavidCary, Dawn Bard, Dbfirs, De728631, Defparadox, Dekisugi, Denisarona, Derild4921, Dharmabum420, Dimosvki, Discospinster, Dmeranda, Docboat, Docu, Doodle77, Dp67, Dpro369, Drew335, Drilnoth, Dsajga, Dwward, Dxnlmb, DylanW, Dynaflow, Dysepsion, Eagle999, Earizon, Ecksemmess, Editor at Large, Edivorce, Edmundred, Edward Z. 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